NPL
National Physical Laboratory

Neutron Metrology: Why and How?

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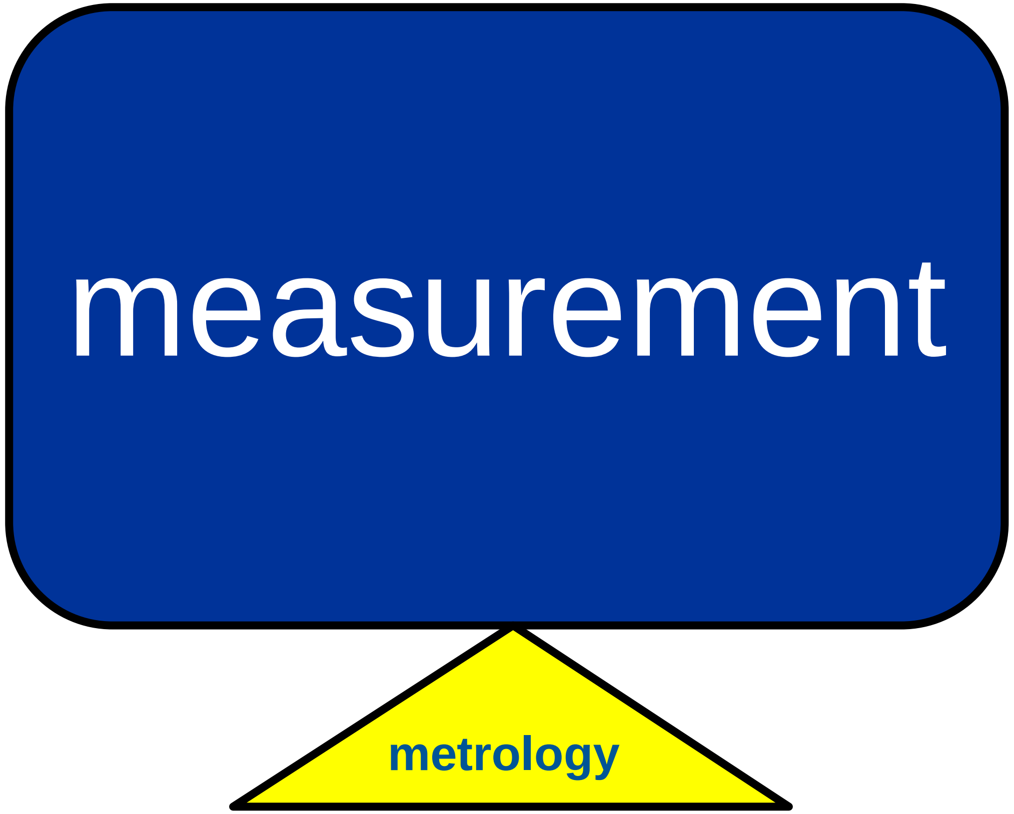
nBHEAM workshop

8 July 2025

Metrology is the (often invisible) infrastructure ensuring the reliability of measurement



Metrology involves measurement, but not all measurement is metrology

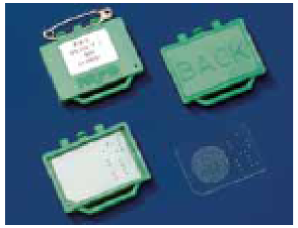
The Results of Metrology

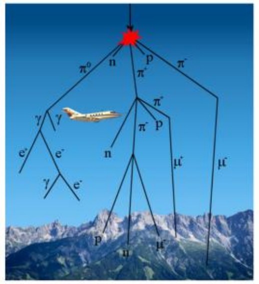
NPL

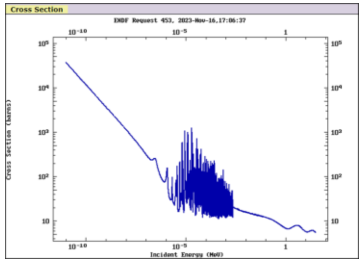
- Generates systems and frameworks for quantification and through these underpins consistency and assurance in all measurement
- Gives a quantified level of confidence in the measurement through an uncertainty statement

- Provides a measurement infrastructure which is ***stable*** over time, ***comparable*** between locations, and ***coherent***, allowing measurements of different properties using different methods to be combined (without scaling factors)
- Removes barriers to trade, improves efficiency and competitiveness, enables technological development, encourages global agreement and collaboration

Why is neutron metrology needed?







Radiation protection

Nuclear reactor control

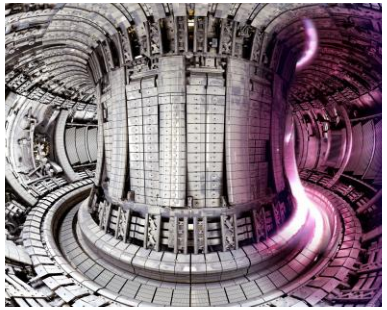
Nuclear safeguards

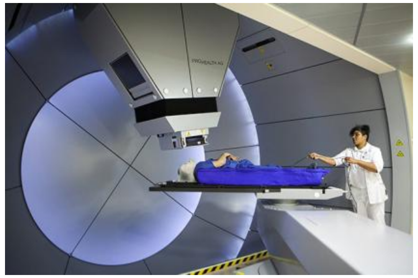
Criticality dosimetry

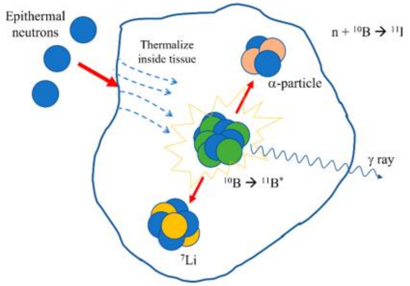
Fusion reactors

Nuclear data

Therapy





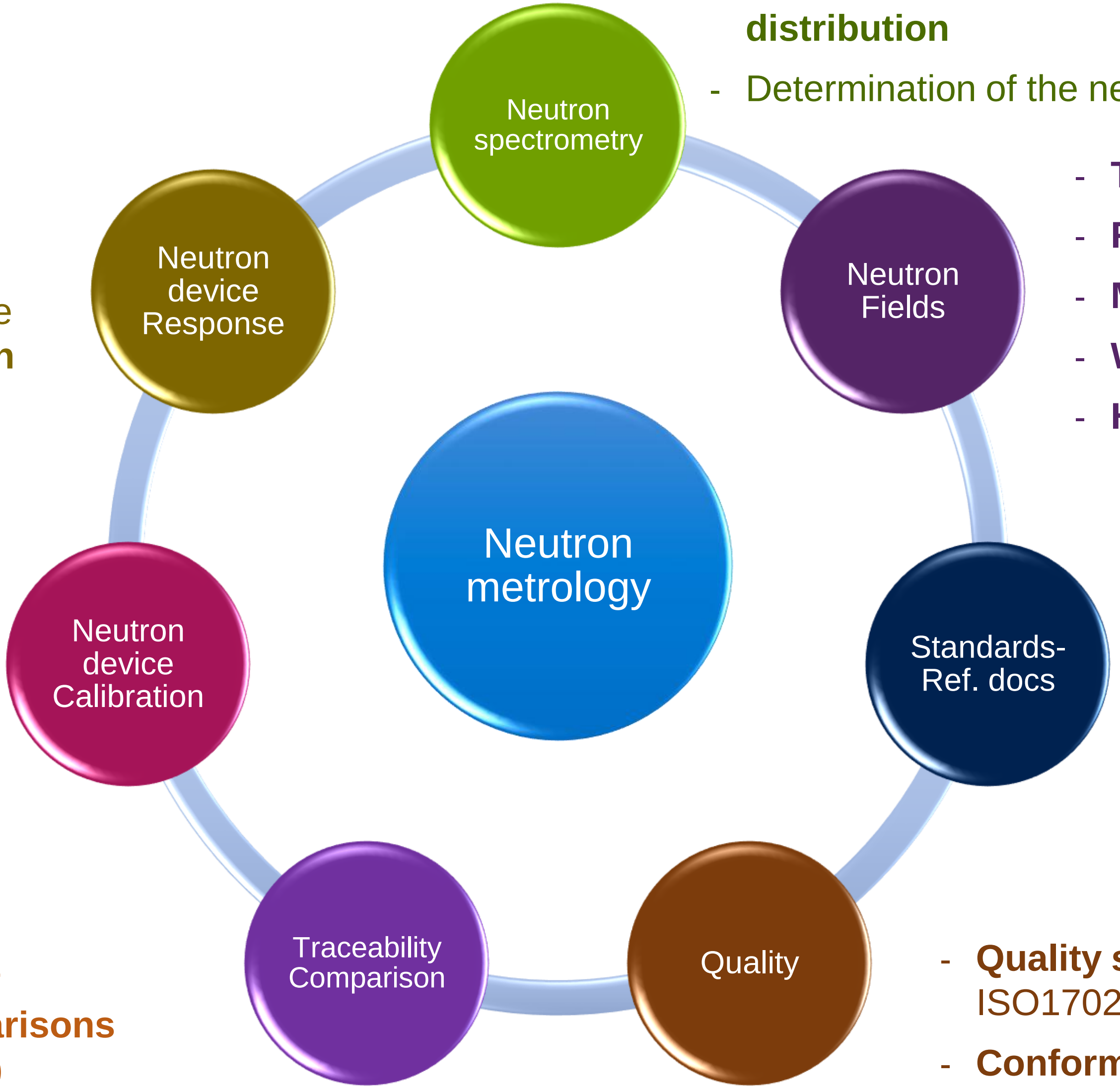


Neutron metrology overview

- **Determination of the neutron fluence energy distribution**
- Determination of the neutron angular energy distribution

- Response variation with energy ~ **response function**
- Response variation with angle = **angular response function**

- **Thermal** neutron fields
- **Radionuclide** neutron sources
- **Monoenergetic** neutron fields
- **Workplace simulated** neutron fields
- **High energy/intensity** neutron fields



- **Full characterization**
- **Calibration factor**
- **Calibration methods**

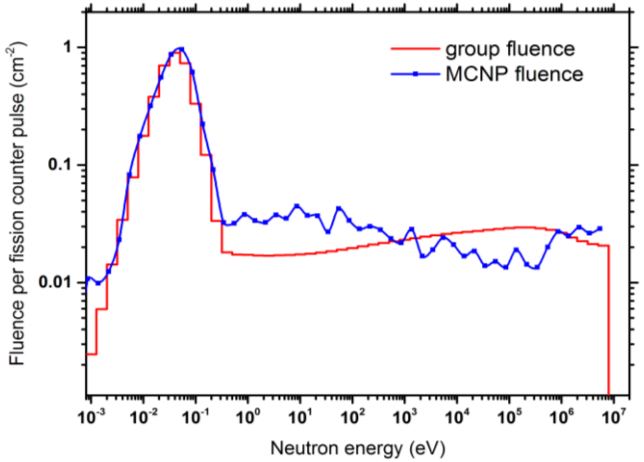
- **ISO** 8529, 12789, 21909, 29661, etc.
- **IEC** 61005, 61526
- **ICRU** 66, 85, 95
- **IAEA** TRS 285, 308, 415, Neutron data standards, etc.

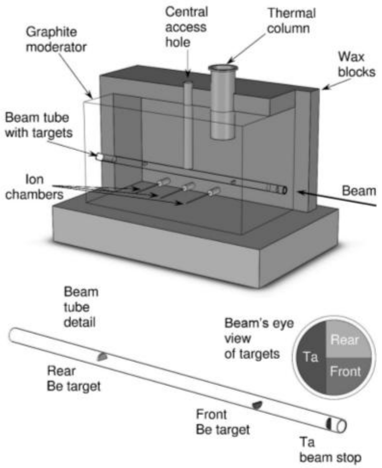
- **Quantities**
- **Transfer instrument**
- **International comparisons** (CCRI, RMO,SSDL?)
- **CMCs**

- **Quality system** following ISO17025
- **Conformity assessment** (audits)

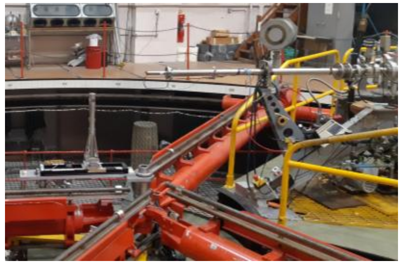
Neutron calibration fields

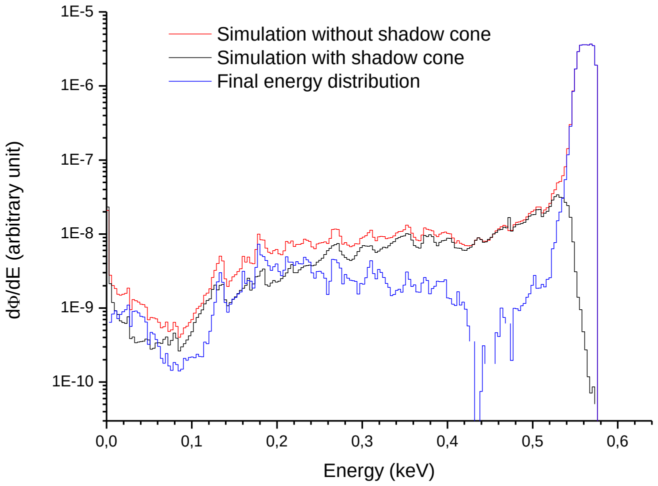
- Thermal



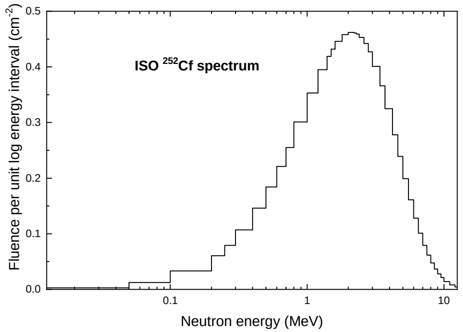


- Monoenergetic

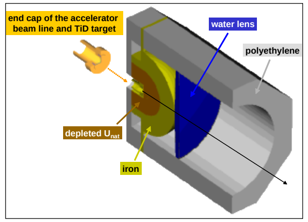


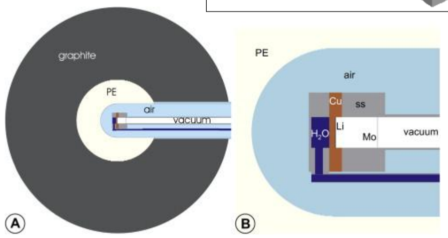


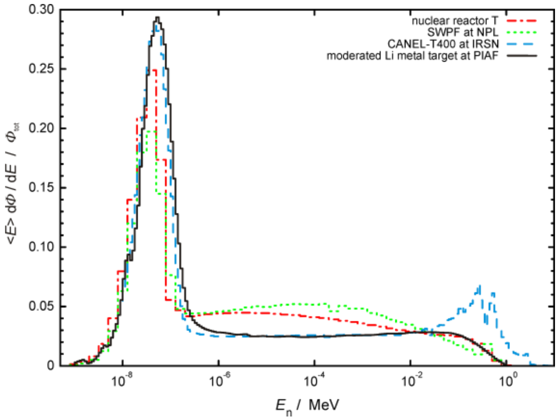
- Radionuclide



- Simulated workplace



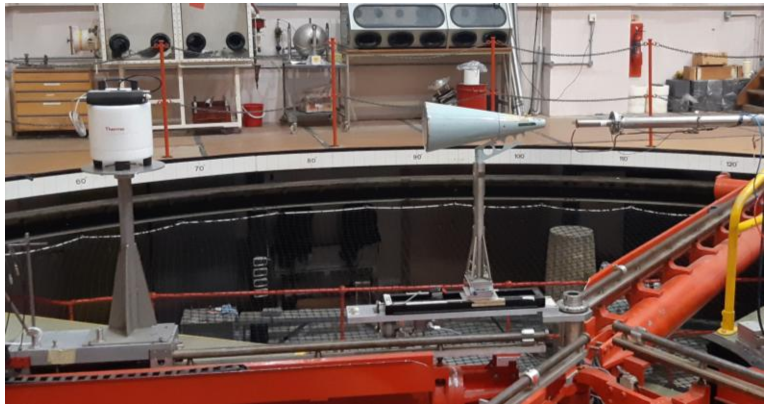




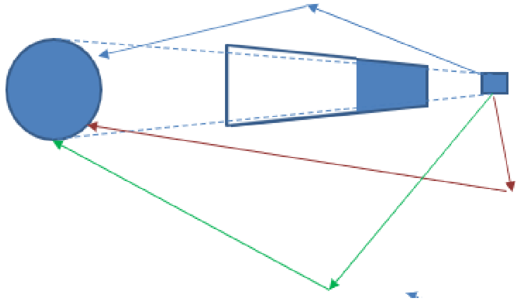
Neutron device calibration

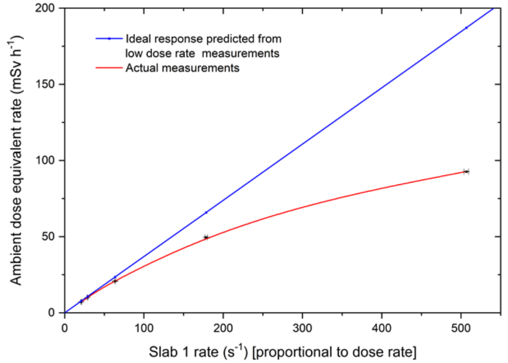
Calibration coefficient → $N = \frac{H}{M}$

- H ← *Quantity (Fluence, dose equivalent)*
- M ← *Reading of the device (corrected!)*



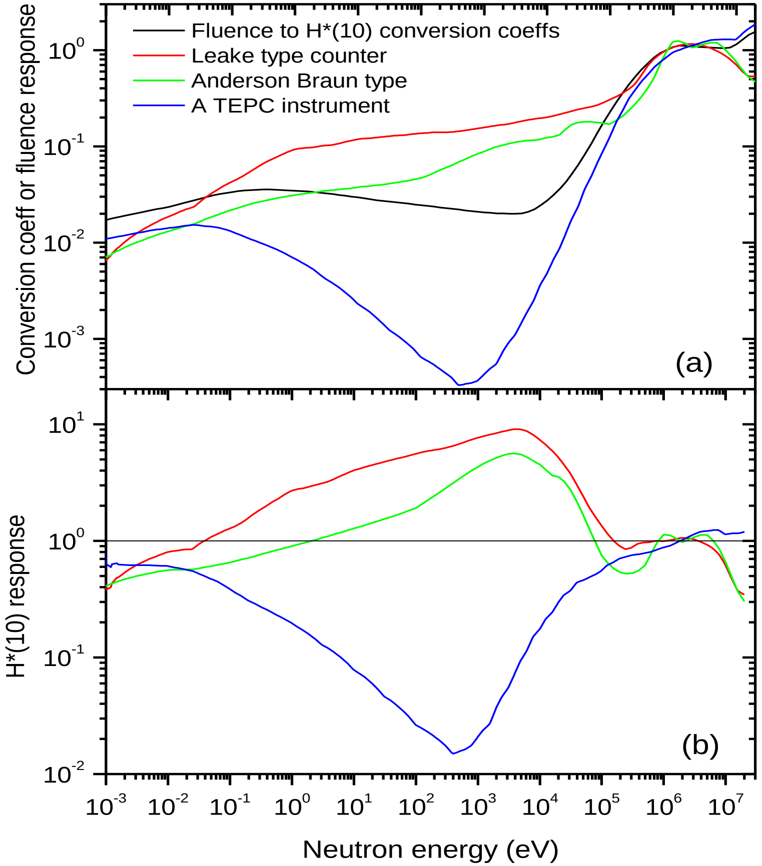
- The instrument reading has to be corrected for several effects, as we only want the reading due to the neutrons emitted directly by the source
  - The instrument effective centre
  - The geometric effect: the fluence is not homogeneous over the entire detection area in the case of large instruments and/or short distances
  - Scattered neutrons (source holder, room and air)
  - The non-neutrons ionizing radiations (mainly photons)
  - The background (electronics + natural radiation)
  - The instrument linearity as a function of the fluence dose equivalent rate (or dead time if count rate available)
- All these corrections and methods are described in ISO 8529 series of standards



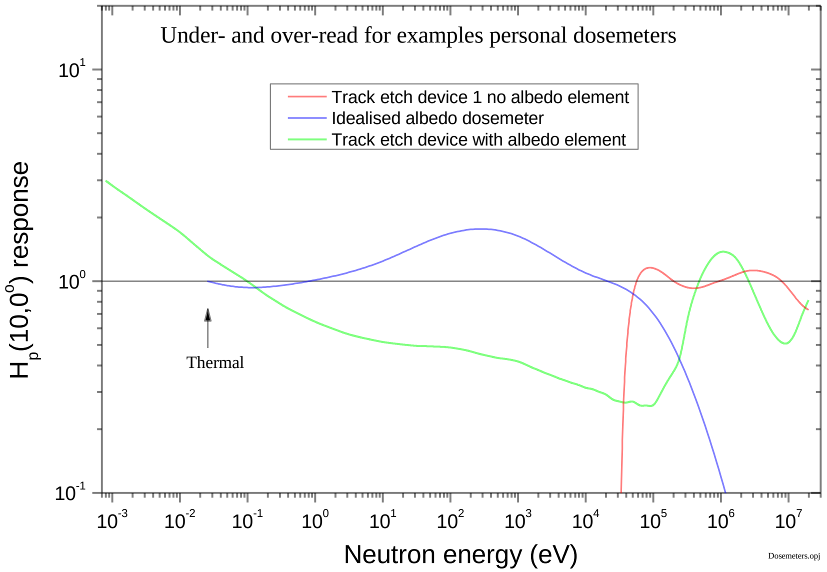


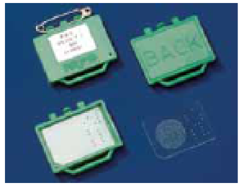
Neutron device response

- Survey instruments

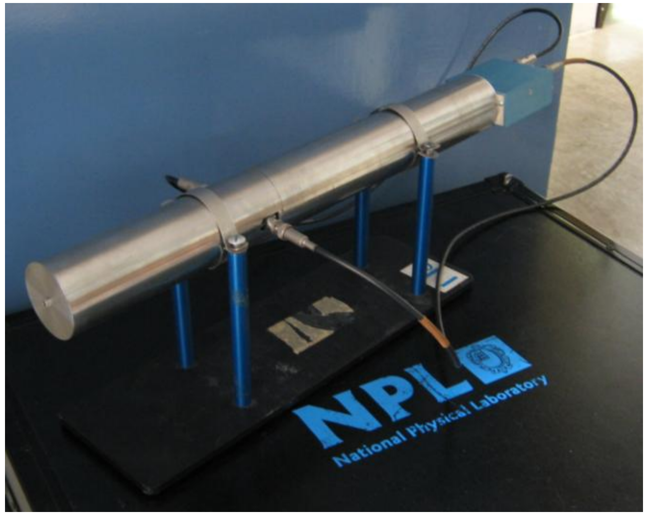


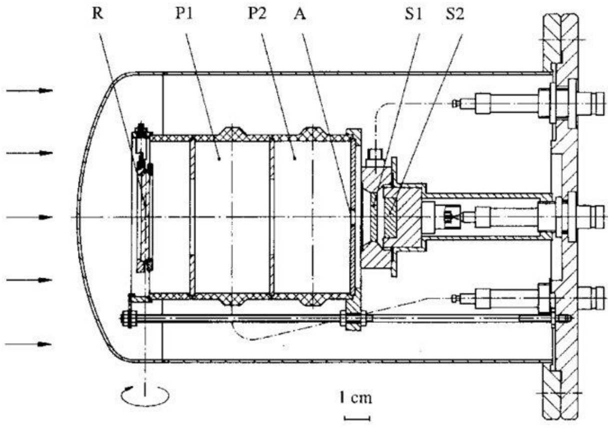
- Personal dosemeters



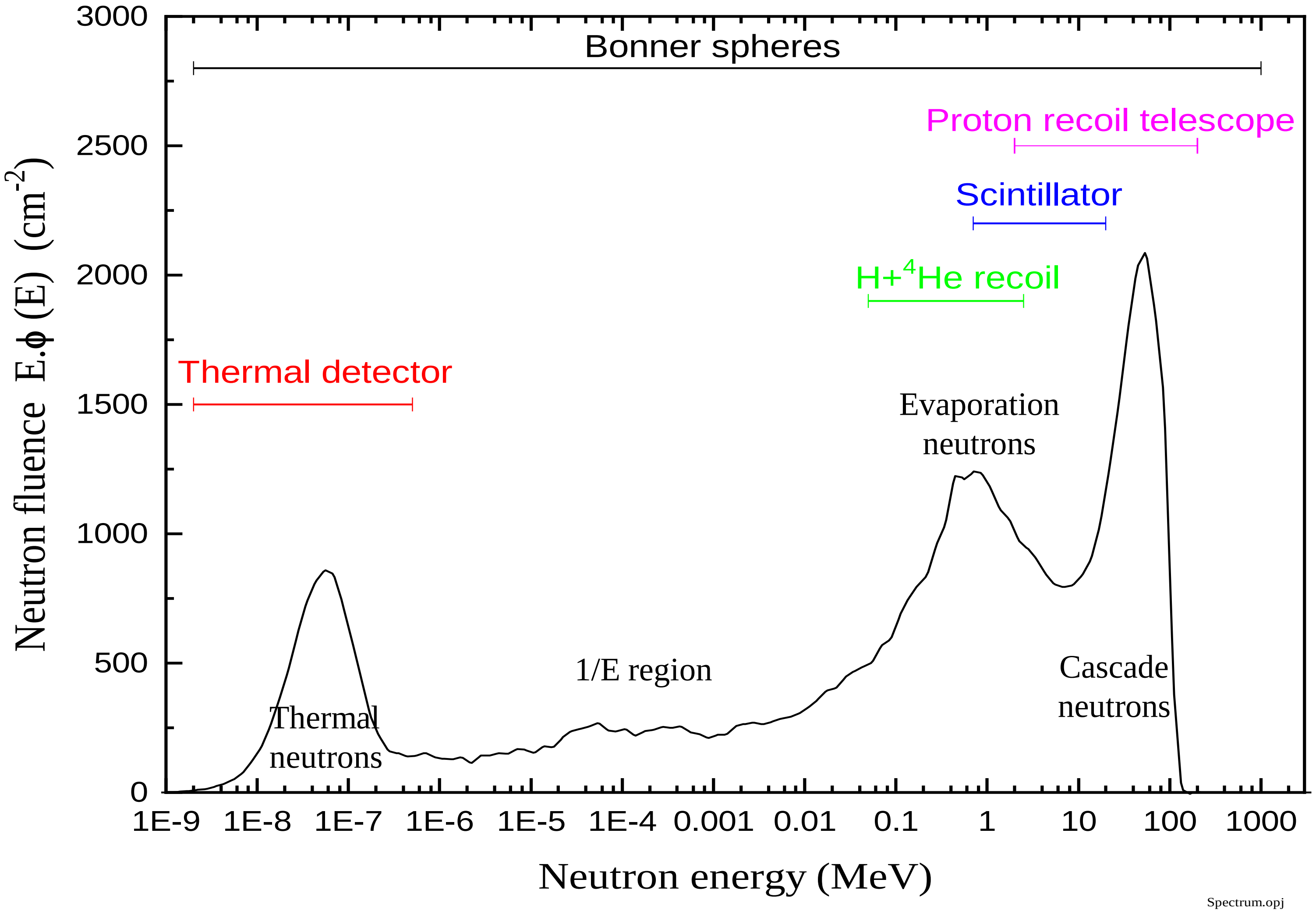


Neutron spectrometers





Energy ranges of neutron spectrometers



Quality system

ISO 17025:2017: General requirements for the competence of testing and calibration laboratories

- Personnel, Facilities and environmental, Equipment, Metrological traceability, Technical records, Evaluation of measurement uncertainty, Ensuring validity of results, Reporting of results

Conformity assessment

- Internal and peer-reviewed audits
- Against agreed standards such as ISO17025

Standards

- ISO 29661:2012 - Reference radiation fields for radiation protection — Definitions and fundamental concepts
  - defines terms and fundamental concepts for the calibration of dosemeters and equipment used for the radiation protection dosimetry of external radiation — in particular, for beta, neutron and photon radiation.
  - defines the measurement quantities for radiation protection dosemeters and dose rate meters and gives recommendations for establishing these quantities.
  - Guidelines are given for the calibration of dosemeters and dose rate meters in reference radiation fields.
- ISO 8529-1:2021 - Neutron reference radiations fields Part 1: Characteristics and methods of production
  - specifies the neutron reference radiation fields, in the energy range from thermal up to 20 MeV, for calibrating neutron-measuring devices used for radiation protection purposes and for determining their response as a function of neutron energy.
- ISO 8529-2:2000 - Part 2: Calibration fundamentals of radiation protection devices related to the basic quantities characterizing the radiation field
  - specifies the procedures to be used for realizing the calibration conditions of radiation protection devices in neutron fields produced by these calibration sources, with particular emphasis on the corrections for extraneous effects
  - particular emphasis on calibrations using radionuclide sources
- ISO 8529-2:2023 - Part 3: Calibration of area and personal dosemeters and determination of their response as a function of neutron energy and angle of incidence
  - describes procedures for calibrating dosemeters for area and individual monitoring and determining the response in terms of the ICRU operational quantities.

Neutron traceability (radionuclide sources)

Time second

Mass kg

Area m^2

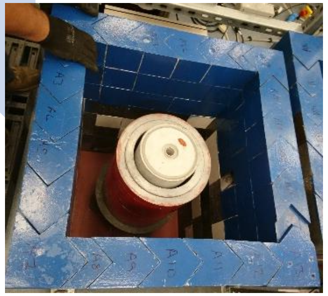
Ionisation chambers $Bq.g^{-1}$

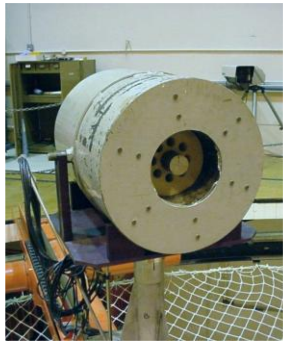
Manganese bath

Radionuclide sources

Neutron fluence or dose



Neutron traceability (activation foils)

Time second

Mass kg

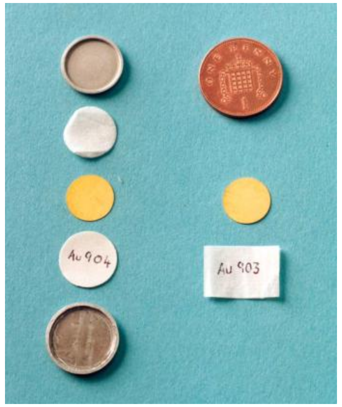
Area m^2



4πβγ coincidence counting

$Bq.g^{-1}$

Neutron fluence or dose



Neutron traceability (other techniques)

Time second

Mass kg

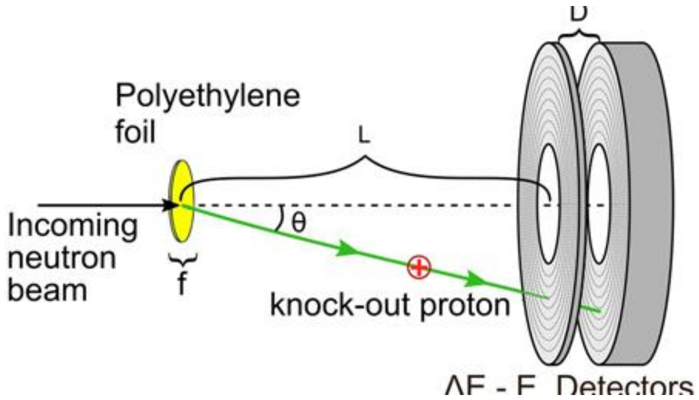
Area m^2

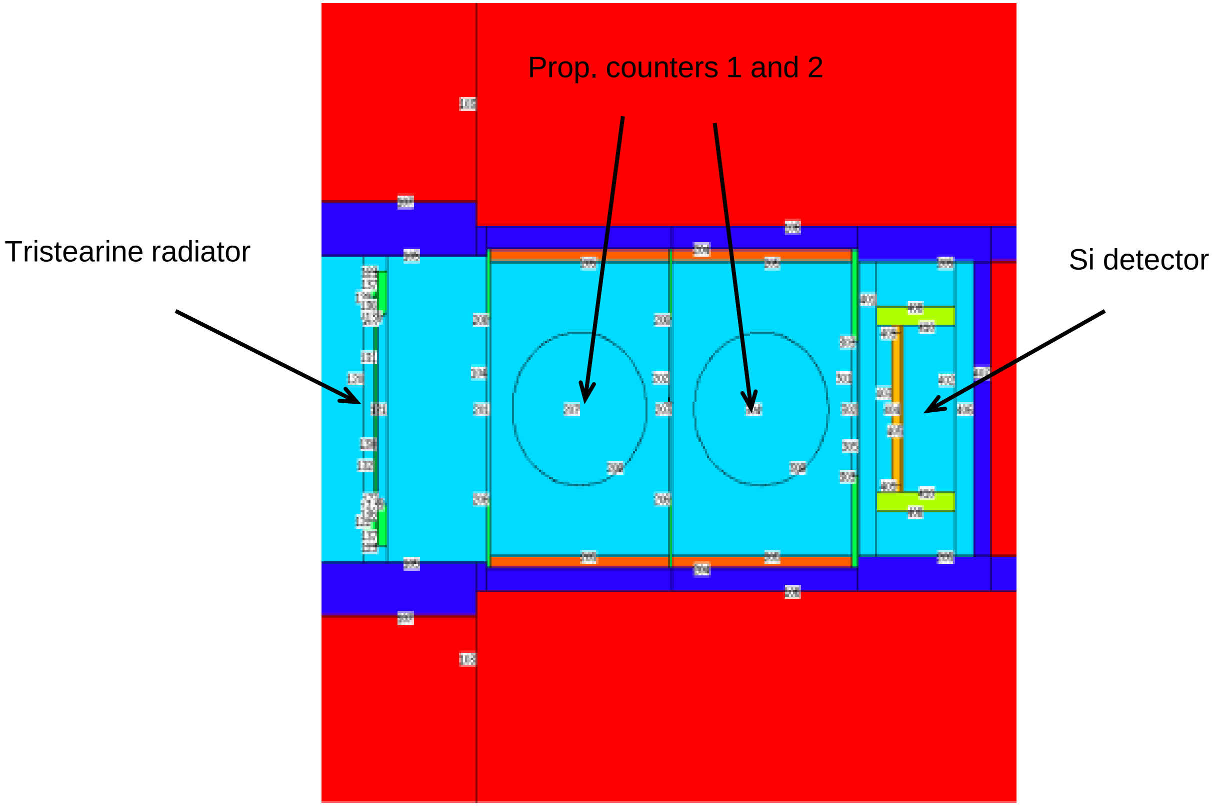
Neutron fluence or dose



Proton recoil telescope

- Measures both neutron energy and fluence
- Uses elastic scattering from hydrogenous radiator to give recoil proton
- Requires n-p scattering cross section
- Protons pass through first detector and stop in final detector
- Primary method but inefficient and has limited energy range

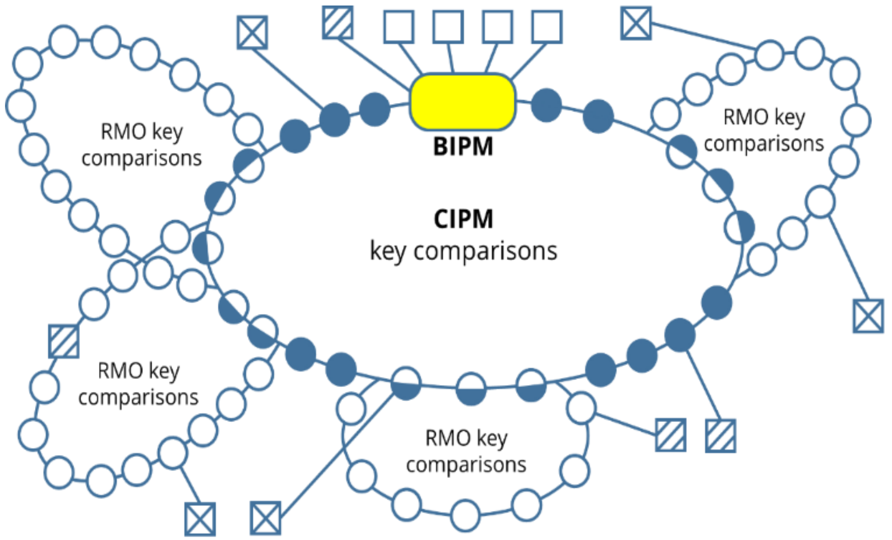




(tungsten wires pointing into the plane)

Comparisons

- A fundamental mechanism of the CIPM MRA.
- Establish the degrees of equivalence of national measurement standards.
- Demonstrate NMI measurement capabilities.
- Peer-evaluated by RMOs and CCs.
- Published in the KCDB.



There are 3 basic categories

- CIPM key - Restricted to laboratories of Member States and normally members of the corresponding Consultative Committees, deliver a “reference value” for the key quantity chosen.
- RMO key- Linking RMO members to a key comparison
- Supplementary - Intended to cover areas or techniques not addressed by key comparisons, reports published in KCDB

- Subsequent – extending a key comparison where one or more participants considers its results unrepresentative or was unable to participate at time of key comparison

Comparisons

- Two models for comparisons in use in CCRI(III)
- Transfer instrument sent in turn to every participant
  - Can be very slow due to scheduling and customs issues (2 or more years for measurement phase)
  - Tests each participant’s ability to produce and measure the neutron field
  - Used for K9, K12, S1 and S2 comparisons
  - New approach planned for K8 with two circulating instruments to reduce overall time
- Every participant visits a host lab and brings their device
  - Much quicker measurement phase (weeks or months)
  - Doesn’t test each participant’s field
  - Used for K10 and K11 monoenergetic comparisons

Thanks for listening