The next generation of ionization chambers for radionuclide metrology: a proposal to form a joint Task Group

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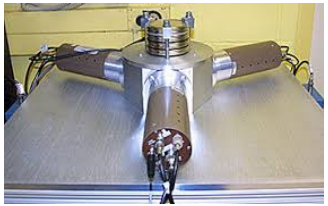
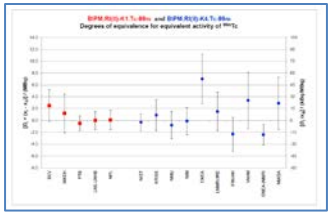
One challenge for radionuclide metrology

Hospitals need a way to check the activity content of radiopharmaceuticals



NMIs / DIs need a way to prepare reference sources for hospitals without repeating complex realizations of primary standards



The BIPM needs a way to compare the national primary standards

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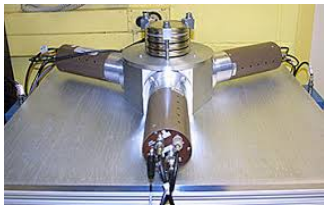
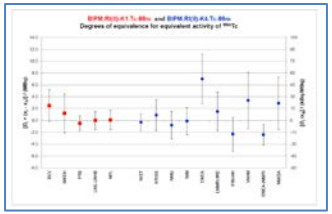
One challenge for radionuclide metrology





One type of instrument solves all three problems – the well-type ionization chamber

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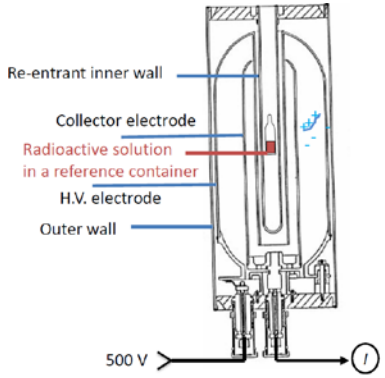
Ionization chamber / radionuclide calibrator



- Simple, robust & reproducible
- Three components - a gas-tight vessel, a HV power supply and a current-measurement system
- Easy-to-use

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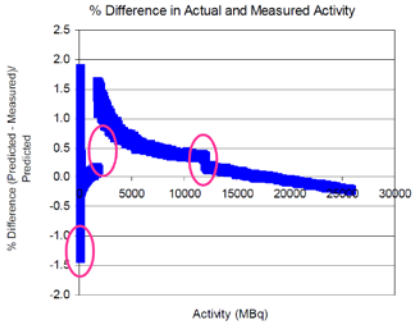
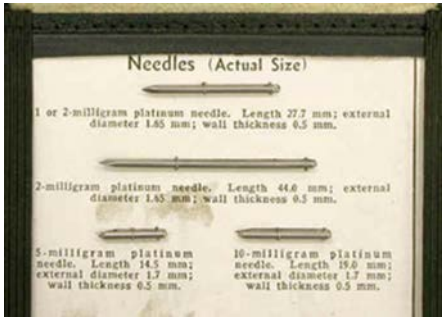
Why is a new generation needed?



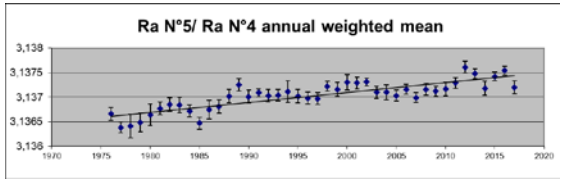
http://www.npl.co.uk/upload/pdf/20080625_rcuf_fernandez_1.pdf



Existing electrometers are not linear enough

Sealed radioactive sources are used as reference points

Sealed radioactive sources can be safety and security risks, are difficult to obtain, and can change...



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We need:

Robust, rapid recovery from overload, low sensitivity to electrical interference

Reproducibility better than 0.1 % under normal laboratory conditions

Traceability to the SI

Linear response from 10^{-13} to 10^{-8} A better than 0.1 %

A CCRI-CCEM workshop was held at NIST in September 2018 to discuss new technologies to meet this specification

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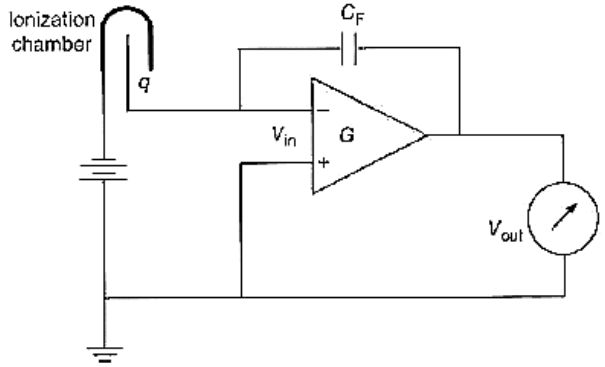
NIST National Institute of Standards and Technology U.S. Department of Commerce

Method used at present



Method 1:
Measure the time Δt to charge the capacitor until $V_{out} = V_{ref}$

Method 2:
Measure V_{out} versus time and calculate the slope.

Sealed reference sources are used to solve the linearity problem

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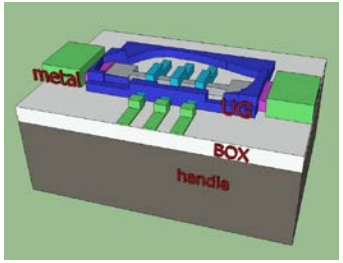
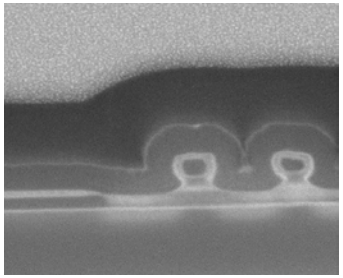
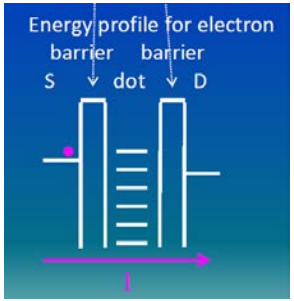
Option 1: Quantum Electrical Standards

- Charge pumps produce very accurate currents to calibrate electrometers
- They ‘pump’ electrons using an input frequency
- Very accurate as frequency can be defined to 1 part in 10^{-8}
- But the maximum current is 0.3 nA
- And they are very expensive
- The ULCA was a spin-out from this research…







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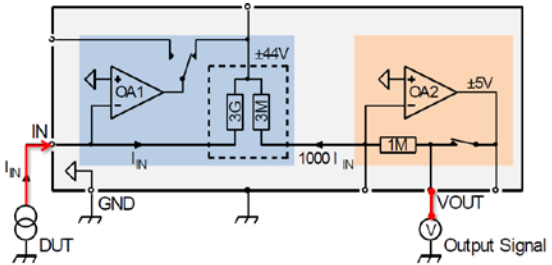
Option 2: The Ultrastable Low-noise Current Amplifier

- Developed by the PTB
- A 2-stage transimpedance amplifier (a current to voltage convertor)
- Uses 3000 thin-film chip resistors, a metal foil precision resistor and amplifiers with gain >10^9
- Calibration interval – 50 years
- Measures currents up to 5 µA
- Calibration uncertainty <0.02 ppm traceable to quantum Hall resistance



D. Drung et al,
Rev Sci Instrum **86** 024703 (2015)

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Option 3: Conventional electronics (NIST)

- The largest uncertainty – the voltage burden of the electrometer depends on the range
- The new NIST system avoids this by calibrating the electrometer at the same current

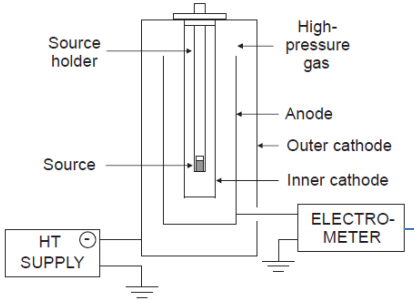
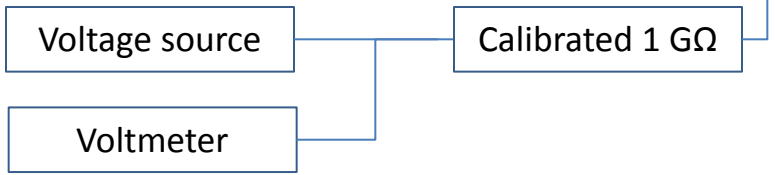


Fig. 1. Schematic diagram of well-type ionisation chamber. The chamber is surrounded by an overall electrical screen (not shown).



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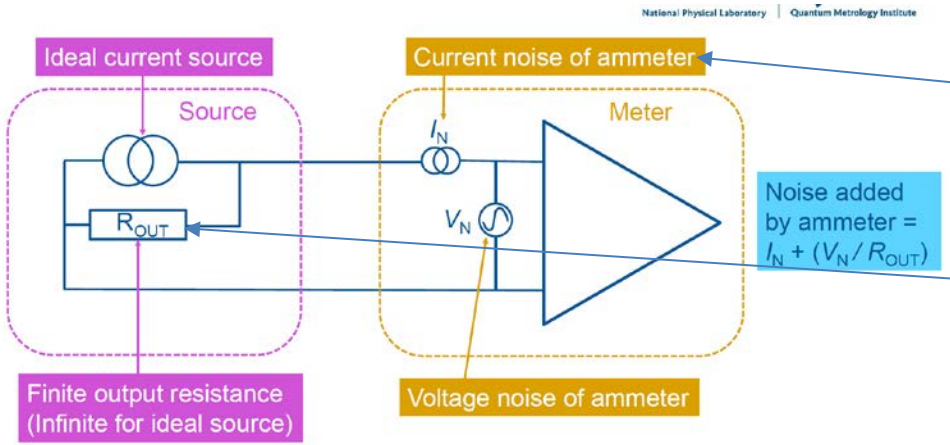
Option 4: Using a commercial ammeter



All ammeters have to balance current noise vs voltage noise

Commercial amplifiers minimize the current noise

Ionization chambers have high R_{OUT}, so custom-designed ammeters can be better than commercial ammeters for this application

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Giblin and Lorusso, arXiv: 1808.09217 (2018)

Option 4 (continued)

- Studies at the NPL (UK) using a capacitative-feedback electrometer have shown:

Parameter	Commercial ammeter	Custom electrometer
Traceability to SI	Calibrated using current source	0.05 % bias due to the frequency dependence of the capacitor calibration
Best possible Type A uncertainty	5 fA	1 fA
Sources of noise	Fluctuations in the ion chamber current are 100 x larger than the ammeter noise – this could be due to the HV power supply	

- NPL's conclusion: commercial ammeters can be a viable option at the 0.1 % level but custom electrometers can do better.

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Giblin and Lorusso, arXiv: 1808.09217 (2018)

Next steps?

- The BIPM and some NMIs (eg PTB, NIST and NPL) are working to replace their existing systems
- But the biggest challenge is having the confidence to switchover to the new technology

Broader questions

- Current measurement is only part of the system
- Still must control/monitor consistency of IC response vs. environmental conditions, chamber pressure (leaks), geometrical changes (sample position) etc.
- Keeping reference sources for shorter time periods poses challenges for consistency in quality assurance (QA)
- These challenges may inspire innovative design of the next generation of instruments

Proposal

- We form a joint CCEM-CCRI Task Group to oversee the work
  - To provide expert technical guidance
  - To advise on key decisions
  - To help ‘open doors’- eg, identify secondees from both fields
  - To encourage and support the work
  - To advise on promoting the outcomes, to achieve the best impact

With thanks to:

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