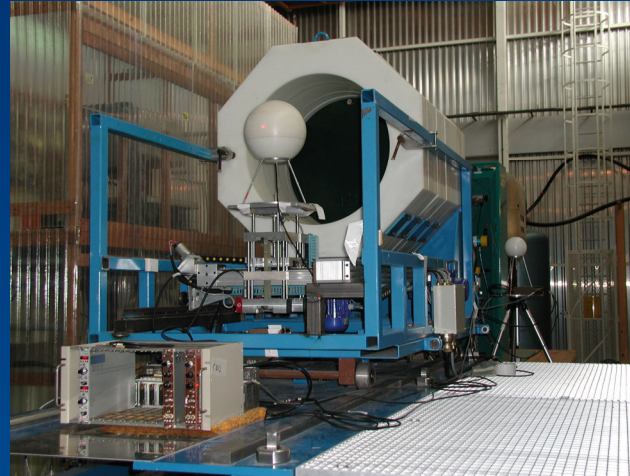


Neutron calibration and importance of workplace fields

EURADOS 18th Winter School

Neil Roberts, NPL (UK)



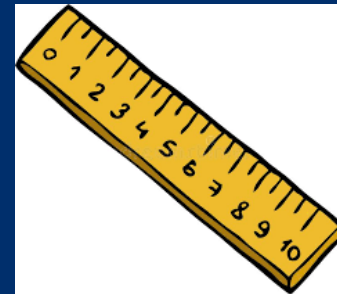
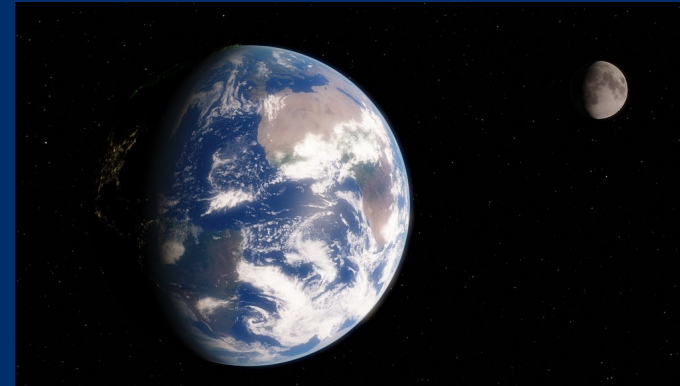
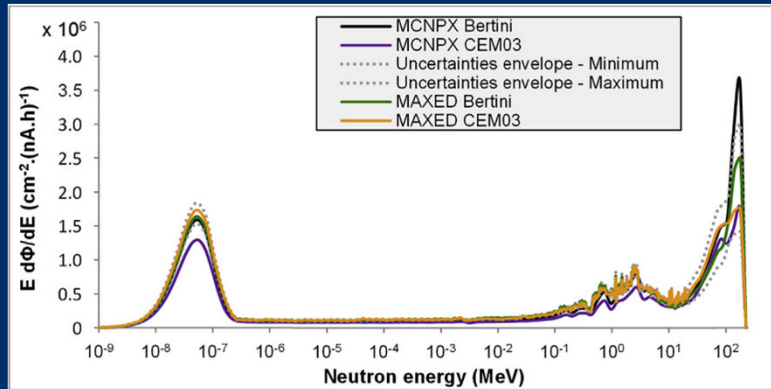
Overview

- Neutron introduction
 - difficulties, energy range
- Importance of calibration
 - energy responses of devices, under- or over-read of dose
- Overview of neutron facilities
 - thermal, monoenergetic, simulated workplace, high energy broad range
- Gaps in neutron metrology facilities
 - high energy monoenergetic, pulsed fields

The problems with neutrons...

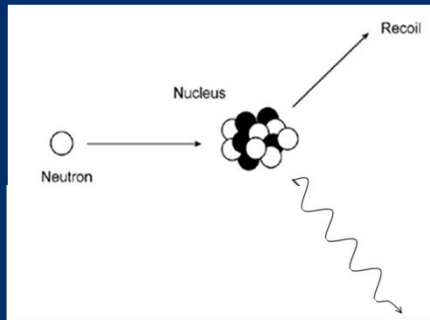
Energy range can cover 12 orders of magnitude

Like using a ruler to measure distance to the moon

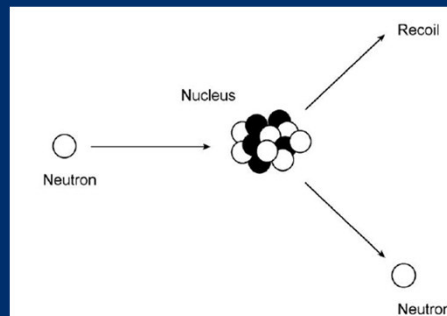


Uncharged, so only react with nucleus

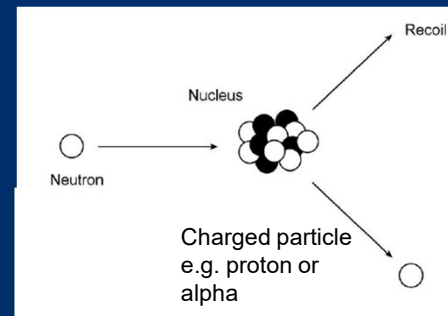
Neutron capture
(n,γ)



Neutron scatter
(n,n)



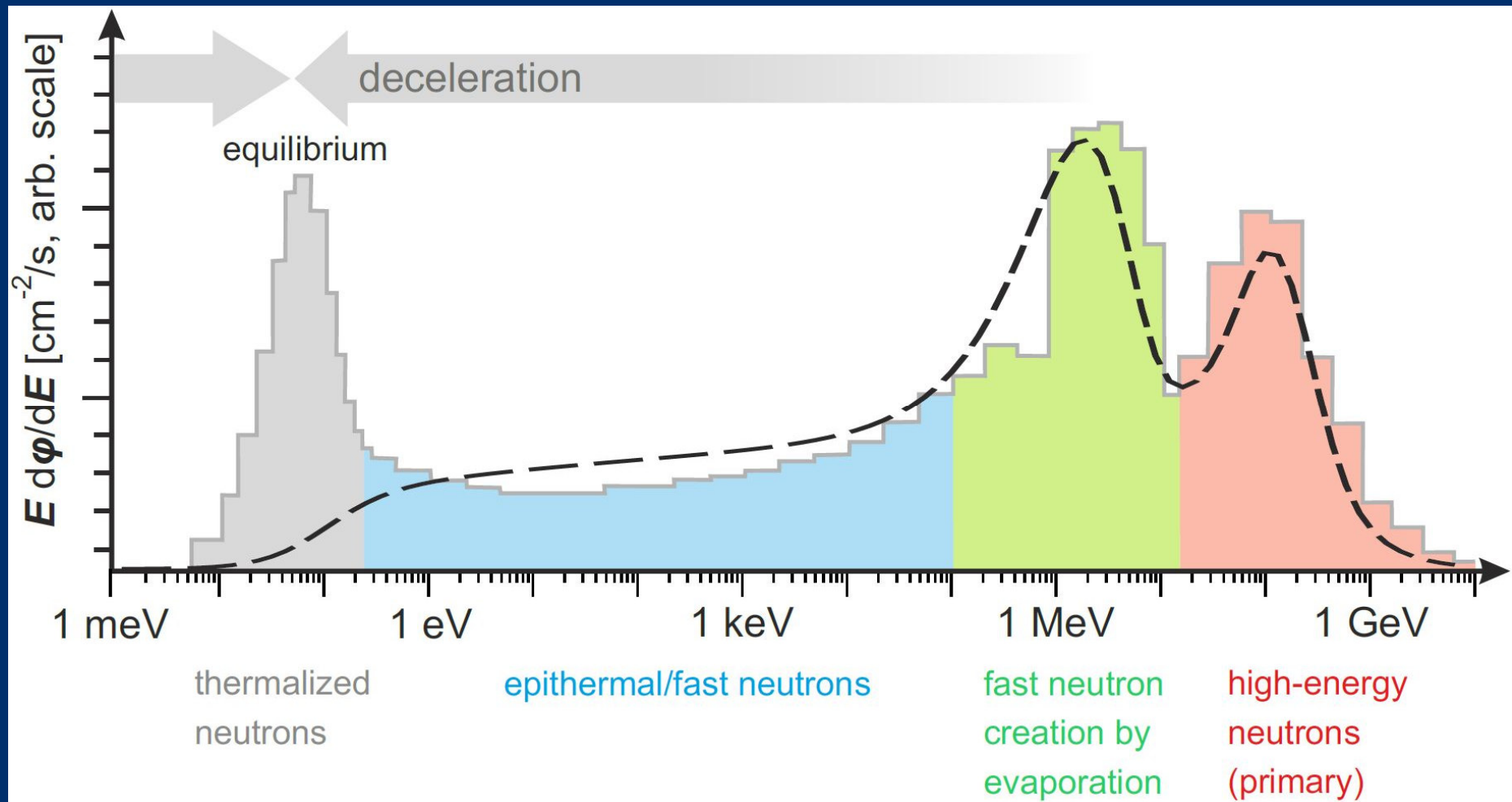
Nuclear reaction
e.g. (n,p) or (n,α)



Secondary particles are responsible for dose

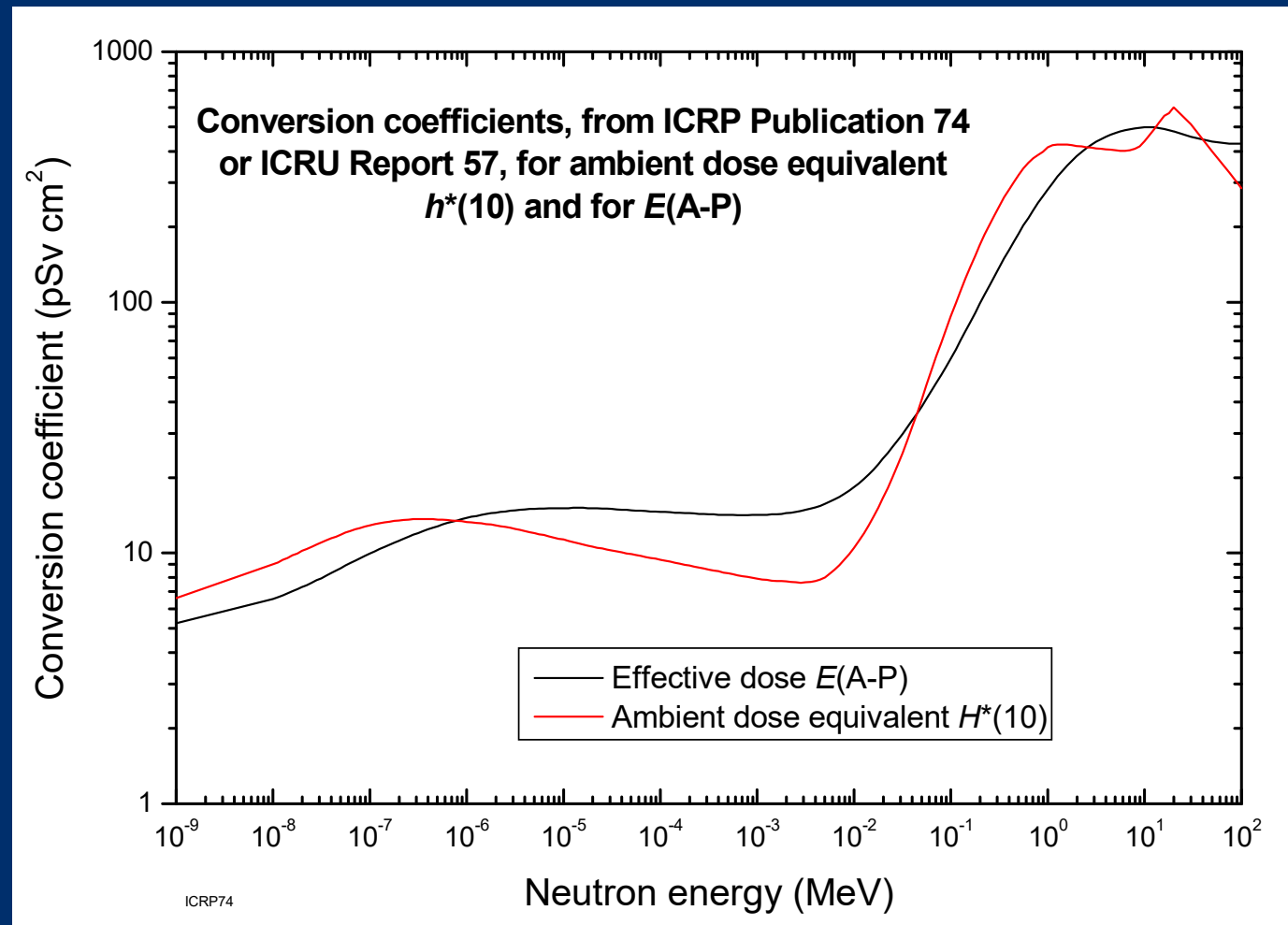
- Low LET
- High LET
- Strong energy dependence

Important features of a neutron field

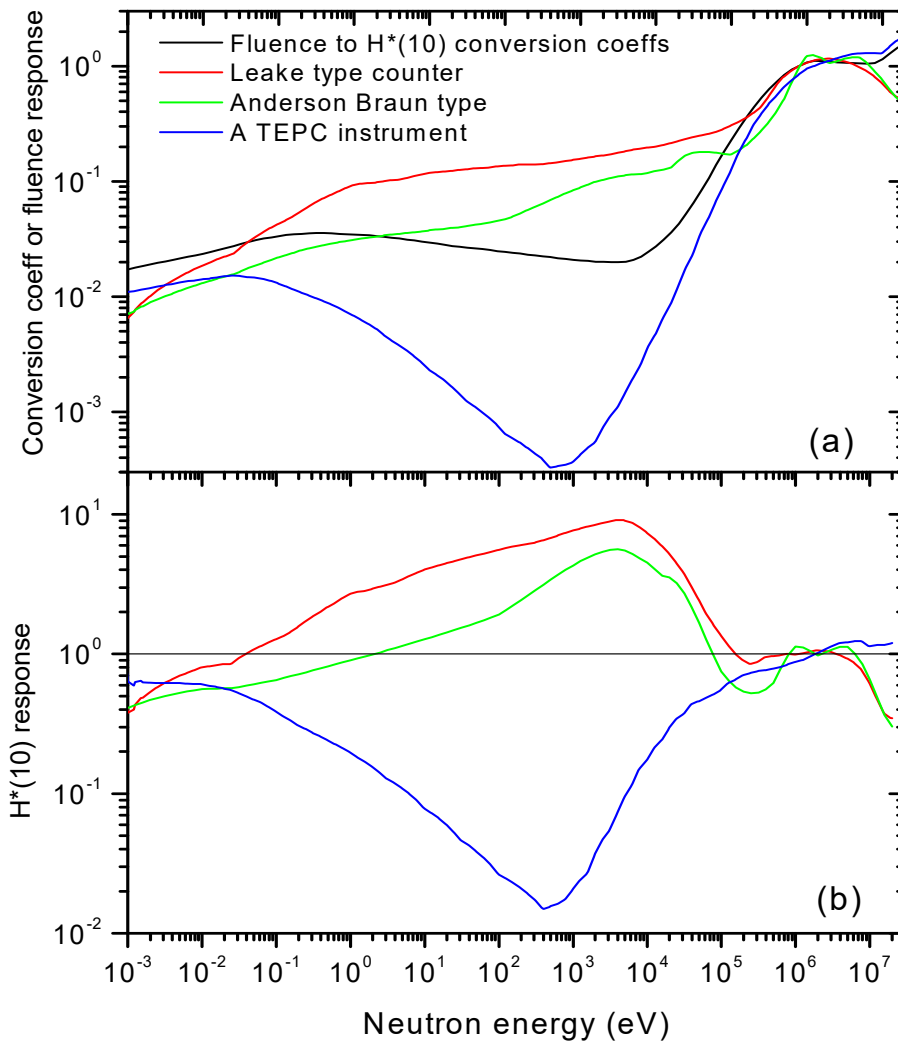


Neutron fields & conversion coefficients

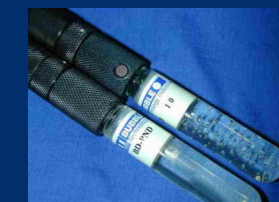
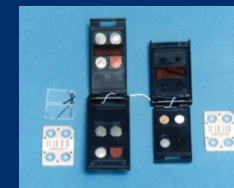
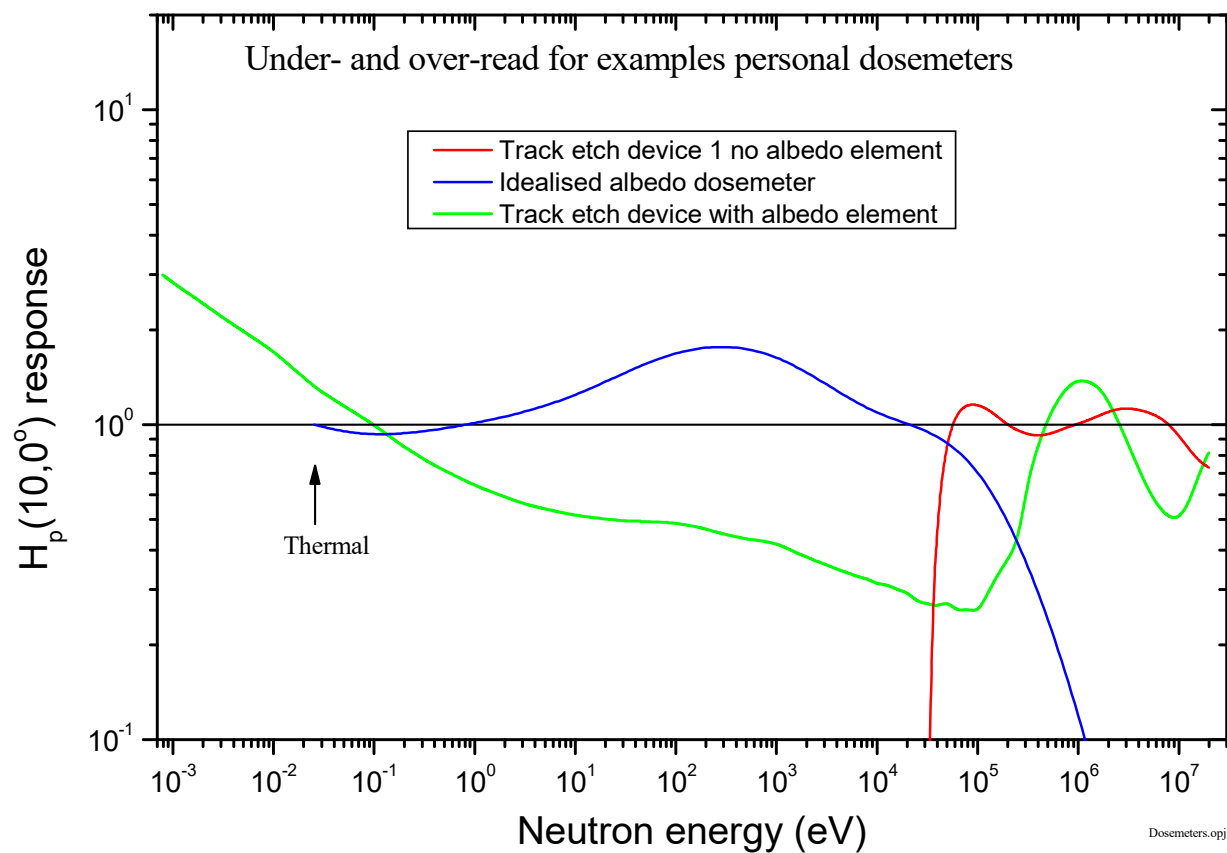
- Dose = fluence x conversion coefficient
- 1 to 10 MeV neutron 50x more harmful than 1 to 10 keV neutron
- Ideal device has dose equivalent response



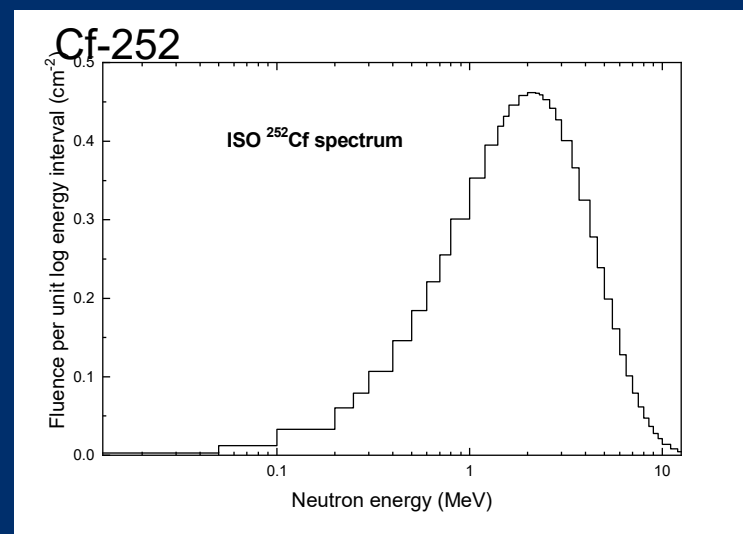
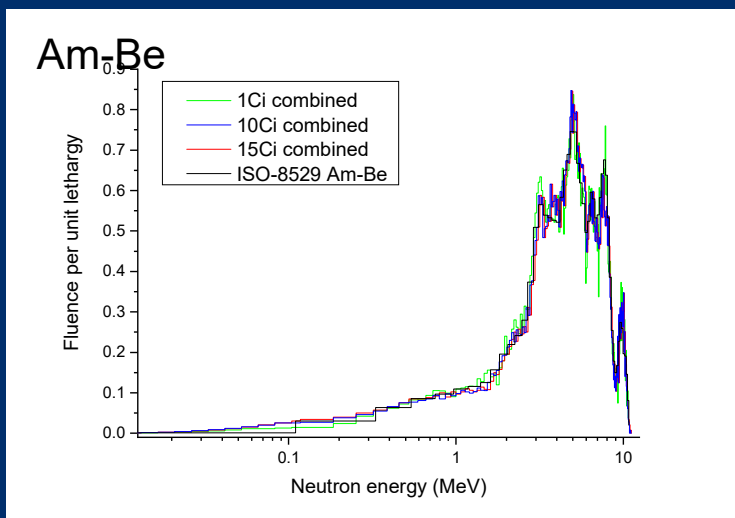
Area survey instrument responses



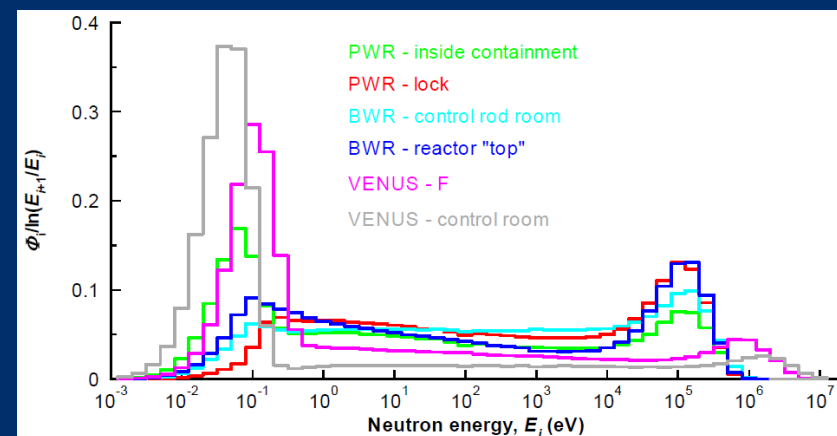
Personal dosimeter responses



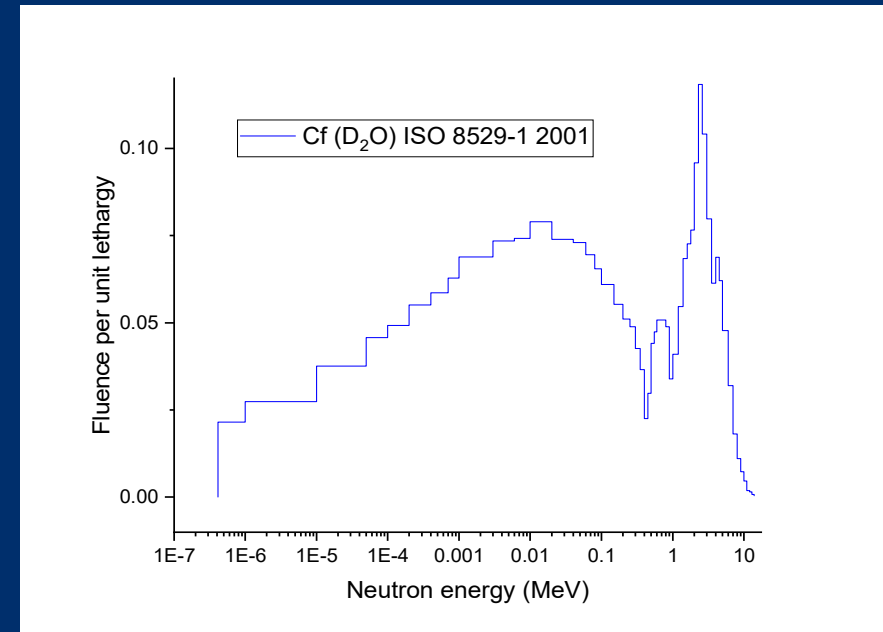
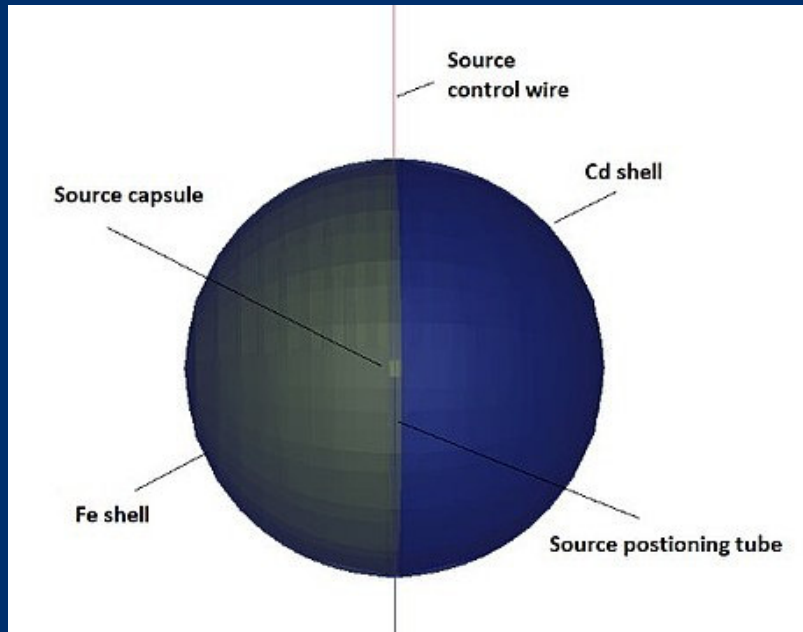
Energy spectra of radionuclide sources



- Almost no neutrons below 0.1 MeV
- Workplace fields go down to meV
- Can lead to significant under- or over-read



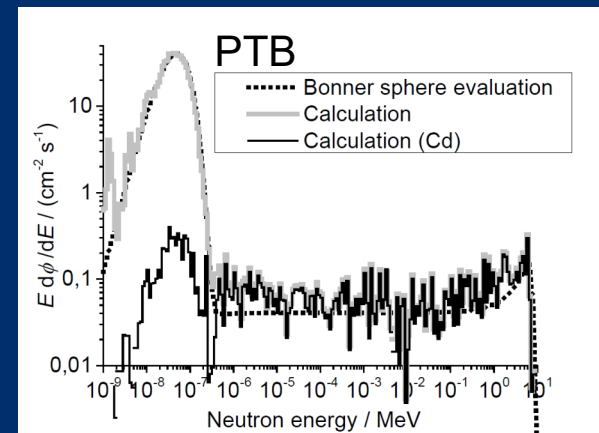
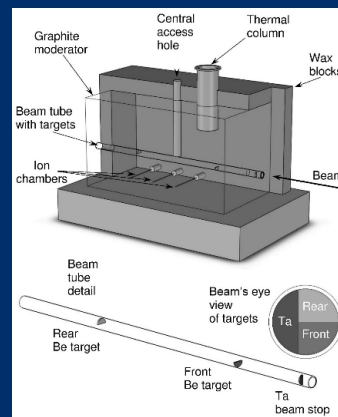
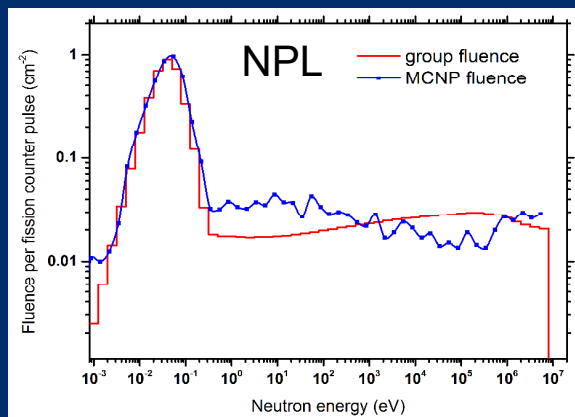
Moderating radionuclide spectrum



- Cf-252 neutron source inside sphere of heavy water
- Optional Cd shell to remove thermal neutrons
- Similar to reactor spectrum

Thermal neutron calibration fields

- 3 main types all involving moderation of fast neutrons:
 - Reactor
 - Accelerator
 - Radionuclide sources



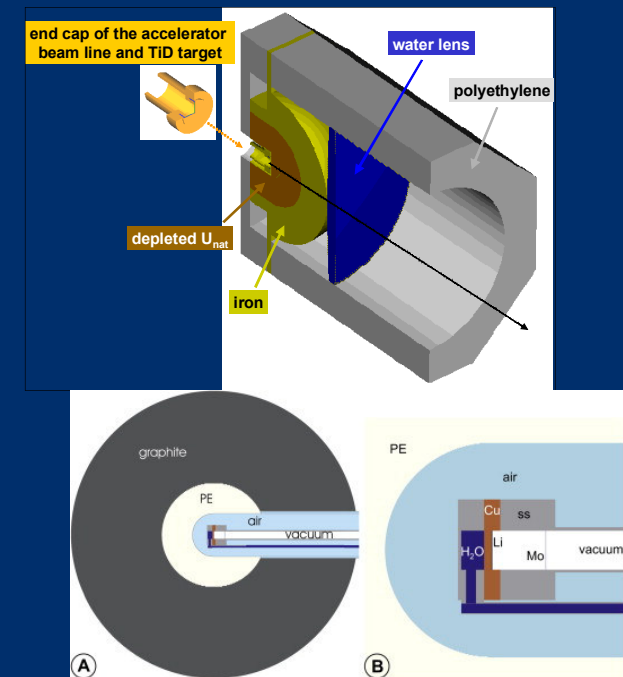
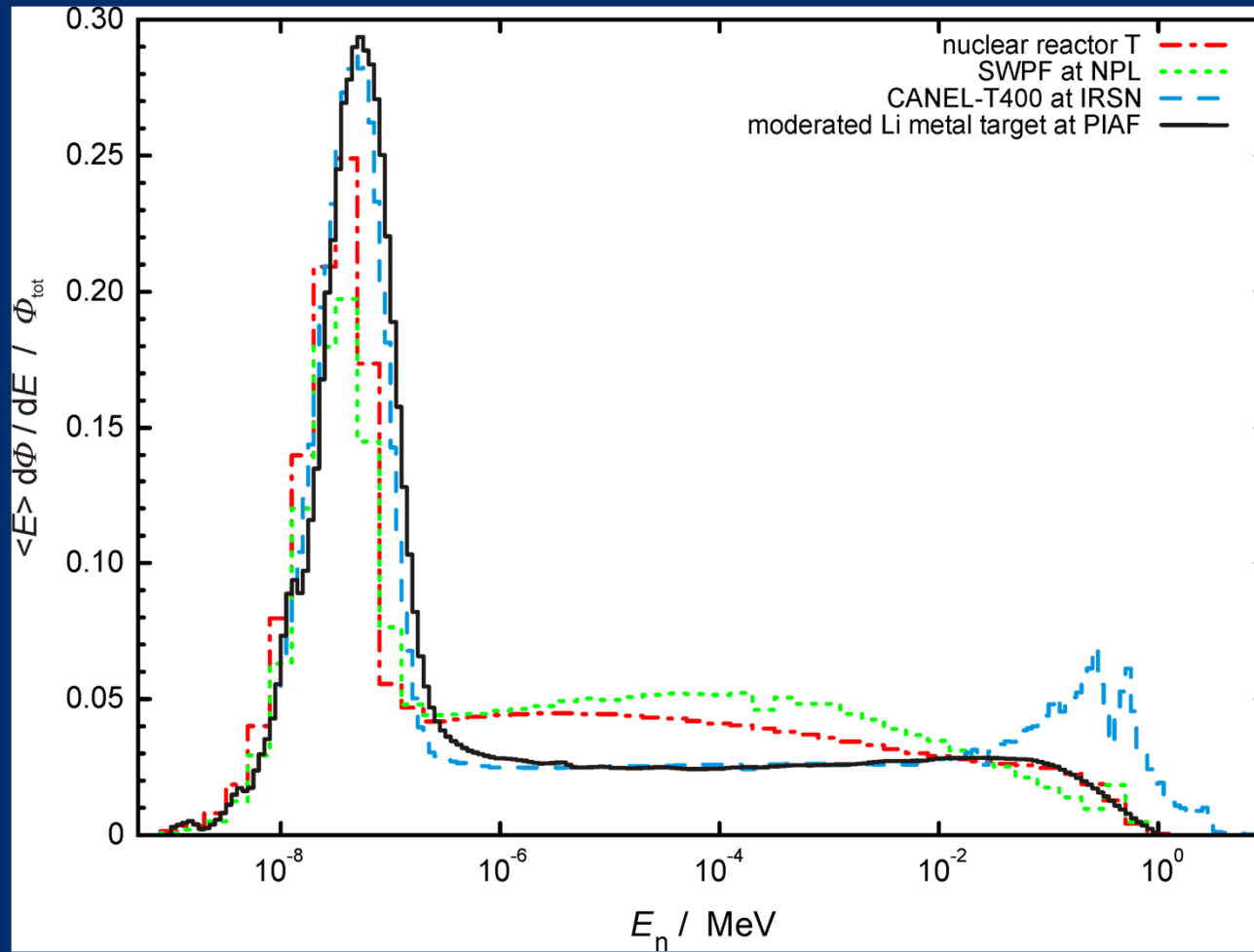
- Fast and epithermal neutrons always present
- Use Cd to absorb thermals and subtract fast response of device

Simulated workplace fields

Facility	Institute/Country	Neutron source production	Moderator	Application
CANEL/T400	IRSN/France	D(d,n) ³ He	Polyethylene	Personal dosimetry at PWR
NPL realistic field	NPL/United Kingdom	⁷ Li(p,n) ⁷ Be	Heavy water	Gas-cooled reactors
PIAF	PTB/Germany	⁹ Be(p,n) ⁷ B ⁷ Li(p,n) ⁷ Be	Polyethylene and graphite	Personal dosimetry at PWR
CERF	CERN/Switzerland	Hadrons on Copper target	Concrete or Iron	Cosmic-rays-like fields, for aircrew dosimetry
	JAEA/Japan	²⁴¹ Am-Be source	Concrete	Personal doseimeters calibration
	JNC/Japan	²⁵² Cf source	PMMA and Steel	Personal dosimetry at glove-boxes for MOX fabrication

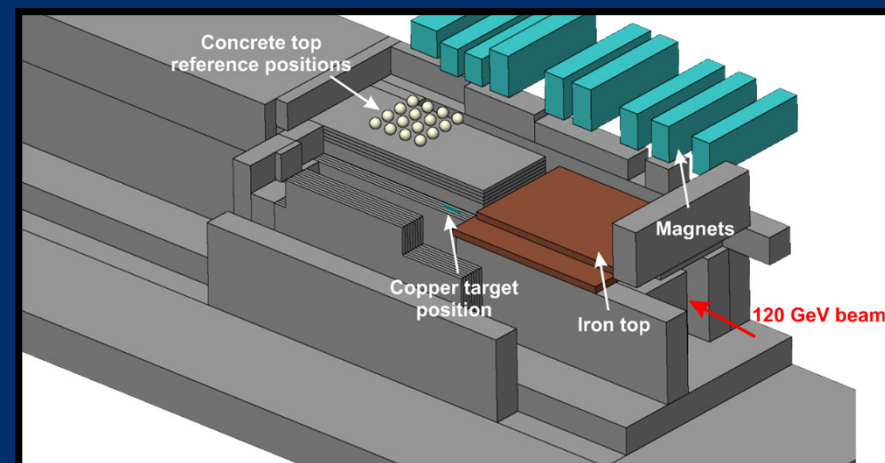
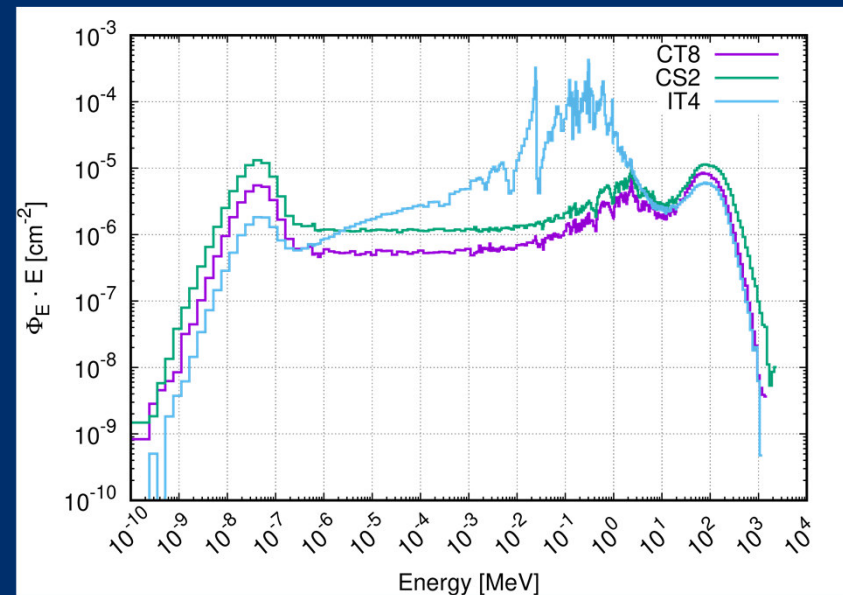
- Many designed as calibration fields for doseimeters
- Spectra are similar to real workplaces so energy response of devices not an issue
- Tailored to specific requirements in a particular country

NPL, IRSN, PTB simulated workplace fields



Broad high energy fields: CERF

- CERF installed in the North Experimental Area of CERN
- High energy simulated cosmic ray field
- SPS proton beam hits a 10 cm long Be target
- Secondary hadron beam hits 50 cm long Cu target
- $5 \mu\text{Sv/h}$ to $360 \mu\text{Sv/h}$



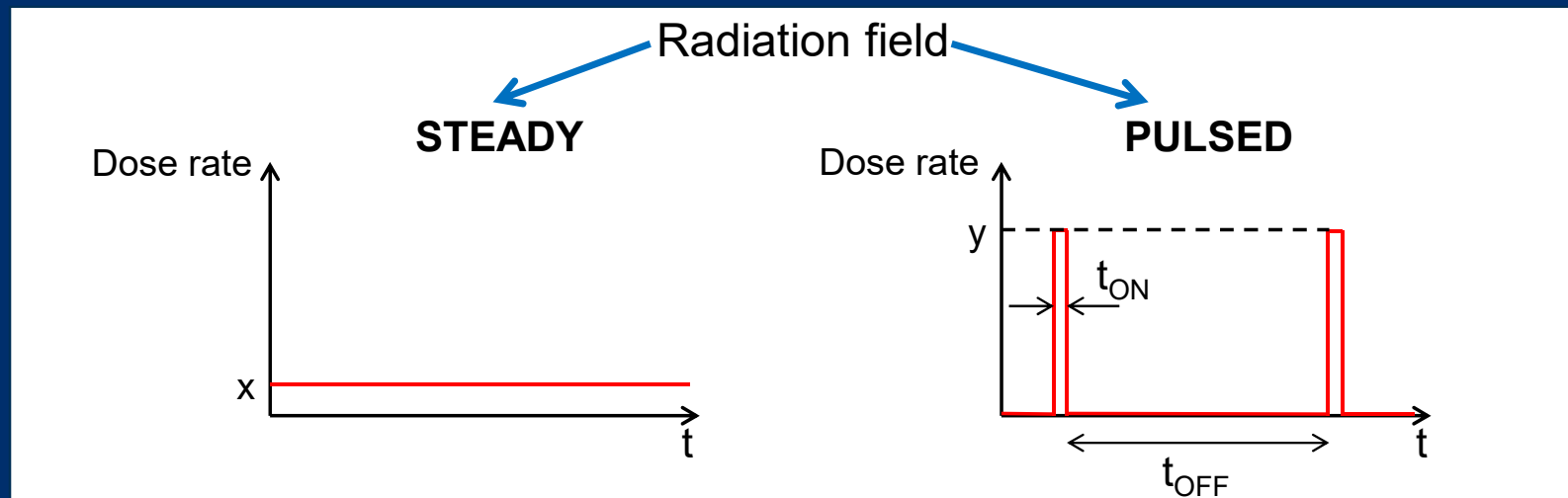
High energy monoenergetic neutrons

- Defined as over 20 MeV
- Most labs like NPL, PTB, IRSN etc offer neutron fields up to 20 MeV
- Most nuclear data ends at 20 MeV
- Only 2 monoenergetic neutron fields > 40 MeV available (South Africa & Japan)
- Not optimised for instrument calibrations
- Difficult to test and calibrate instruments designed for high energy neutrons
- CCRI(III) task group holding nHBEAM2025 workshop
- Collaboration to develop iThemba facility in South Africa for metrology

Facility	Beam energy (MeV)	Fluence rate (cm ⁻² s ⁻¹)
NRF-iThembaLABS (SA)	35-200	10 ⁴
RCNP (Japan)	100-400	10 ⁵
TIARA (Japan)	40-90	10 ⁴
CYRIC (Japan)	20-90	10 ⁶
NPI/Rez(Czech Republic)	<40	Up to 10 ⁹
NFS (France)	<40	

Pulsed neutron fields

- Many workplace neutron fields are pulsed, e.g.
 - Conventional radiotherapy
 - Proton therapy
 - Fusion facilities



Same averaged dose rate but different instantaneous dose rates

Measuring pulsed neutron fields

- Active instruments suffer dead time losses or even saturate during pulse
- Newer instruments being developed to work in pulsed fields (e.g. LUPIN)
- However there are no reference facilities to test them in
- WG11 have plans to use SwissFEL for a comparison



[http://refhub.elsevier.com/S0168-9002\(13\)01635-5/sbref23](http://refhub.elsevier.com/S0168-9002(13)01635-5/sbref23)

For more information

- ISO 8529: Neutron reference radiation fields Parts 1, 2 and 3
- Metrologia neutron special issue 2011 (Volume 48, Number 6)
 - [What is neutron metrology and why is it needed?](#)
 - [Simulated workplace neutron fields](#)
 - [Quasi-monoenergetic high-energy neutron standards above 20 MeV](#)
- [CCRI Webinar - 26/01/2023 - Fast neutron reference fields above 20 MeV](#)
- Upcoming WG11 webinars on pulsed fields

Thank you for listening!



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