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# Accurate measurement of low flow rates

*Traceable calibration from 2 to 3 L/h down to leak-detection level*

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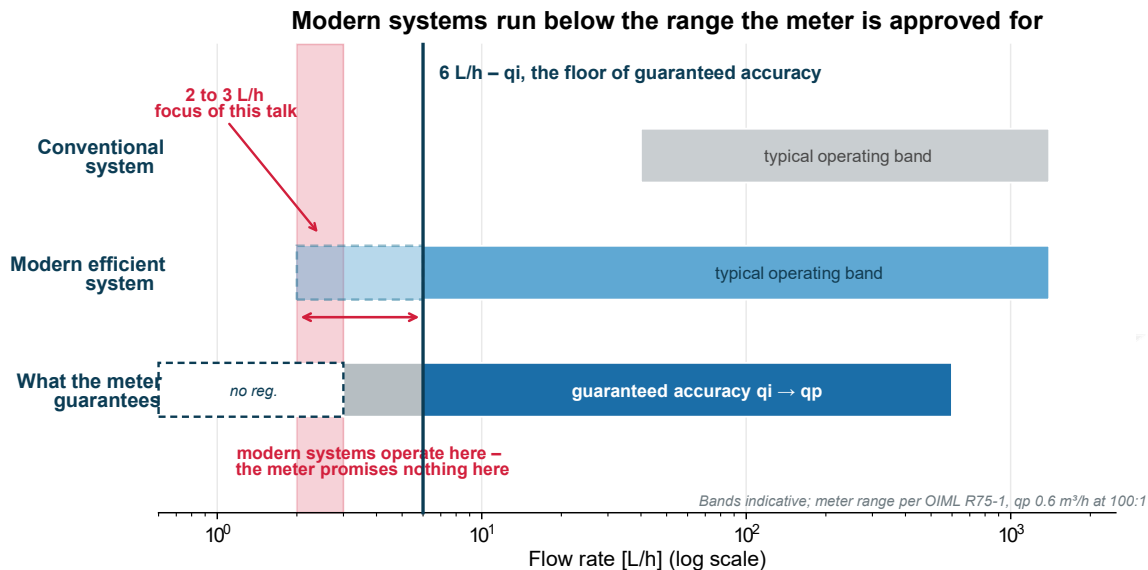
Oliver Büker · RISE Research Institutes of Sweden – Sweden's National Metrology Institute

22nd International EMATEM Summer School · Haydau Monastery in Morschen (Germany) · 23–24 September 2026

# // Why low-flow measurement matters

- ❑ Modern high-efficiency systems such as low temperature heating, modulating pumps and water-saving fixtures, operate long periods at or below a meter's lower limit.
- ❑ Missed low flows cause systematic under-registration of consumption exactly where these systems spend most of their runtime, which biases heat-cost allocation and billing.

**Traceable low-flow measurement is essential for fair billing, standards compliance, and consistent energy-performance evaluation.**



*Operating bands are indicative, not measured data; the meter range is per OIML R75-1 for  $q_p = 0.6 \text{ m}^3/\text{h}$  at 100:1.*

## // Heating: everyday part load sits at 2 to 4 L/h



### Single radiator at part load

On a mild autumn day, a well-insulated room: the thermostatic valve reduces the emitter's output to a few percent of its design capacity.  
50 W at  $\Delta T = 10$  K

→ 4.3 L/h



### A valve that no longer closes

Lime or debris on the seat allows a small amount of water to pass through all summer – enough to register, but too small for anyone to notice.

30 W at  $\Delta T = 10$  K

→ 2.6 L/h



### Flat station kept warm

An apartment substation or district heating service that maintains the temperature during the off-season.

60 W at  $\Delta T = 15$  K

→ 3.4 L/h



### Pump off: gravity circulation

Thermosiphon movement occurs behind a nominally closed valve. R75-1 §6.2 is explicit: this must not be registered at all.

must read zero

$$\dot{m} \text{ [L/h]} = Q \text{ [W]} / (1.163 \cdot \Delta T \text{ [K]})$$

Each of the figures above represents a worked-through heat-balance identity, not a field measurement.

**Not every small load lands here:** Underfloor heating has a smaller spread (5 to 8 K), so 100 to 200 W still requires 10 to 35 L/h. The 2 to 4 L/h band is a radiator and part-load problem.

# // Cooling: the same flows, a harder measurement



## Server & electronics

→ 2.6 L/h

A small dedicated circuit rejecting a few tens of watts at a tight setpoint, for long continuous periods.

15 W at  $\Delta T = 5$  K



## Lab & medical devices

→ 4.3 L/h

Lasers, analysers and imaging components are held at a fraction of a kelvin in a continuous dosing flow.

20 W at  $\Delta T = 4$  K

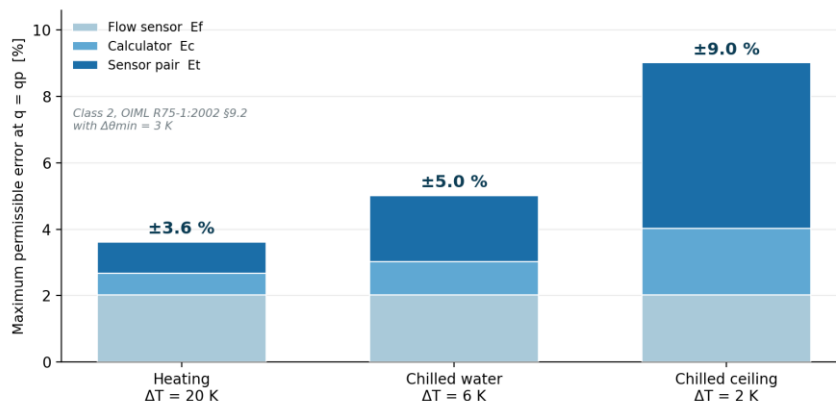


## Chilled ceiling

≈ 8 L/h

It runs at about 40 L/h at around 90 W by design. Even a fifth of that load requires 8 L/h, which is above our target range. Two-point valves cause bursts and zeros.

The same meter, a bigger error budget: MPE grows as  $\Delta T$  shrinks



**By nature, cooling is the more difficult process.** Chilled water runs at about 6 K, whereas a chilled ceiling runs at only about 2 K. It is not possible to go below the dew point. As  $\Delta T$  shrinks, the permitted error increases before the flow sensor has registered anything.

At  $\Delta T = 6$  K and  $q = q_i$ , the same class 2 meter is allowed  $\pm 7$  %.

## // Water: leaks live below the meter's starting flow



### Dripping tap

A single drop of water dripping at a rate of one drop per second adds up to more than 11,000 litres per year – the classic invisible loss.  
(US EPA WaterSense)

≈ 1.3 L/h



### Running WC cistern

A fill valve that never quite seats. The most common household leak, and often the largest.

4 to 20 L/h



### Micro-irrigation

Single drip emitters, humidifiers and reverse osmosis units are designed to run at a rate of a few litres per hour.

≈ 2 L/h each



### Minimum night flow

A baseline that never returns to zero between 2am and 4am is the classic leak signature in smart metering.

the detection method

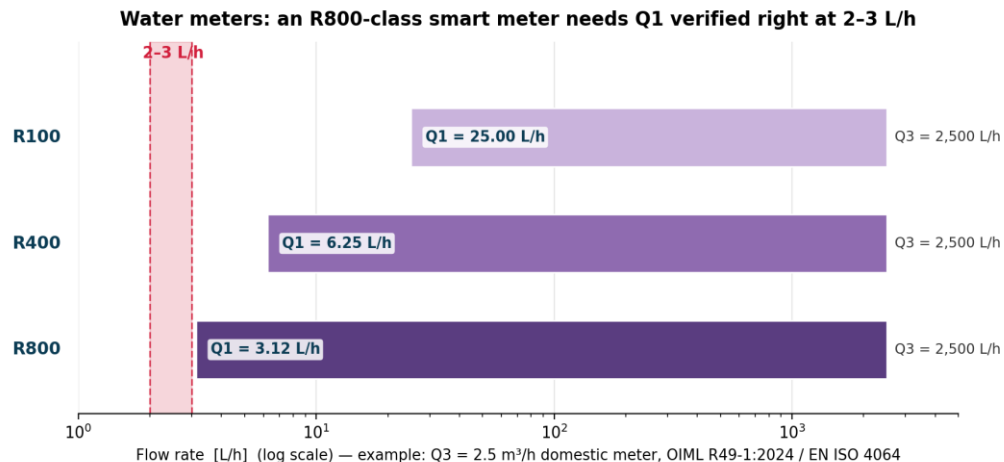
**In order to detect a leak of 1 L/h, the meter has to start at around 1 L/h.**

Modern ultrasonic domestic meters have starting flows of 0.9 to 1.4 L/h and vendors claim continuous leak detection from 1.2 L/h. In contrast, a mechanical Q3 = 2.5 m<sup>3</sup>/h meter starts at around 8 L/h and is therefore unable to detect the leak it is designed to find. This is the “real” metrological argument for the technological change, not the radio module.

*1 L/h running continuously = 8.8 m<sup>3</sup> per year.*

## // Water meters: dynamic range pushes Q1 down

- ❑ Water meters are characterised by Q1 (min), Q2, Q3 (permanent) and Q4 (overload) flow rates; dynamic range  $R = Q3 / Q1$  (OIML R49-1:2024 / EN ISO 4064).
- ❑ Modern ultrasonic and electromagnetic smart meters have a R400 to R800 and beyond, far greater than that of older mechanical meters.
- ❑ For a typical domestic meter with  $Q3 = 2.5 \text{ m}^3/\text{h}$ , an R800 class already puts Q1 at just 3.1 L/h, which is right at the edge of today's focus range.
- ❑ Field evidence shows that domestic meters tested at 15 L/h had an error of between -7.9 % to -16.5 % for multi-jet and single-jet types, compared to +0.37 % for a volumetric meter (Karadirek et al., 2020).

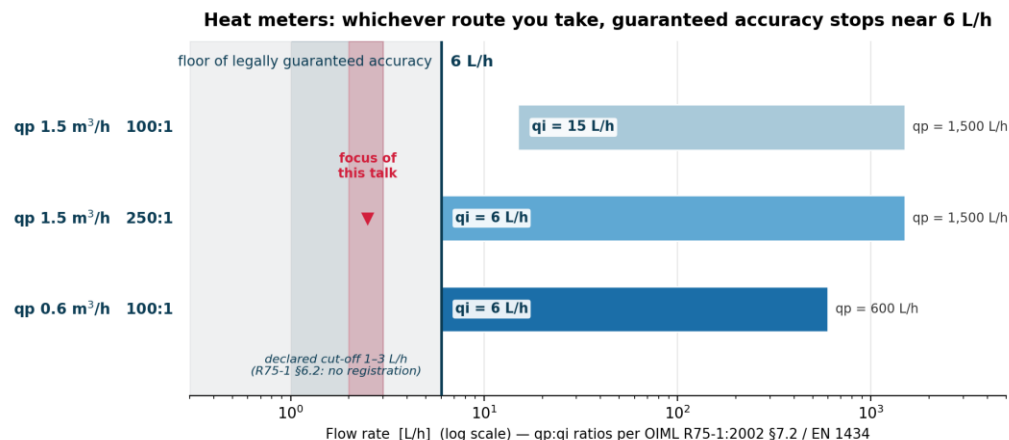


Worked example from OIML R49-1:2024 / EN ISO 4064 R-classes;  $Q3 = 2.5 \text{ m}^3/\text{h}$  is a typical domestic size.

**Higher R = better leak sensitivity**, but only if Q1 has been verified directly rather than extrapolated from the meter's specifications.

# // Heat meters: guaranteed accuracy stops near 6 L/h

- Heat meters are characterised by  $q_i$  (min),  $q_t$ ,  $q_p$  (permanent) and  $q_s$ ; OIML R75-1:2002 §7.2 fixes the  $q_p/q_i$  ratio to either 10, 25, 50, 100 or 250.
- A compact  $q_p = 0.6 \text{ m}^3/\text{h}$  meter (the smallest common apartment size) is typically approved at a ratio of 100:1, giving a  $q_i = 6 \text{ L/h}$ .
- In practice, 250:1 is only offered from  $q_p = 1.5 \text{ m}^3/\text{h}$  upwards, where  $q_i = 6 \text{ L/h}$  is again achieved. Both ratios result in the same value.



## OIML R75-1:2002 §6.2

*“When the flow rate is less than a threshold value declared by the supplier, no registration is allowed.”*  
Declared thresholds at  $q_p 0.6 \text{ m}^3/\text{h}$ : 1 to 3 L/h.

## The focus of this talk is below the legal threshold.

Between the declared cut-off point and  $q_i$ , a meter may not register anything at all – this is by design and is in line with the standard. However, these flows are real and increasingly common, so it is important to be able to measure them accurately to understand what is being missed.

## // **Cooling meters:** with liquids other than water (LOTW)

### Marking and declaration

EN 1434-1 / OIML R75-1 §11 requires the heat-conveying liquid to be labelled if it is not water. §8 requires the supplier to provide the heat coefficient as a function of temperature and pressure. (This is not included in the MID's MI-004 inscription list.)

### What glycol does to the reading

A study at TU Berlin with PTB, VDDW and ARGE HeiWaKo measured -45 % to +30 % deviation on ultrasonic flow sensors in glycol–water mixtures; impeller sensors -8 % to +7 %, Coriolis and Magmeter within  $\pm 1$  %. Medium-specific correction recovers roughly  $\pm 2$  % (Baack, 2020).

### Why low flow makes it worse

A  $q_p$  0.6 m<sup>3</sup>/h meter runs from  $Re \approx 38,000$  at  $q_p$  down to  $Re \approx 380$  at  $q_i$  – it transitions from turbulent to laminar flow within its approved range. The diametral profile factor changes from about 0.94 for turbulent flows to 0.75 for laminar flows, and glycol reduces  $Re$  by another factor of five.

## // Sweden's National Metrology Institute

- ❑ The government-appointed National Metrology Institute (NMI), headquartered in Gothenburg, is part of RISE, one of Europe's largest technology research institutes.
- ❑ It maintains Sweden's national measurement standards and issues internationally recognised calibration certificates (incl. DCC).

**3,260**  
employees

**4,394 MSEK**  
net sales (2025)

**~130**  
technology infrastructures

**83**  
customer satisfaction index (2026)

*Funded to remain an independent, neutral partner: 50% business sector · 25% public funds · 18% state skills-development funding · 7% EU (2025). Also active internationally: 594 scientific publications and 188 EU-funded projects in 2025.*

**Our operations  
are located all  
over Sweden**

We also have  
operations in  
Norway and France



*Research Institutes of Sweden RISE (2026)*

# // Riksmätplats — Sweden's national reference standards

- ❑ Fourteen national laboratories (“Riksmätplatser”) cover 32 physical quantities.
- ❑ Each Riksmätplats maintains the national reference standards for its respective field and issues internationally recognised CMCs.
- ❑ Riksmätplats “Volume, Flow & Density” (highlighted) is the laboratory behind today’s talk (where I work).

*All 14 Riksmätplatser realise SI-traceable national standards. Ionising radiation is also a national metrology area in Sweden but responsibility for this falls to the Radiation Safety Authority (SSM), not RISE.*

Mass

Length & dimensional

Time & frequency

Electrical quantities

Temperature

Chemical metrology

Photometry & radiometry

Pressure & vacuum

Force & torque

Power & energy

High voltage & current

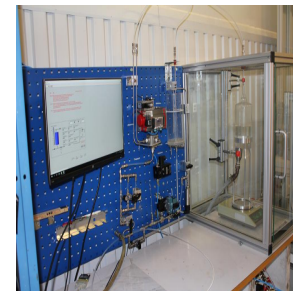
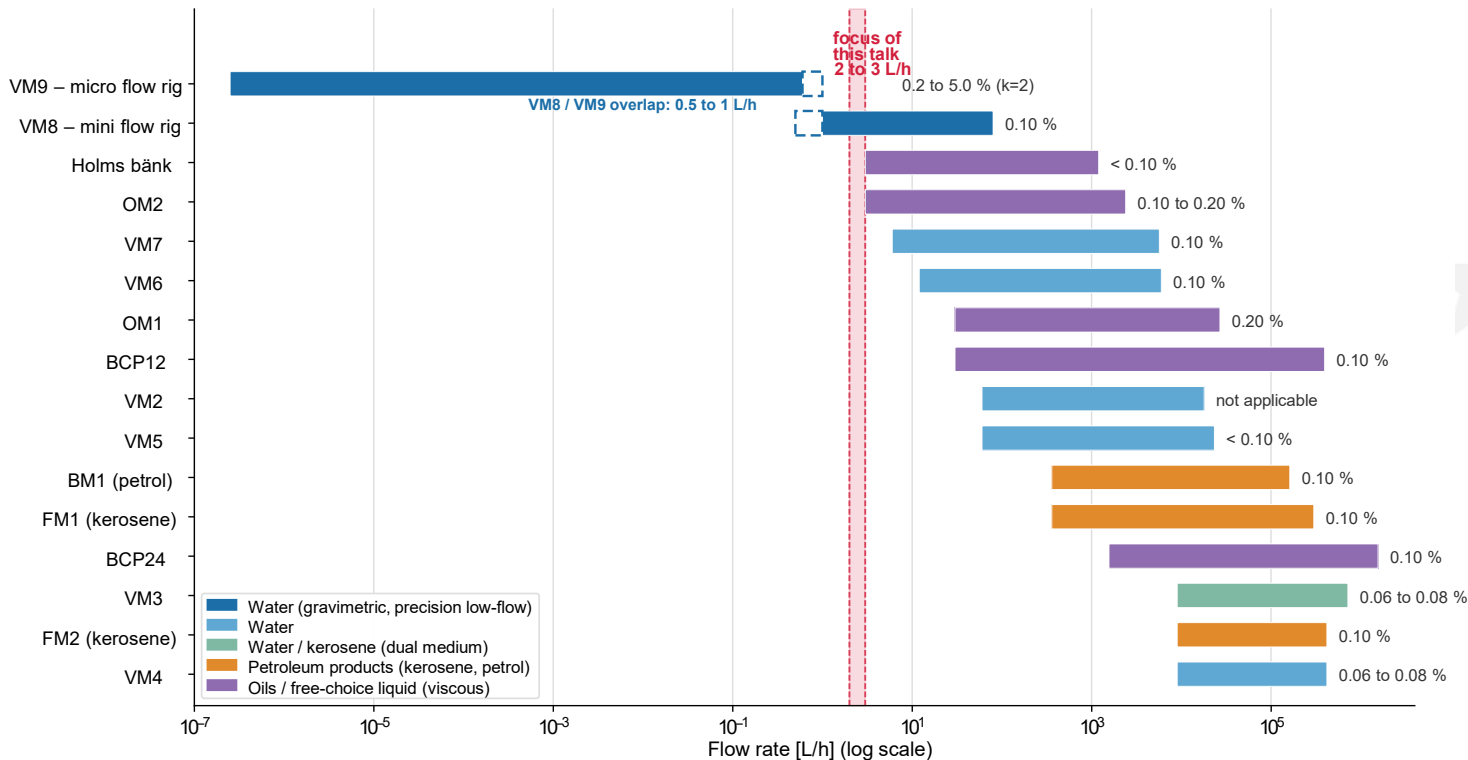
**Volume, Flow & Density**

Sound & vibration

High frequency & microwaves

# // Flow calibration capabilities at RISE

RISE flow calibration facilities – measurement range & medium



VM8

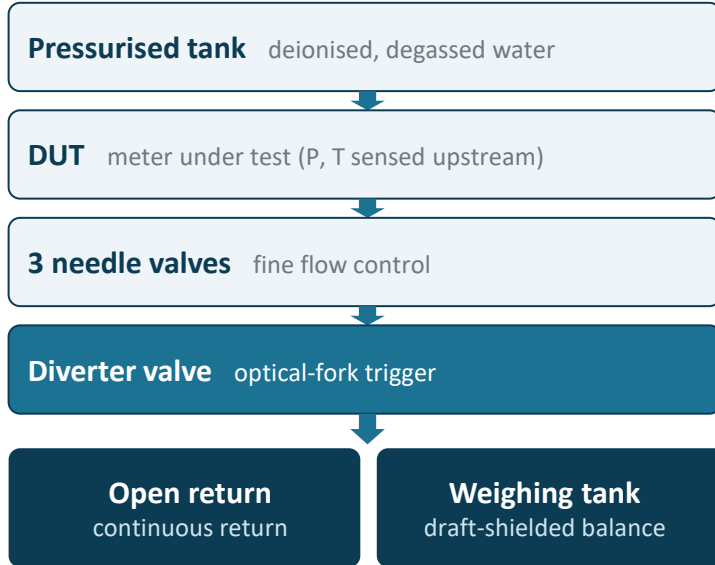


OM2 (Low-flow liquid calibrator)

16 rigs, water to viscous oils,  
0.06 to 0.2 % uncertainty

## DEEP DIVE

### // VM8 – the mini flow rig built for 2 to 3 L/h



*Both collection tanks are levelled to avoid switching asymmetries; the scale sits in a draft-proof enclosure, with condensate return limiting evaporation loss.*

|                    |                                          |
|--------------------|------------------------------------------|
| <b>Flow range</b>  | (0.5) 1 to 80 L/h (pressure up to 2 bar) |
| <b>Temperature</b> | ambient (around 20 °C)                   |
| <b>Tubing</b>      | DN 4                                     |
| <b>Medium</b>      | deionised, degassed water                |



*The VM8 gravimetric mini flow rig at RISE*

## // VM8 – performance and traceability



- ❑ An air-buoyancy correction of about 0.10% is applied to every weighing (based on Archimedes' principle).
- ❑ 'Double time measurement' against an 80 MHz clock improves the pulse-count resolution of the device under test (DUT).
- ❑ Validation is performed against VM7 ( $U = 0.2\%$ ,  $k = 2$ ) using a Danfoss CFM Di1.5 as the transfer standard.

### EURAMET project 1805

INRIM pilot, RISE co-pilot: Flow rates 6 kg/h to 20 000 kg/h

### Planned EURAMET project

PTB/CETIAT: Flow rates 0.5 L/h to 10 L/h

**0.1 % (k=2)**

expanded uncertainty,  
≥30 s / ≥0.1 L sample

**0.04 to 0.07 %**

agreement with VM7  
(transfer standard)

### Comparison with VM7

(VM7 has a limit of 6 L/h, there is no other facility available.)

|                  |          |          |
|------------------|----------|----------|
| Flow rate        | 6 L/h    | 12 L/h   |
| Systematic diff. | ≤ 0.07 % | ≤ 0.07 % |
| En number        | -0.18    | -0.31    |

*The claimed uncertainty is consistent with the observed agreement at both flows:  
 $|En| < 1.0$ .*

### Bottom line

VM8 provides gravimetric calibration that is SI-traceable, exactly where modern meters and leak-alarm functions require verification: the 1 to 80 L/h flow range, currently up to 2 bar.

## // ...and beyond: toward leak-detection flows

- ❑ The same gravimetric approach can be scaled down. RISE micro flow rig (VM9) covers 0.25  $\mu\text{L/h}$  to 600  $\text{mL/h}$  and uses degassed water and a syringe pump as a reference (Büker et al., 2022).
- ❑ Even the components inside VM8 must demonstrate extreme leak-tightness; a bypass valve was verified to leak by less than 0.04 g over 3100 s.
- ❑ This equates to less than 0.0008  $\text{mL/h}$ , over three orders of magnitude below the 2 to 3  $\text{L/h}$  focus range discussed in this talk.

**Up next:** T. Firlé & I. Jursic (JUMO) take leak detection in metering further:  
A global game changer for water losses, energy efficiency and network transparency.

**2 to 3 L/h**

focus of this talk

**1 to 80 L/h**

VM8 range

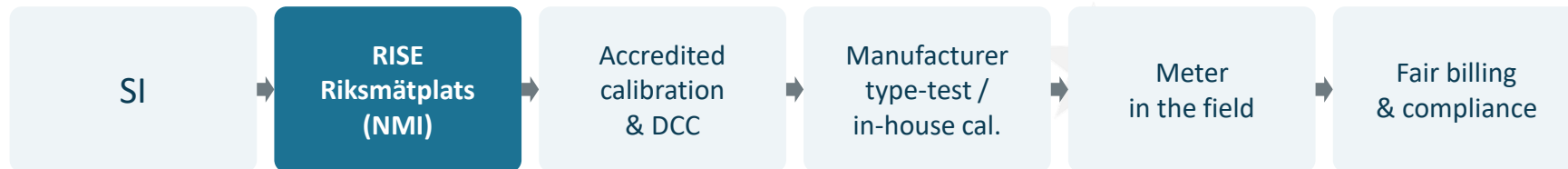
**0.25  $\mu\text{L/h}$  to 600  $\text{mL/h}$**

VM9 micro flow rig range

**< 0.0008  $\text{mL/h}$**

VM8 bypass-valve leak tightness

## // What manufacturers & users gain from traceability



- ❑ Verified qmin / low flow performance claims are backed by an internationally recognised CMC (CIPM MRA / EURAMET equivalence).
- ❑ Direct support for MID conformity assessment and market surveillance is aligned with OIML and WELMEC.
- ❑ Root-cause data for R&D enables the separation of meter error from installation and media effects at realistic low flows.
- ❑ A documented, traceable low-flow uncertainty turns a specification claim into a defensible one, providing the basis for fair billing to end customers.

# Take-home messages

- 1 For an apartment heat meter, legal accuracy stops near 6 L/h. Real systems and real leaks run below this, down into the 2 to 3 L/h range that this talk targets.
- 2 RISE offers traceable gravimetric calibration at this level (VM8) and extends towards leak detection flows via VM9.
- 3 Traceable low flow calibration ensures compliant, reliable and fair measurements for manufacturers and end customers alike.
- 4 RISE can calibrate and benchmark devices in the low-flow range.

# Thank you

*Questions & discussion welcome*

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RISE Research Institutes of Sweden – Sweden's National Metrology Institute