



# A New Calibration Method For TEWL With Traceability To Measurement Standards

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- (a) Protocols for the calibration of TEWL instruments that provide traceability to recognised standards.
- (b) Components, accessories and materials for calibrating TEWL instruments in accordance with the above protocols.
- (c) Results from field tests providing evidence of comparability of TEWL measurements performed using different instruments and measurement methods.
- (d) Publication of the theoretical background and practical implementation of the new calibration method.

The TEWL calibration project is focused on the traceable calibration of **water vapour flux density**. The correct and traceable calibration of individual humidity and temperature sensors used for the measurement of flux density is a necessary pre-condition for a correct calibration of flux density.





# Flux Density Calibration Methods

Two main calibration methods were studied, as follows:-

## 1. The Membrane Method

Such methods have been widely used to calibrate and compare TEWL instruments [1-4]. Our mathematical and numerical modelling has now revealed that this approach is fundamentally flawed.

## 2. The Water Droplet Method

This is a new approach, adopted when it became clear that the membrane method would not be suitable.

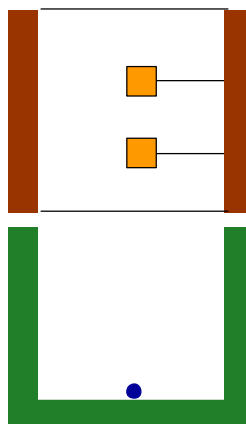
- [1] G. E. Nilsson, *Measurement of Water Exchange through Skin*, Med. Biol. Comput., **15**, 209-18, 1977.
- [2] J Pinnagoda, R A Tupker, T Agner, and J Serup, *Guidelines for Transepidermal Water Loss (TEWL) Measurement*, Contact Dermat, **22**, 164-78, 1990.
- [3] G L Grove, M J Grove, C Zerweck and E Pierce, *Comparative Metrology of the Evaporimeter and the DermaLab Probe*, Skin Res & Technol, **5**, 1-8, 1999.
- [4] J. Nuutinen, E. Alanen, P. Autio, M-R. Lahtinen, I. Harvima & T. Lahtinen, *A Closed Unventilated Chamber for the Measurement of Transepidermal Water Loss*, Skin Res. & Technol., **9**, 85-9, 2003.

# The Droplet Method 1

Dispense a small quantity of water, typically  $1\mu\text{L}$ , into a calibration well. Couple the TEWL measurement chamber to the well. Record a continuous time-series of flux density readings until the droplet has evaporated and the flux density returned to zero. The calibration constant can be worked out from the relationship between the quantity of water dispensed and the area under the flux density time-series curve.

Measurement  
chamber

Calibration well

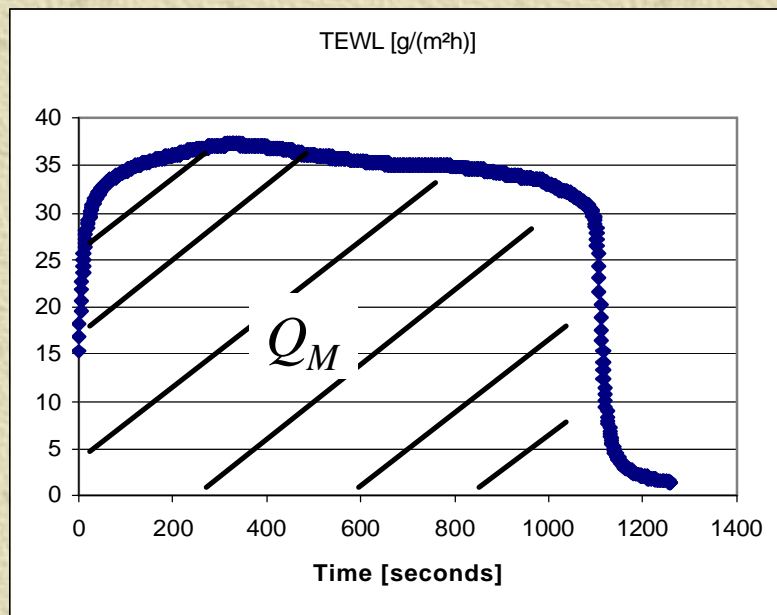




$$C = J_U \cdot \left( \frac{Q_M}{Q_D} \right)$$



## The Droplet Method 2



$$J_C = J_U \cdot \left( \frac{Q_D}{Q_M} \right)$$

$J_C$  = Calibrated flux density  
 $J_U$  = Uncalibrated flux density  
 $Q_D$  = Quality dispensed  
 $Q_M$  = Quantity Measured

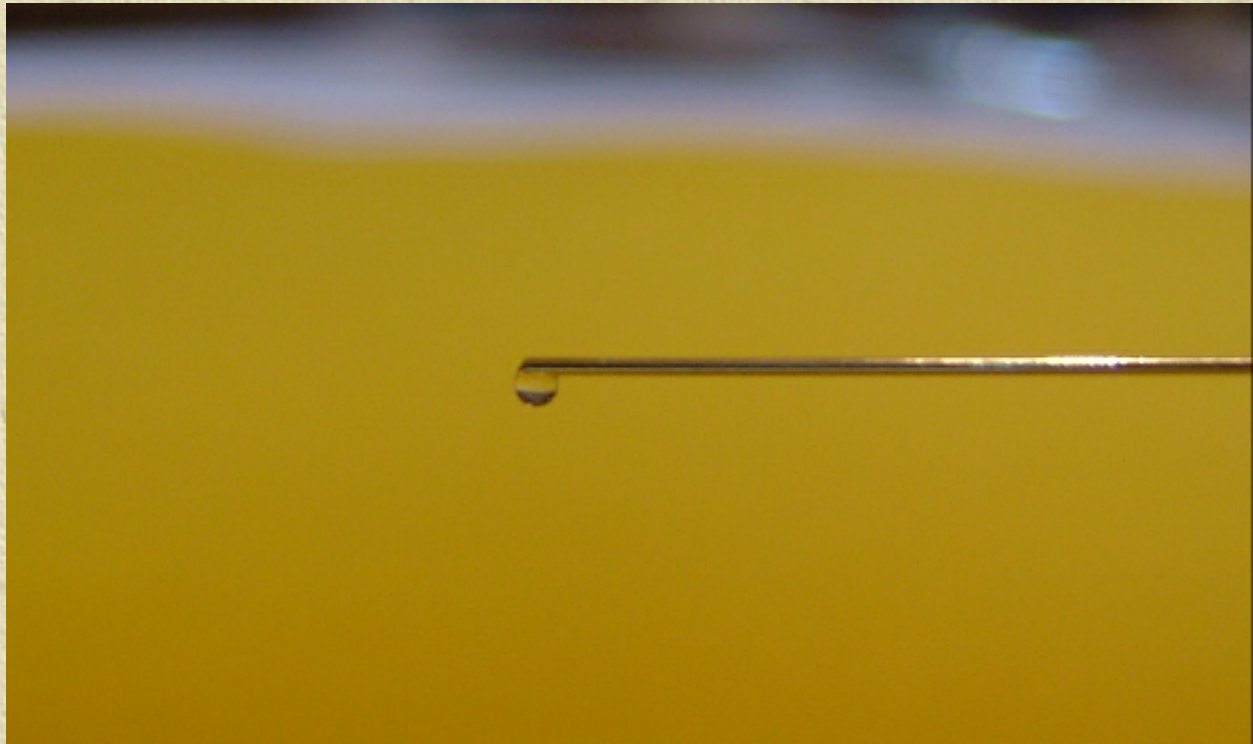
## The Droplet Method 3



Traceability is provided via a calibrated micro-syringe such as the one shown above.

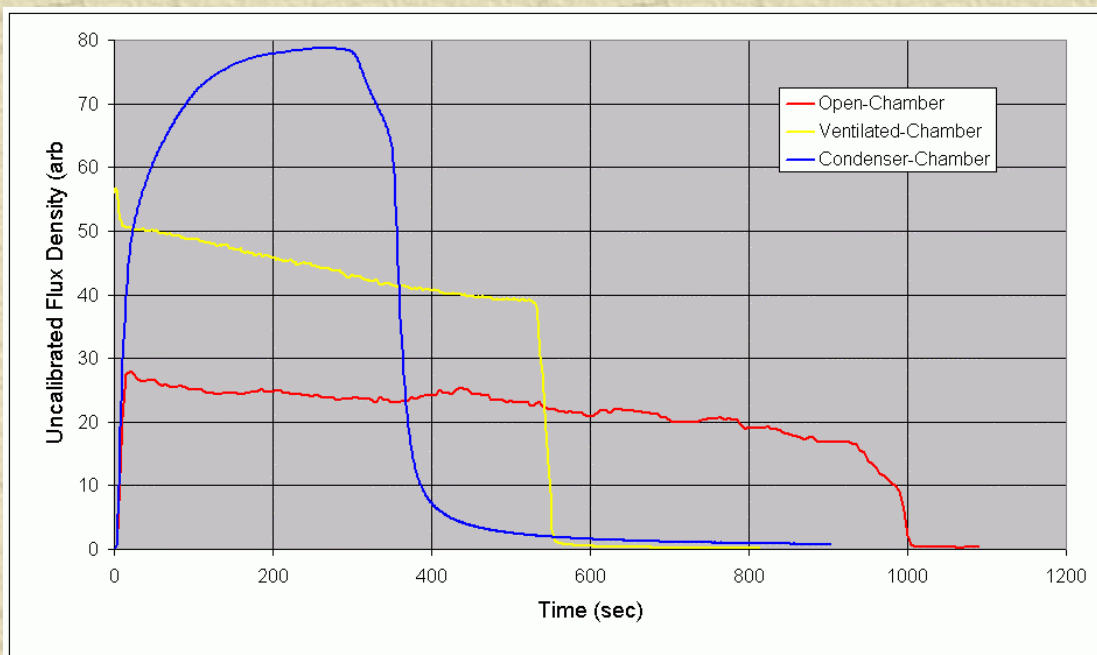


## The Droplet Method 4



This is what a 1  $\mu\text{L}$  droplet looks like. Droplets as small as 0.05  $\mu\text{L}$  are used in the research.

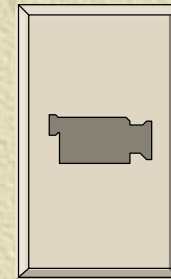
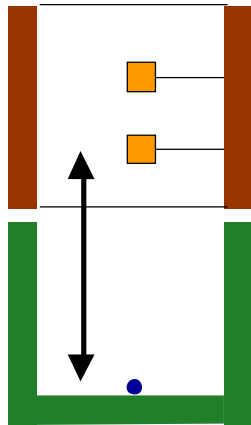
# Typical Calibration Curves



Shown above are examples of calibration curves measured using Open-Chamber, Ventilated-Chamber and Condenser-Chamber instruments.

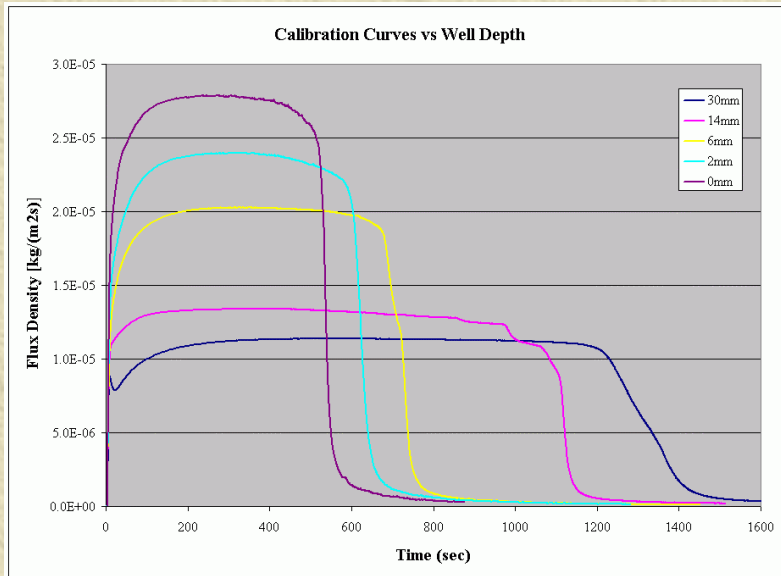


# Effect of Point Source & Source – Sensor Distance



Movie of a finite-element simulation of how the water vapour spreads as it diffuses away from the droplet.

# Mean Flux Density during Calibration

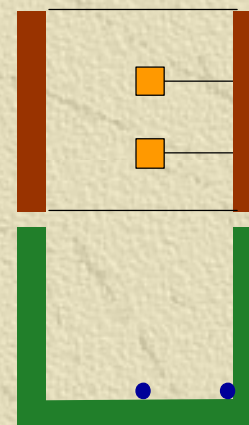
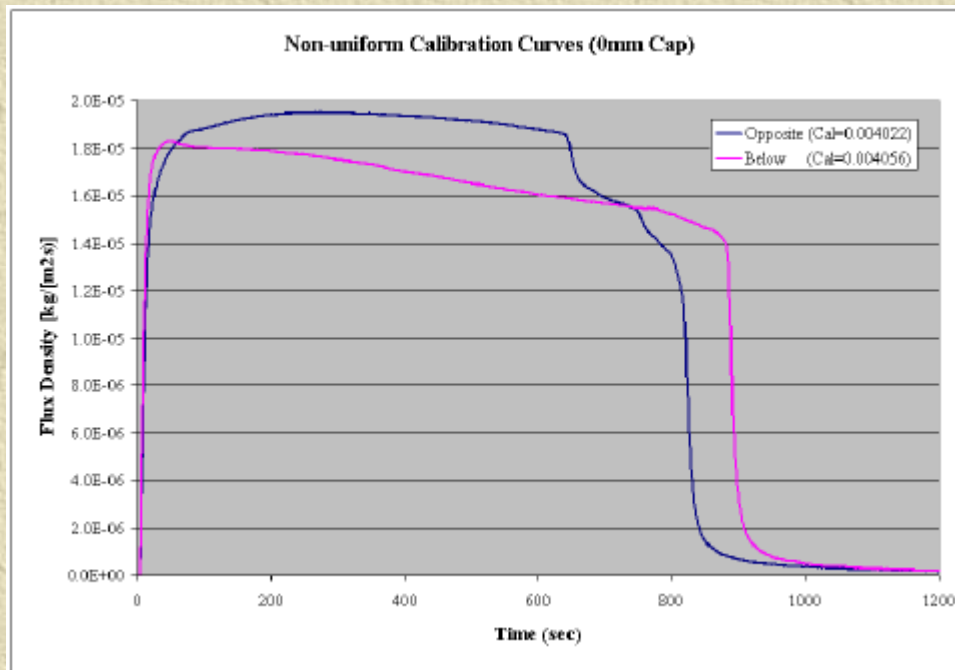


Instrument linearity can be checked by measuring calibration factors for a range of mean flux densities. Mean flux density can be controlled through temperature and/or the use of calibration wells of different depths. This is illustrated here for well depths in the range 0-30mm.

According to our numerical modelling work, the separation between the droplet and the nearest sensor needs to be at least one chamber diameter in order to ensure radial flux uniformity. For well depths greater than this minimum, the calibration factor is expected to be independent of well depth for linear instruments.

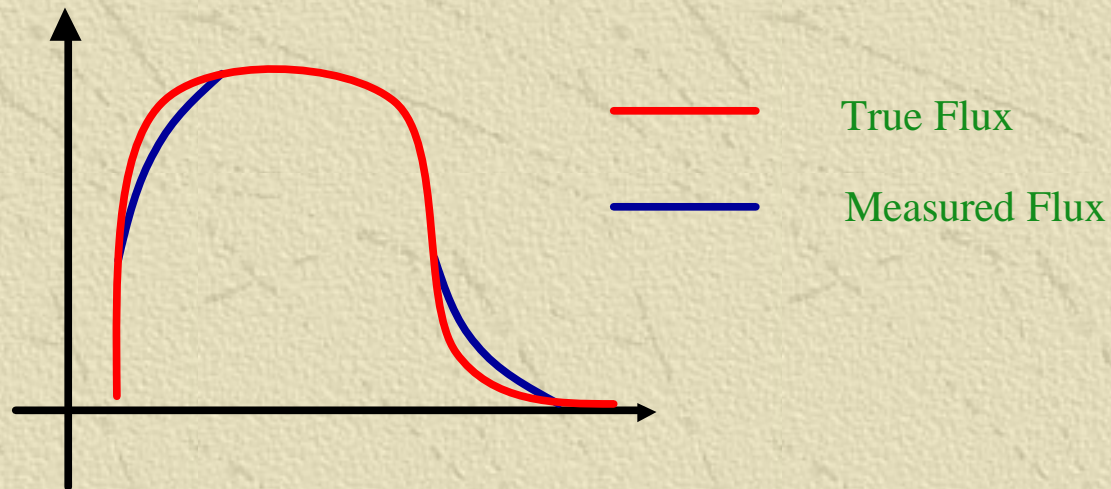


## Effect of Droplet Position



Shown above is the effect of radial droplet position on the flux curves. The main effect is in the initial rate of rise of the flux. The area beneath the curve, and therefore the measured calibration factor, is not affected.

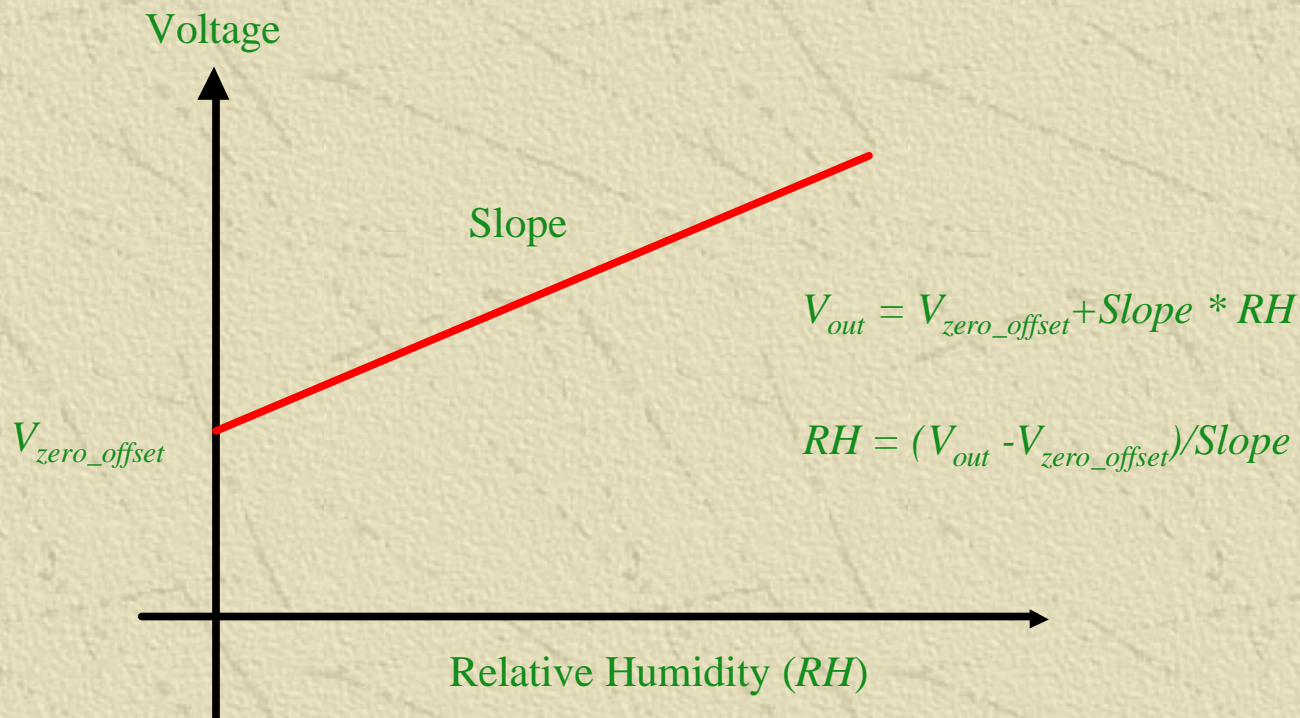
## Effect of Instrument Response Speed



This analysis shows that the finite response speed of the instrument has no effect on the measured calibration factor. This is because the loss of area during the rising part of the curve is compensated by a matching gain of area in the falling part of the curve. The mathematical analysis assumes that the instrument response is linear.



# Effect of Mis-Calibration of the Humidity Sensor 1



Another concern is the effect of RH sensor calibration on flux density calibration. Here we analyse the effect in a Condenser-Chamber instrument, where a single RH sensor is used. The response of the RH sensor is represented by a zero-offset and a slope.

## Effect of Mis-Calibration of the Humidity Sensor 2

$$RH = (V_{out} - V_{zero\_offset}) / Slope$$

$$VD = RH * f(T_s)$$

$$J = C * (VD - f(T_c))$$

$$J = C * RH * f(T_s) - C * f(T_c)$$

$$J = C * ((V_{out} - V_{zero\_offset}) / Slope) * f(T_s) - C * f(T_c)$$

This is how the flux density in a Condenser-Chamber instrument is calculated from the output of the RH sensor.



## Effect of Mis-Calibration of the Humidity Sensor 3

### Baseline Calibration

$$J = C * V_{out} * f(T_S) / Slope - C * V_{zero\_offset} * f(T_S) / Slope \\ - C * f(T_C)$$

$$J = 0$$

$$C * V_{zeroRH} * f(T_S) / Slope - C * V_{zero\_offset} * f(T_S) / Slope \\ - C * f(T_C) = 0$$

### Flux Density Calibration

$$J = C * V_{out} * f(T_S) / Slope - C * V_{zeroRH} * f(T_S) / Slope \\ J = Y(V_{out}) / Slope$$

This shows that the baseline (ie zero-offset) and flux density calibrations effectively cancel any errors there may be in the calibration of the RH sensor.

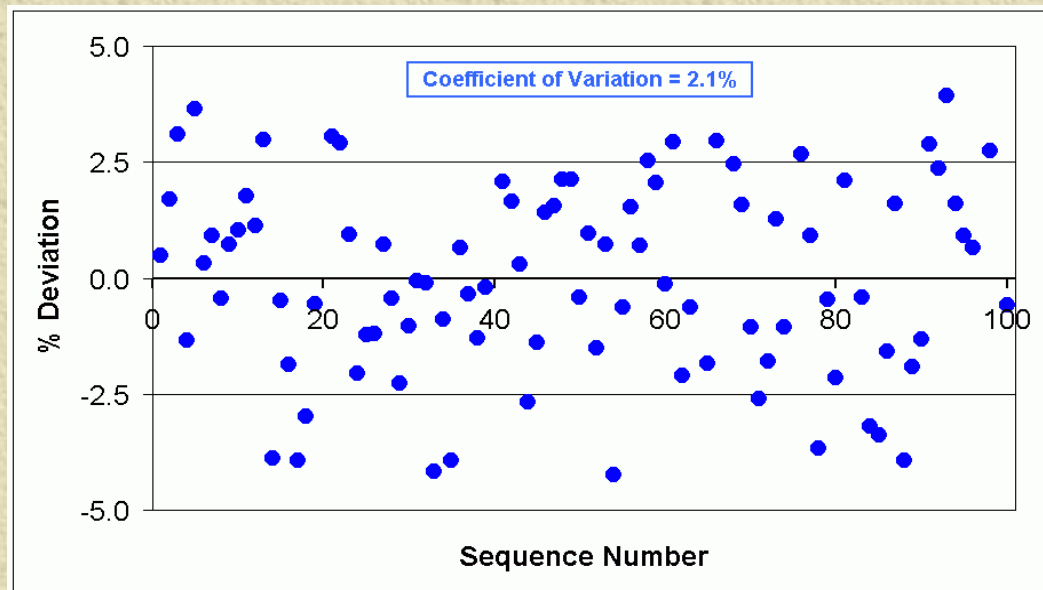
# Effect of Mis-Calibration of the Humidity Sensor 4

Therefore, for a linear RH sensor in a Condenser-Chamber Instrument:-

1. The baseline calibration will correct any mis-calibration of the zero offset voltage parameter of the RH sensor.
2. The flux density calibration will correct any mis-calibration of the slope parameter of the RH sensor.



# Calibration Repeatability



This repeatability test used a Condenser-Chamber instrument in a measurement sequence of 100 calibrations. A smaller than usual dispensed volume of  $0.5\mu\text{L}$  was used, partly to speed up the work and partly to amplify any measurement errors. Shown above is a residuals plot for the individual measurements, which are all contained within a  $\pm 5\%$  band of deviation.



# Droplet Calibration Summary

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1. The Droplet method can be used with all TEWL instruments capable of measuring flux time-series.
  2. Calibration traceability is achieved via a calibrated micro-syringe.
  3. A high degree of repeatability can be demonstrated for the method.

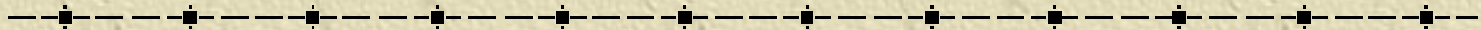
Work is in progress to:-

- Develop calibration protocols for individual instrument types.
- Develop calibration accessories for individual instrument types.
- Compile an error budget for the method.
- Verify the calibration via practical trials.





# Acknowledgements



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