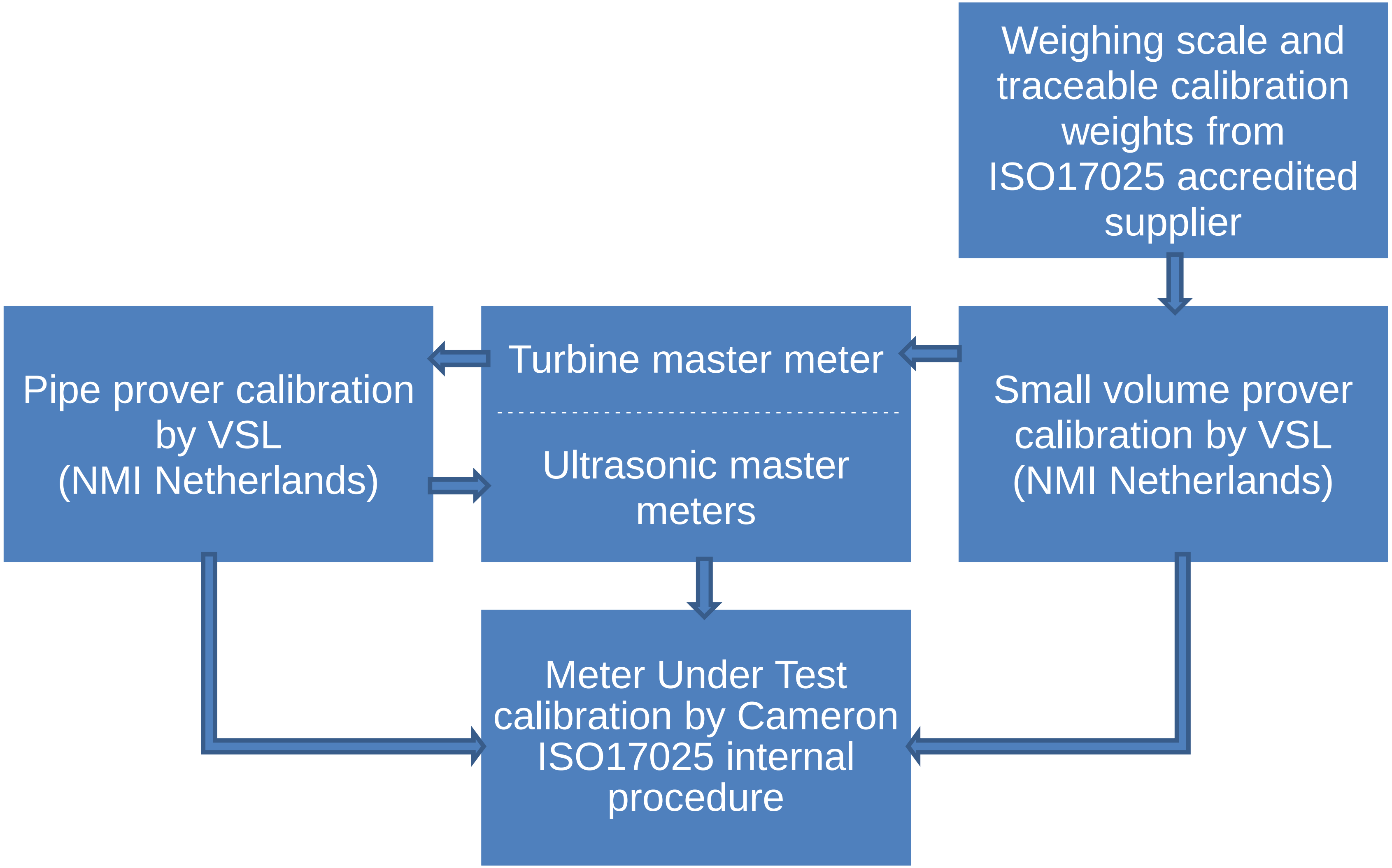
Traceability overview



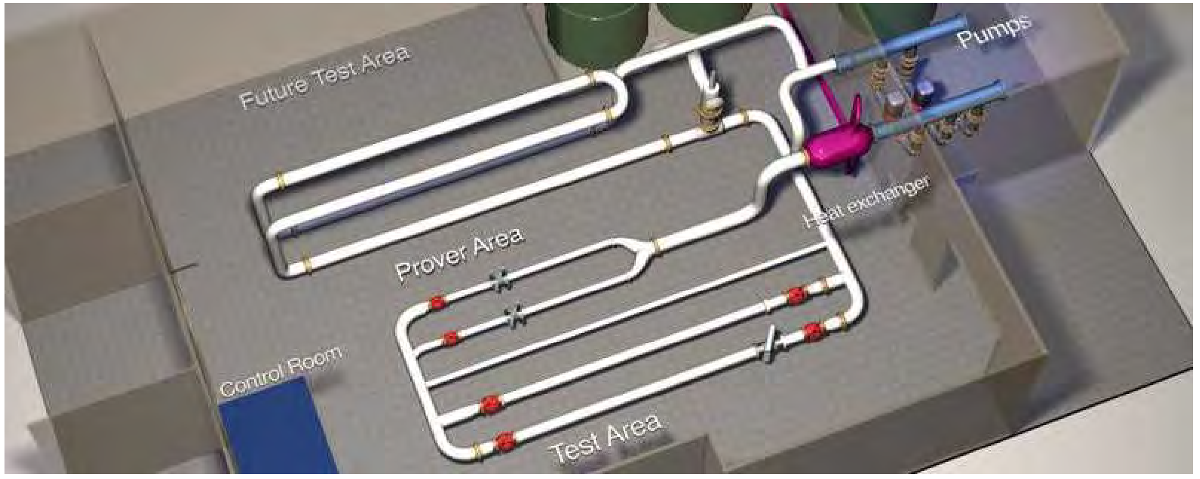
Uncertainty analysis example

Quantity [Xi] ID	Name	Value [Xi]	Sensitivity coefficient (Amplification Factor) Ci		Source	Type (A or B)	Distribution	Sensitivity Coeff	dXi	dXi/Xi [%]	[%]	Fraction Total Unc.
X1	Vap	10.06475	1	1	Nmi	B	Normal (k=2)	1	3.52E-03	0.035%	0.035%	79%
					1(a)	B	Normal (k=2)	1	1.36E-03	0.013%	0.013%	31%
X2	alpha	-0.0008	7.14E-04	=(DT+DTcv*Vcv/Vp)*alpha	2(a)	B	Normal (k=2)	7.14E-04	-1.20E-04	15.0%	0.011%	24%
X3	beta	9.5E-07	1.75E-04	=-(DP+DPcv*Vcv/Vp)*beta	3(a)	B	Normal (k=2)	1.75E-04	1.90E-07	20.0%	0.004%	8%
X4	ΔT	-1.0	7.58E-04	=(alpha+CTE)*DT	4(a)	B	Normal (k=2)	7.58E-04	2.00E-02	-2.00%	-0.002%	3%
					4(b)	A	Normal (k=2)	7.58E-04	1.40E-01	-14.00%	-0.011%	24%
					4(c)	B	Normal (k=2)	7.58E-04	1.40E-01	-14.00%	-0.011%	24%
X5	ΔTcv	0.1	-8.15E-05	=(alpha+CTE)*DTcv*Vcv/Vp	5(a)	B	Normal (k=2)	-8.15E-05	2.00E-02	20.00%	-0.002%	4%
					5(b)	A	Normal (k=2)	-8.15E-05	1.40E-01	140.00%	-0.011%	26%
					5(c)	B	Normal (k=2)	-8.15E-05	0.00E+00	0.00%	0.000%	0%
X6	ΔP	-200.0	1.90E-04	=beta*DP	6 (a)	B	Normal (k=2)	1.90E-04	40.00	-20.00%	-0.004%	9%
					6 (b)	B	Normal (k=2)	1.90E-04	20.00	-10.00%	-0.002%	4%
					6 (c)	A	Normal (k=2)	1.90E-04	20.00	-10.00%	-0.002%	4%
X7	ΔPcv	14.5	-1.48E-05	=-beta*DPcv*Vcv/Vp	7 (a)	B	Normal (k=2)	-1.48E-05	40.00	275.86%	-0.004%	9%
					7 (b)	B	Normal (k=2)	-1.48E-05	20.00	137.93%	-0.002%	5%
					7 (c)	A	Normal (k=2)	-1.48E-05	20.00	137.93%	-0.002%	5%
											0.044%	

	Values	Imperial Units		SI Units		Comments
X1	Vp	63.3010	barrels	10.06475	cubic meters	Prover Volume
X2	alpha	-4.45E-04	vol/vol/degF	-0.0008	vol/vol/degC	Fluid CTE - Used Average Value for the 3 liquids evaluated by Nmi
	density	38.66158	API Degrees	830.74	kg/m³	Used Average Value for the 3 liquids evaluated by Nmi
X3	beta	6.55E-06	1/psi	9.5E-07	1/kPa	Estimate from API Tables
	Tp	95.0	degF	35.0	degC	Maximum temperature as worst case conditions
	Tm	96.8	degF	36.0	degC	
	Pp	21.0	psi	144.8	kPa	
	Pm	50.0	psi	344.8	kPa	
X8	CTE prover	2.34E-05	vol/vol/degF	4.21E-05	vol/vol/degC	Nil
X9	CTE meter	3.33E-05	vol/vol/degF	5.99E-05	vol/vol/degC	Nil
	CTE	2.34E-05	vol/vol/degF	4.21E-05	vol/vol/degC	
	N	10000	Counts	10000	Counts	Kfactor forced to produce 10,000 Counts.
	Vcv	68.0749	barrels	10.824	cubic meters	See inventory calculation of connecting volume
X5	ΔTcv = Tcvf - Tcvi	0.2	degF	0.1	degC	Change in temperature in connecting volume during test is constrained to be less than 0.1 deg C
X7	ΔPcv = Pcvf - Pcvi	1.0	psi	14.5	kPa	Change in pressure in connecting volume during test is constrained to be less than 14.5 kPa
Known	Tbase	60	degF	15.6	degC	
Known	Pe	14.5	psi	100.0	kPa	
Known	K	0.00633	bbl/count	0.001006	cm/count	
X4	ΔT = (Tp - Tm)	-1.8	degF	-1.0	degC	Difference in temperature between the meter and the prover is constrained to be less than 1 deg C
X6	ΔP = (Pp - Pm)	-29.0	psi	-200.0	kPa	Difference in pressure between the meter and the prover is constrained to be less than 200 kPa
	Change Vcv	-0.0056	barrels	-0.0010	cubic meters	
	Vm	6.34E+01				

Major contributors to uncertainty

- Prover base volume
- Coefficient of thermal expansion for the liquid
- Delta temperature between prover and meter under test
- Delta temperature for connecting volume



NVLAP Certified Uncertainties

- 10 to 750 m^3/hr
  - Small volume prover 0.03%
  - Turbine master meter 0.04%
- 150 to 2200 m^3/hr
  - Ball prover 10 m^3 0.04%
  - Ball prover 3.3 m^3 0.07%
  - One master meter 0.09%
- 600 to 3900 m^3/hr
  - Two master meters 0.08%

NVLAP® National Voluntary Laboratory Accreditation Program

DEPARTMENT OF COMMERCE · UNITED STATES OF AMERICA

SCOPE OF ACCREDITATION TO ISO/IEC 17025:2005

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CALIBRATION LABORATORIES

NVLAP LAB CODE 200813-0
Scope Revised: 2011-08-19

MECHANICAL

NVLAP Code: 20/M05
Flow Rate (Hydrocarbon Fluids Only)[Note 2,3]

Range in m^3/h	*Best Uncertainty (±) in %* [note 1]	*Remarks*
10 to 750	0.03	Brooks Small Volume Prover
10 to 750	0.04	One Master Meter
150 to 2200	0.04	10 Cubic Meter Prover Volume
50 to 200	0.07	3.3 Cubic Meter Prover Volume
300 to 2000	0.09	One Master Meter
600 to 3900	0.08	Two Master Meters

1. Represents an expanded uncertainty using a coverage factor, $k = 2$, at an approximate level of confidence of 95 %.
2. The laboratory performs calibrations of pulse generating flow meters.
3. The laboratory performs volumetric flow calibrations only (not mass flow).

2011-07-01 through 2012-06-30
Effective dates

Sally S. Bruce
For the National Institute of Standards and Technology

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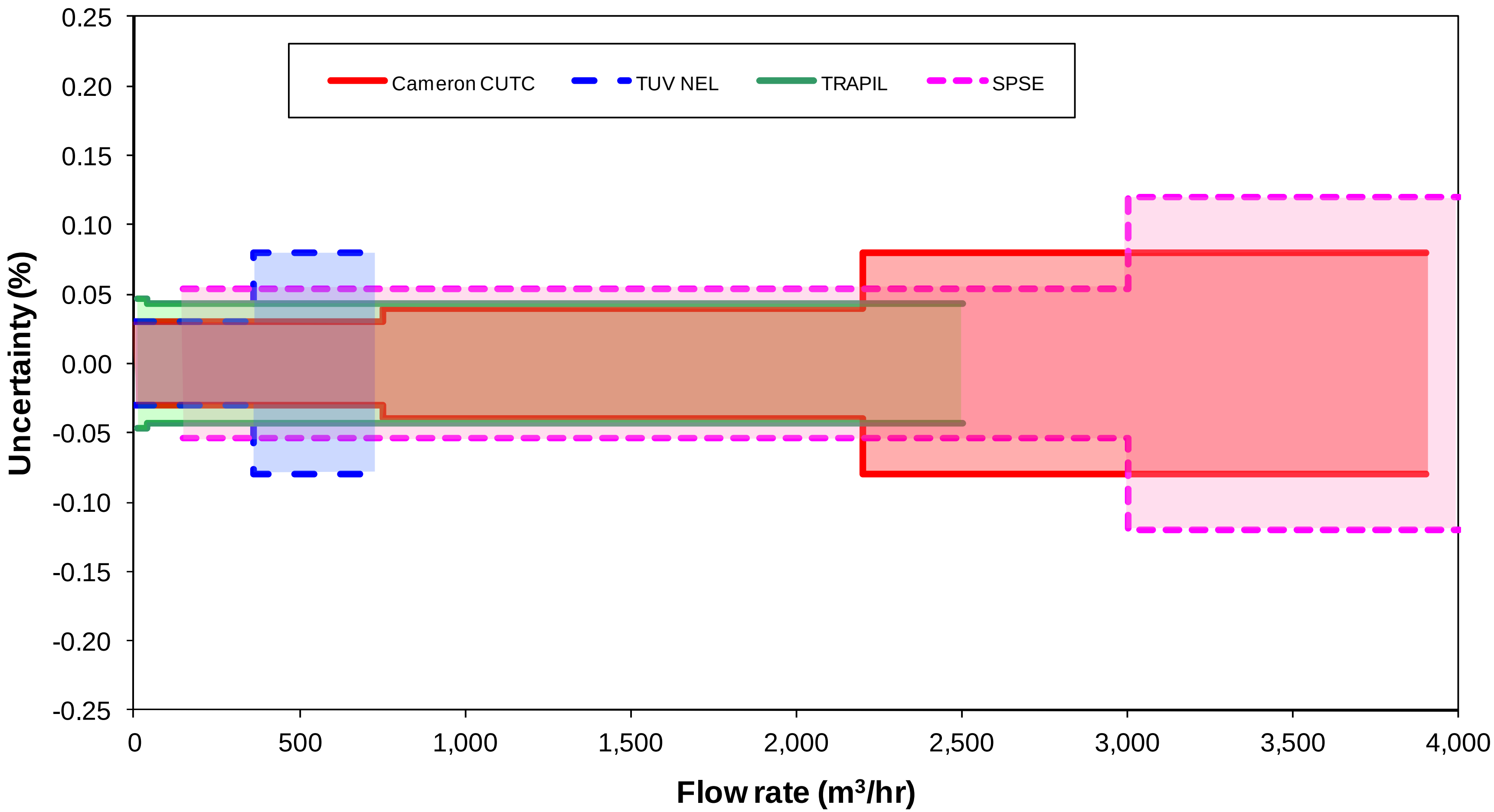
NVLAP-01S (REV. 2004-10-31)

Comparison of ISO17025 capabilities

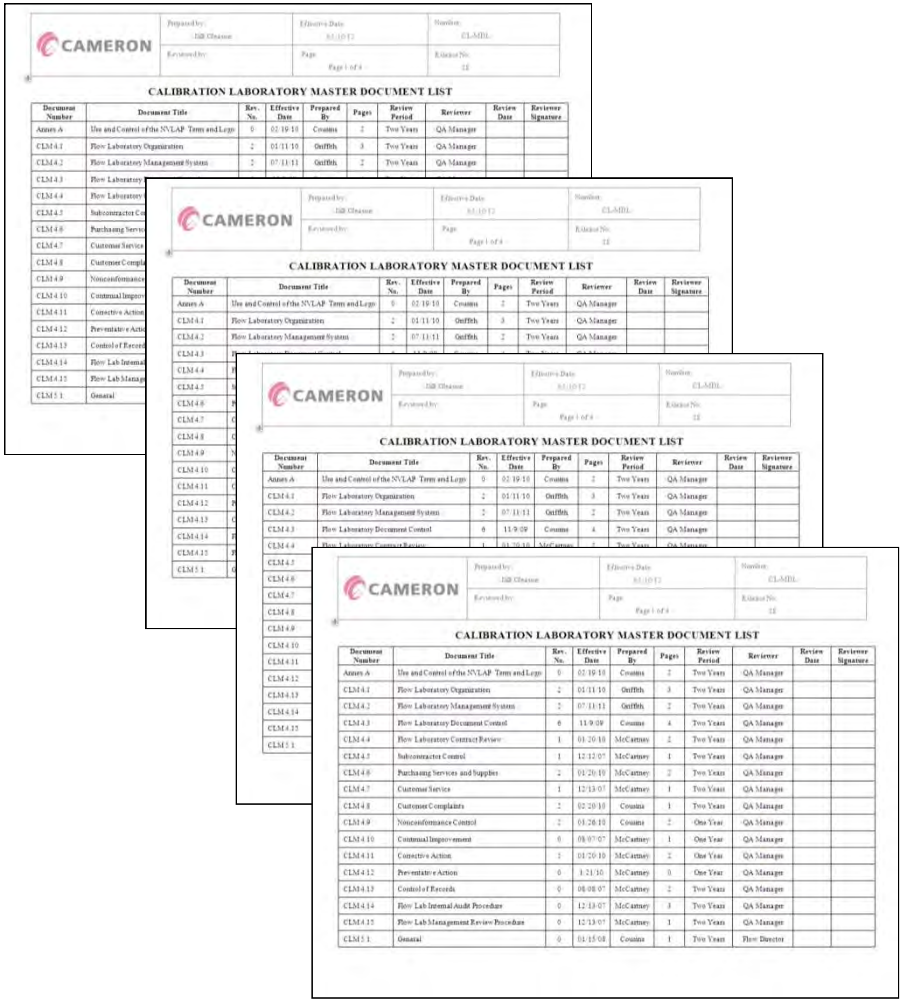


Key standards and documentation

- International Standards Organisation ISO17025:2005 General requirements for the competence of testing and calibration laboratories
- Joint Committee for Guides in Metrology JCGM 100:2008 (GUM 1995 with minor corrections) Evaluation of measurement data — Guide to the expression of uncertainty in measurement
- API Manual of Petroleum Measurement Standards
  - Especially the subchapters of Chapter 4 - Proving
- Selected ISO and ASTM standards

Calibration laboratory management system

- Independent quality system accredited for conformance with ISO17025
- Calibration laboratory quality manual comprising 28 documents
- Plus 26 documented operational procedures



CAMERON

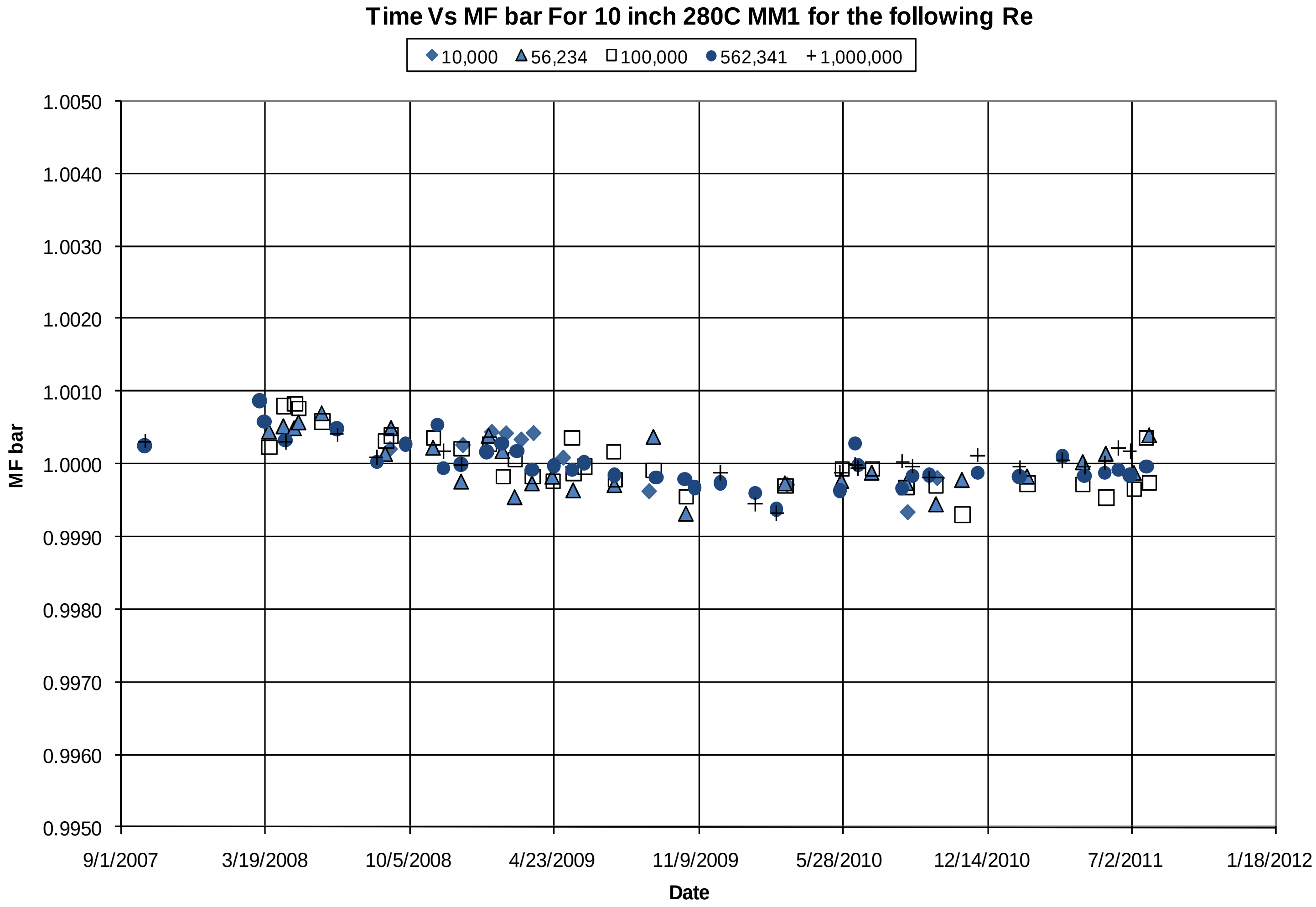
CALIBRATION LABORATORY MASTER DOCUMENT LIST

Document Number	Document Title	Rev. No.	Effective Date	Prepared By	Pages	Review Period	Reviewer	Review Date	Reviewer Signature
Annex A	Use and Control of the NVLAP Term and Logo	0	02/19/10	Cousins	2	Two Years	QA Manager		
CLM 4.1	Flow Laboratory Organization	2	01/11/10	Griffith	3	Two Years	QA Manager		
CLM 4.2	Flow Laboratory Management System	2	07/11/11	Griffith	2	Two Years	QA Manager		
CLM 4.3	Flow Laboratory Document Control	6	11/9/09	Cousins	4	Two Years	QA Manager		
CLM 4.4	Flow Laboratory Contract Review	1	01/20/10	McCartney	2	Two Years	QA Manager		
CLM 4.5	Subcontractor Control	1	12/12/07	McCartney	1	Two Years	QA Manager		
CLM 4.6	Purchasing Services and Supplies	2	01/20/10	McCartney	2	Two Years	QA Manager		
CLM 4.7	Customer Service	1	12/13/07	McCartney	1	Two Years	QA Manager		
CLM 4.8	Customer Complaints	2	02/20/10	Cousins	1	Two Years	QA Manager		
CLM 4.9	Nonconformance Control	2	01/20/10	Cousins	2	One Year	QA Manager		
CLM 4.10	Continual Improvement	0	08/07/07	McCartney	1	One Year	QA Manager		
CLM 4.11	Corrective Action	1	01/20/10	McCartney	2	One Year	QA Manager		
CLM 4.12	Preventative Action	0	1/21/10	McCartney	0	One Year	QA Manager		
CLM 4.13	Control of Records	0	08/08/07	McCartney	2	Two Years	QA Manager		
CLM 4.14	Flow Lab Internal Audit Procedure	0	12/13/07	McCartney	3	Two Years	QA Manager		
CLM 4.15	Flow Lab Management Review Procedure	0	12/13/07	McCartney	1	Two Years	QA Manager		
CLM 5.1	General	0	01/15/08	Cousins	1	Two Years	Flow Director		

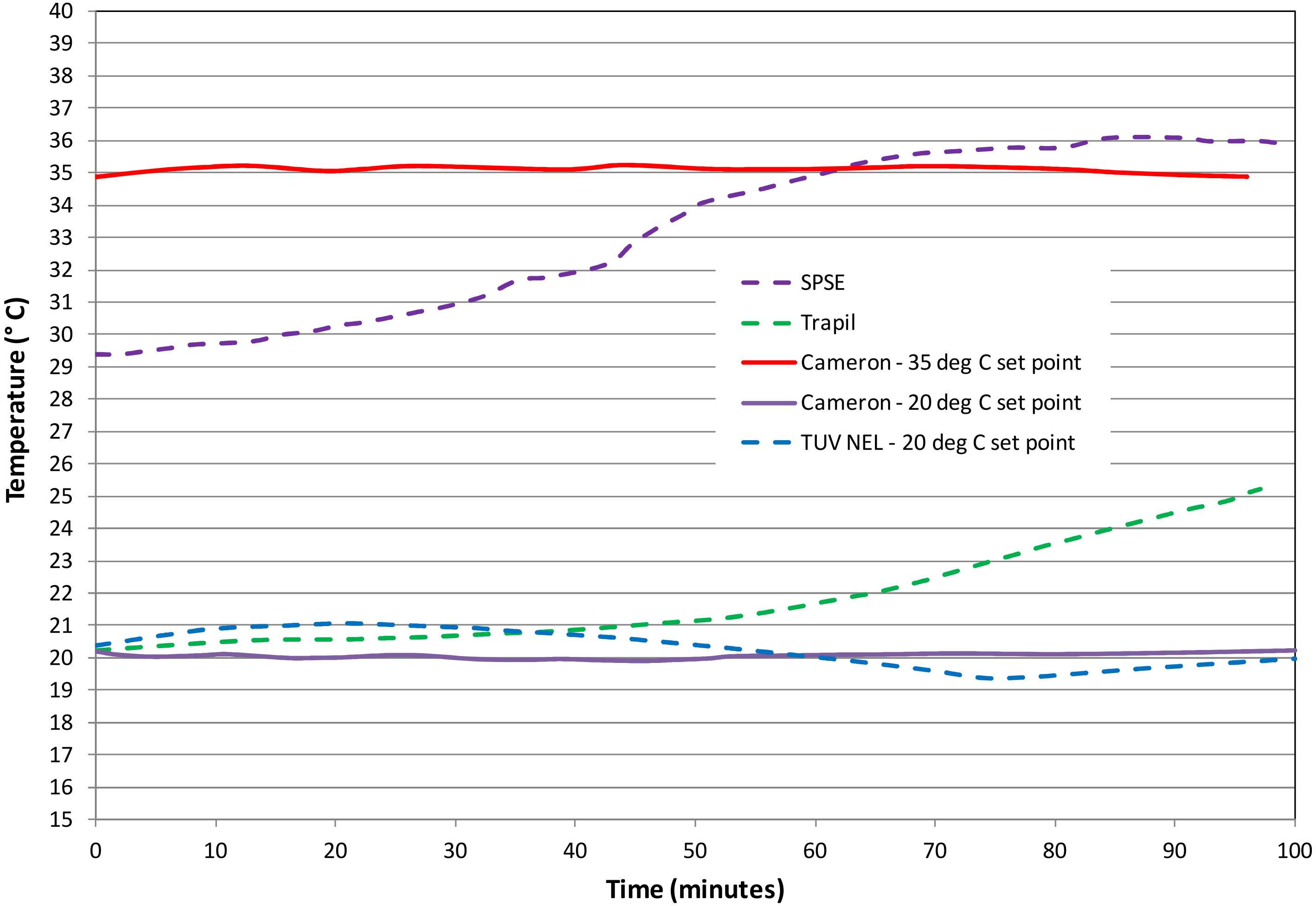
Master meter long term stability

- Master meters are calibrated before use
- Long term stability gives a good indication that everything is working as expected

Master meter long term stability



Temperature control



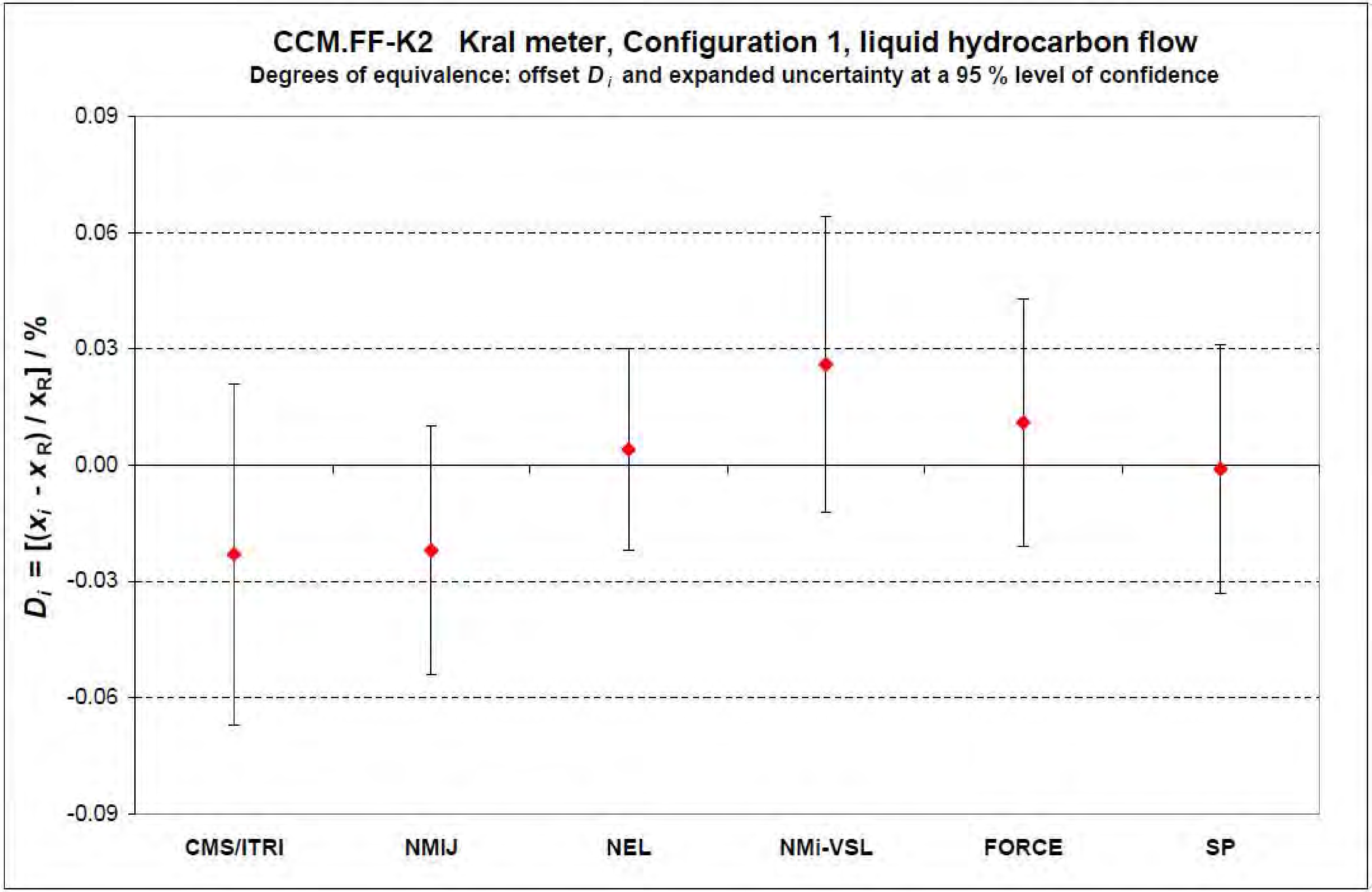
Intercomparison with NEL (UK)

- ISO 17025 states that "Participation in a suitable programme of interlaboratory comparisons is required where possible"
- Flow intercomparisions involving multiple laboratories are rare and tend to involve national measurement institutes
- However, NEL in the UK had been designated at 'pilot lab' in the recently completed Liquid Hydrocarbon Flow Key Comparison CCM-FF-K2, carried out under the auspices of the International Committee of Weights and Measures (CIPM)

Intercomparison with NEL (UK)

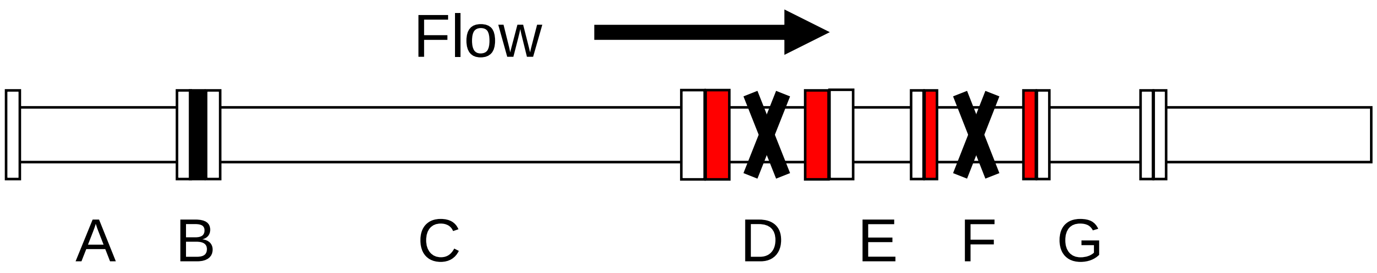
- Other participants in CCM-FF-K2 were:
  - CMS (Chinese Taipei), NMIJ (Japan), NMi VSL (Netherlands), FORCE (Denmark), and SP (Sweden)
- Therefore by carrying out a bi-lateral intercomparision with NEL, a successful result would demonstrate metrological equivalence with a broad group of national metrology institutes

Key Comparison CCM-FF-K2 results



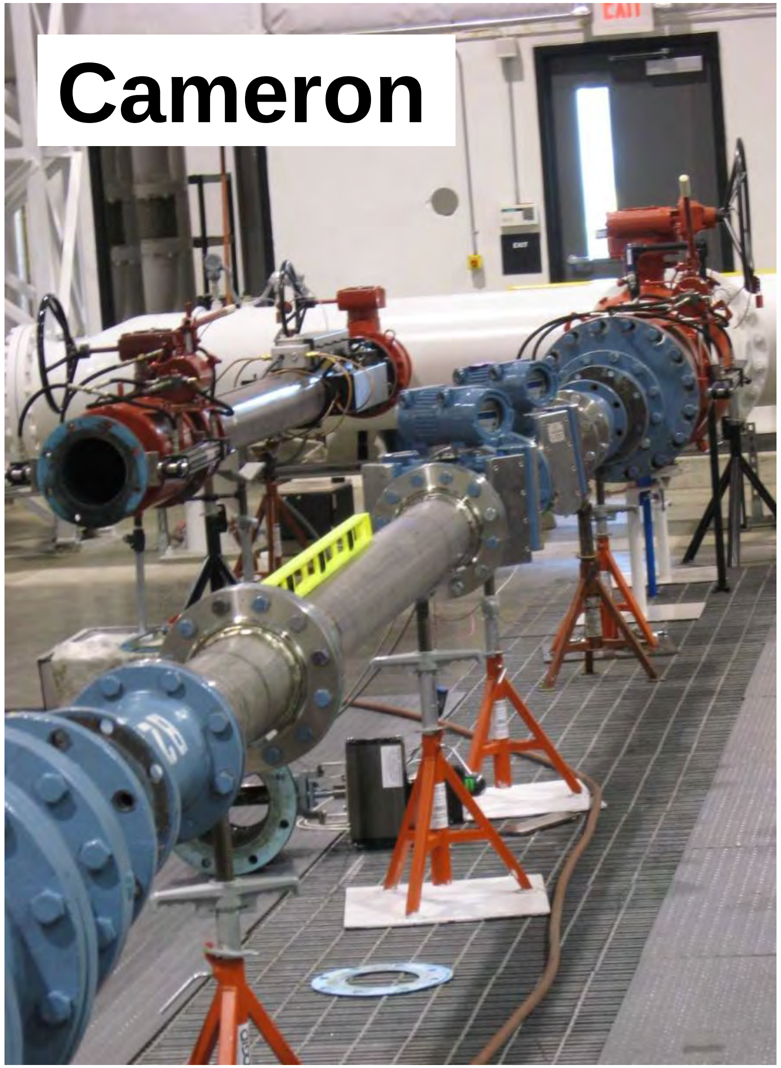
Intercomparision package

- An intercomparision package was assembled using two 6-inch Caldon 8-path meters
- A flow conditioning upstream section was used to ensure absolutely minimal installation effects



A and G	– 5D straight length (matched schedule with internal welds ground flush)
B	– Perforated plate flow conditioner (CPA)
C	– 15D straight length (matched schedule with internal welds ground flush)
D & F	– 280Ci ultrasonic flow meters
E	– 3D 150# to 300# flange adaptor spool

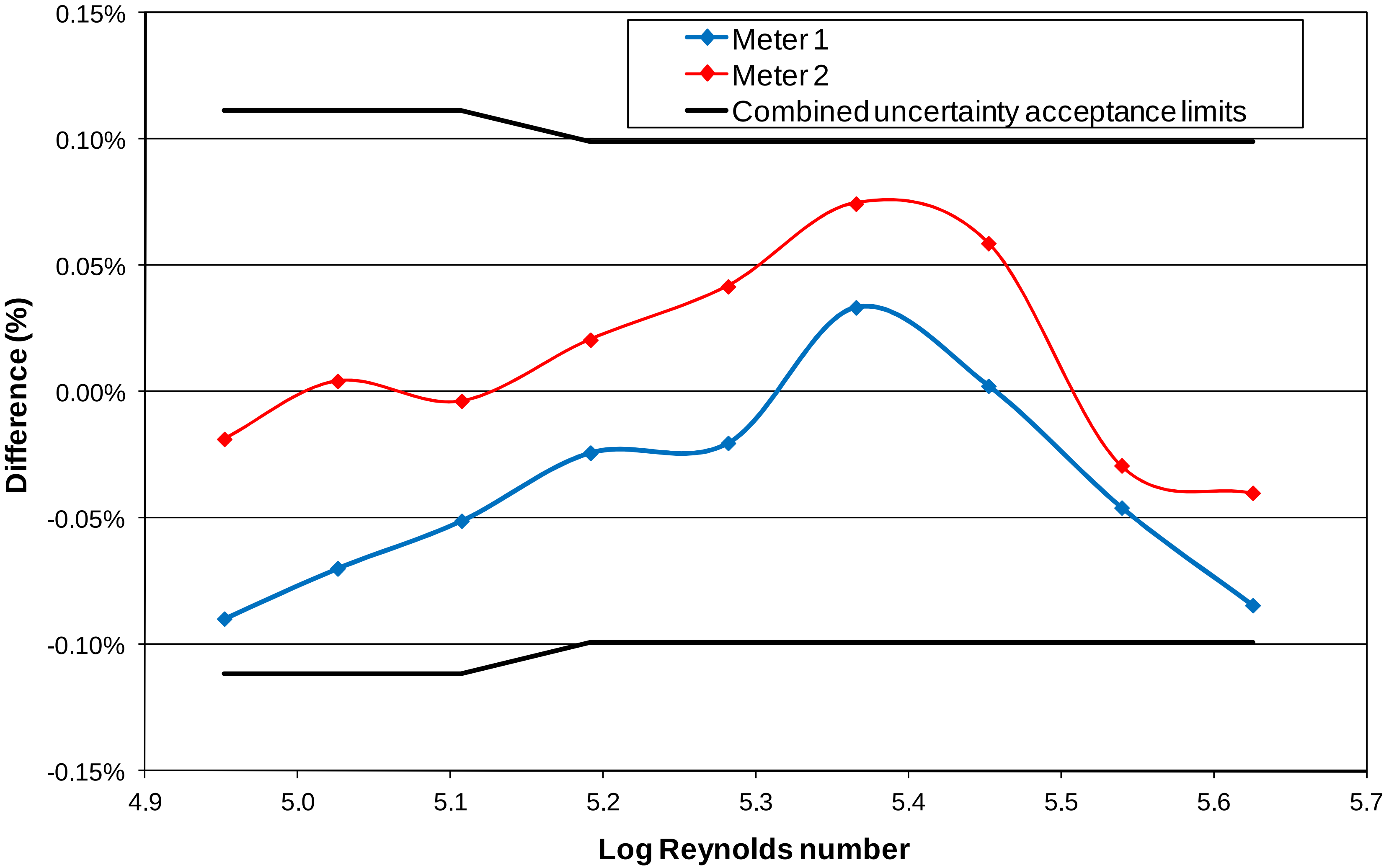
Intercomparision package



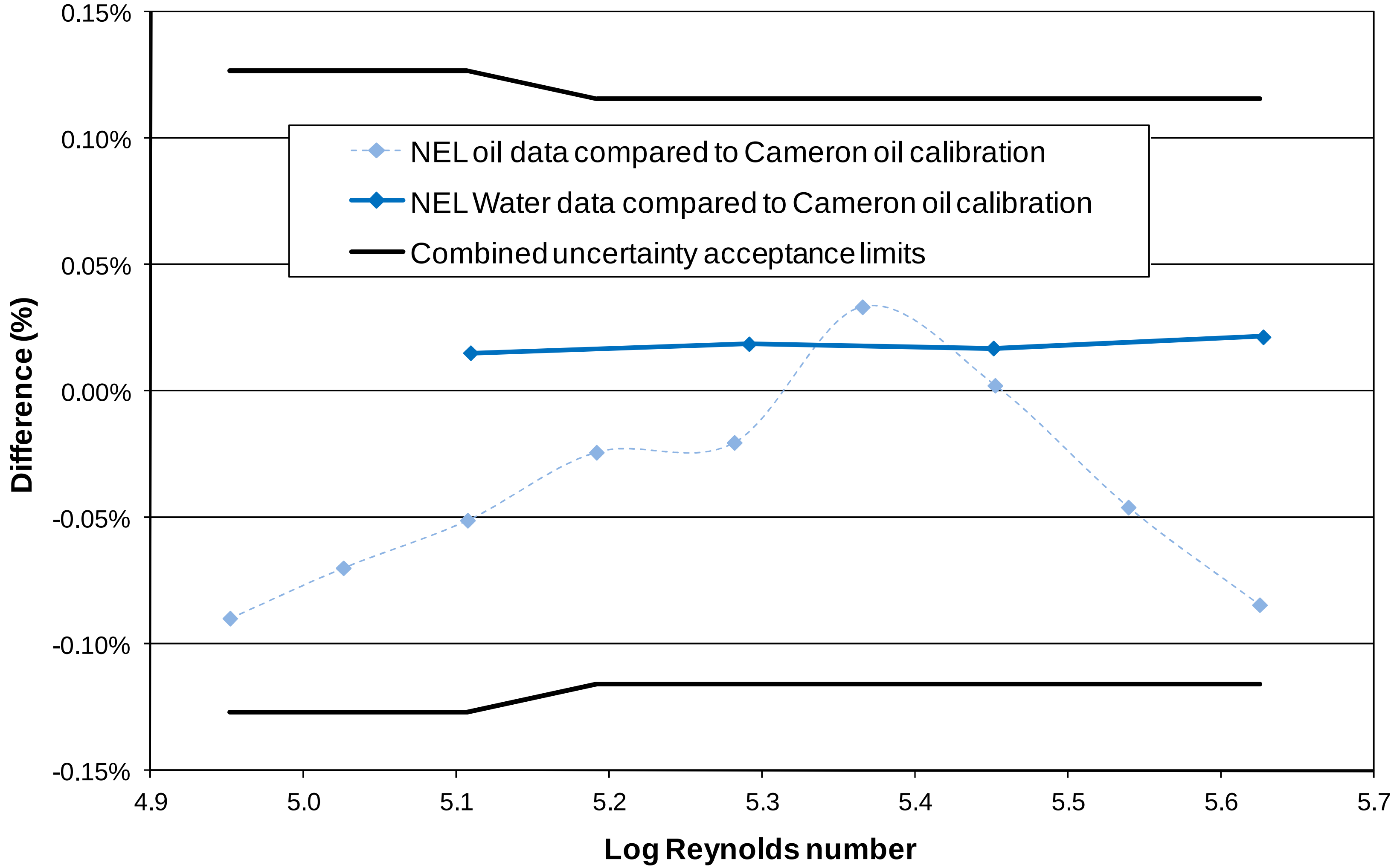
Intercomparision package

- Primary comparison was carried out using kerosene substitute (Exxsol D80) over a flow range of 100 to 600 m^3/hr in both facilities
  – Cameron lab tests vs ball prover
  – NEL tests versus turbine secondary standards
- A secondary comparison was also carried out using the NEL water flow facility gravimetric standard
- Comparisons were made at overlapping Reynolds numbers

Intercomparision results on kerosene



Intercomparision results vs water



Intercomparision results

- The results from both meters and both NEL facilities (oil and water) demonstrated metrological equivalence with the Cameron laboratory
- The closest and most linear agreement was actually found in the case of the water comparison, suggesting that the difference in the oil calibration were in part due to the curve fitting to the NEL secondary standard turbines

SUMMARY

- The Cameron laboratory as constructed exceeds the design expectations
- It offers a capability that surpasses that of the third-party facilities previously used
- The uncertainty has been validated by VSL, NVLAP and the NEL intercomparision
- Use of well understood and reliable system components and methods have resulted in a high availability – the laboratory is in almost constant use

Thank you

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