Neutron Metrology at the National Physical Laboratory

iThemba Labs

4th February 2019

Alberto Boso

Collaboration for the Development of the Fast Neutron Metrology Facility at iThemba LABS

NPL - Teddington

The National Physical Laboratory

NPL National Physical Laboratory

- UK's National Metrology Institute/ Public Corporation
- Formal Partnership between NPL, BEIS and Universities of Surrey and Strathclyde
- ~800+ staff with ~200 visiting researchers/year
- Partner with 200+ organisations and 80+ Universities

Our Science and Engineering

NPL National Physical Laboratory

Chemical, Medical & Environmental Metrology	Engineering, Materials & Electrical Metrology	Quantum Metrology	Data Metrology
• Biometrology • Earth Observation • Medical Radiation Physics • Emissions & Atmospherics • Gas & Particle • Medical Radiation Science • Mass Spec Imaging • Nuclear • Radiochemistry • Surface Technology • Ultrasound & Underwater	• Electrochemistry • EM Measurements • EM Technologies • Electronics • Magnetics • Engineering Services • Manufacturing • Mass • Material Characterisation • Materials Testing • Temperature & Humidity	• Quantum • Time & Frequency	• Data

Neutron Metrology

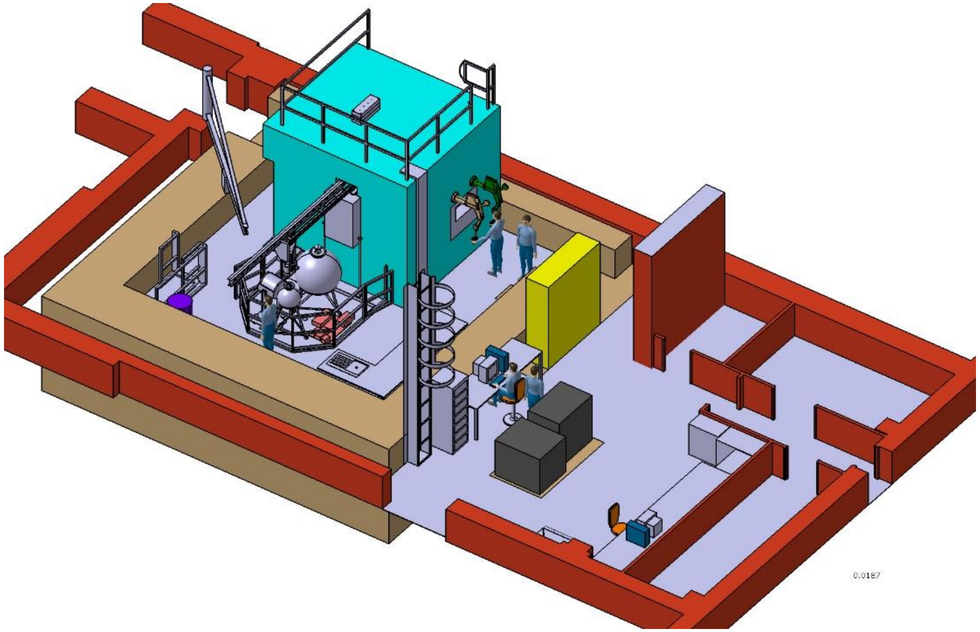
The NPL Neutron Metrology Section operates world-leading facilities for measuring **neutron source emission rates** and providing an extensive range of accelerator- and source-based **calibration fields**

9 staff members

- David Thomas (PRS)
- Nigel Hawkes (PRS)
- Graeme Taylor (PRS)
- Neil Roberts (SRS)
- Michael Bunce (SRS)
- Andy Bennett (SRS)
- Alberto Boso (HRS)
- Sarb Cheema (RS)
- Nicola Horwood (RS)
- *Vacancy x 2 (RS)*

- Paddy Regan (PRS) - SAL

Manganese Bath – Primary Standard



- Manganese Sulphate soln.
- $^{55}Mn(n,\gamma)^{56}Mn \rightarrow 2.6hr$

Radioisotope Sources

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Source	Total output (s^{-1})
^{252}Cf	2.6×10^3 - 6.8×10^7
^{241}Am-Be	7.9×10^4 - 3.2×10^7
^{241}Am-B	4.3×10^5
^{241}Am-F	1.3×10^5
^{241}Am-Li	2.1×10^5

VdG Accelerator

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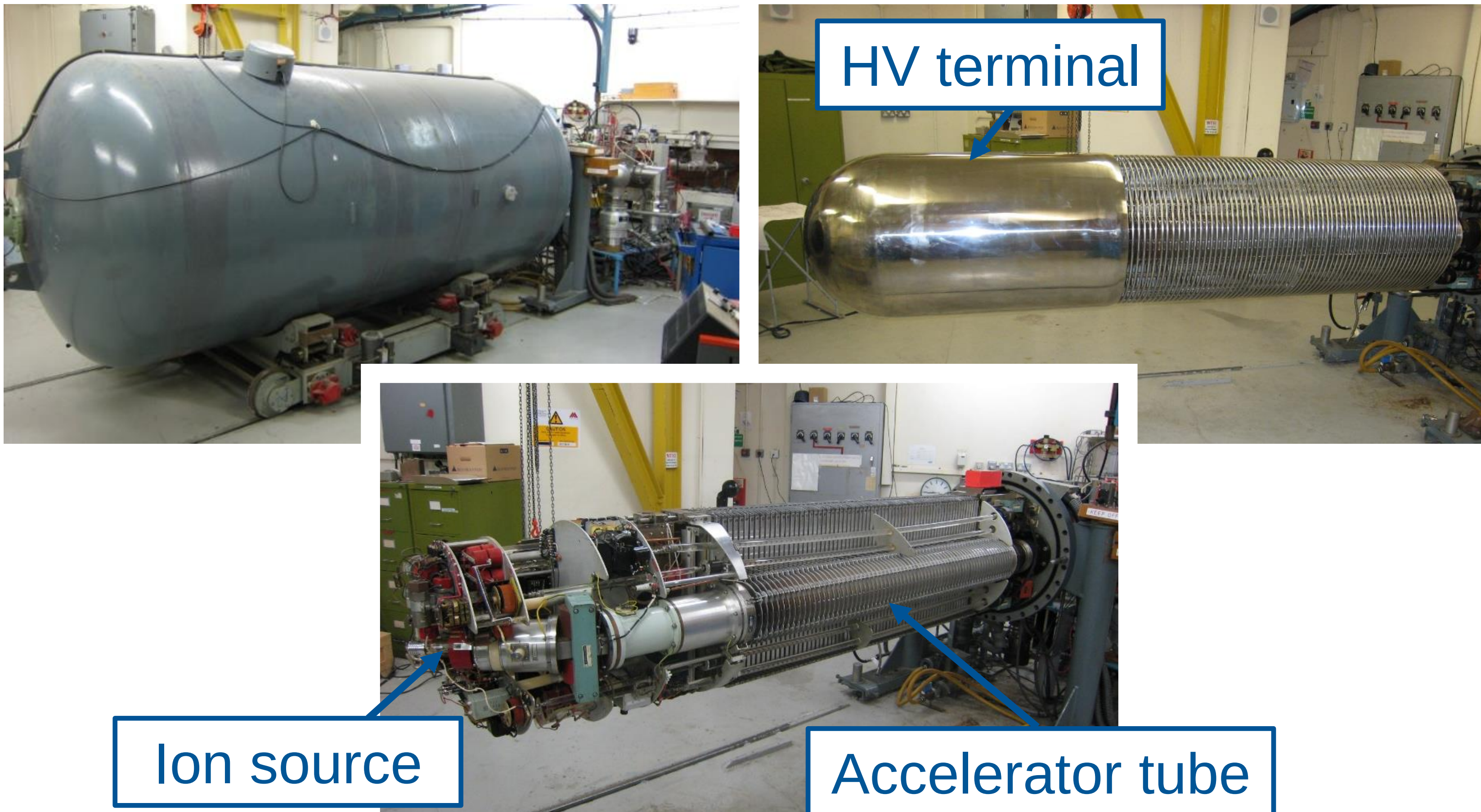
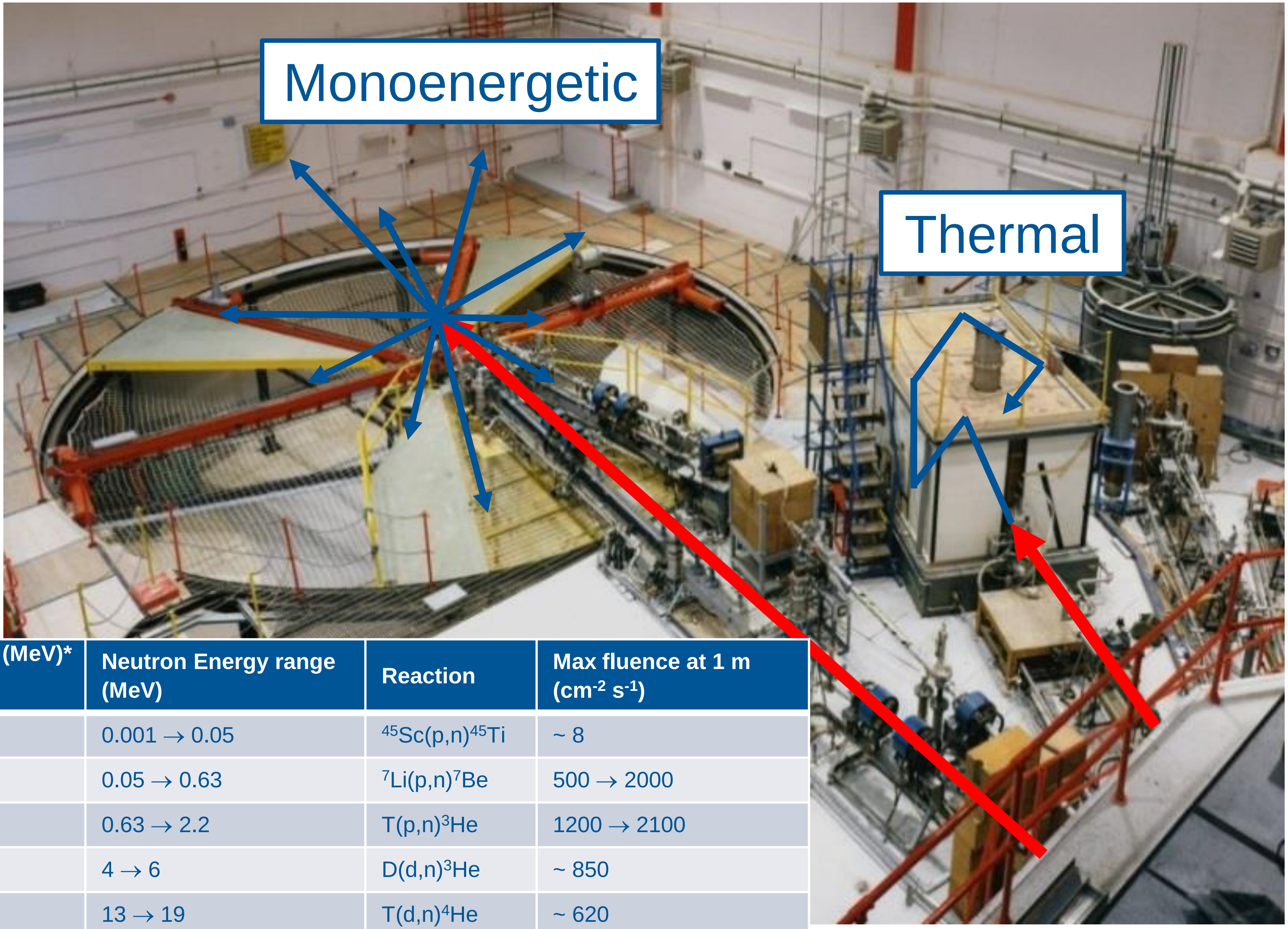
3.5 MV Van de Graaff accelerator.

Protons and deuterons to energies 880 keV - 3.5 MeV.



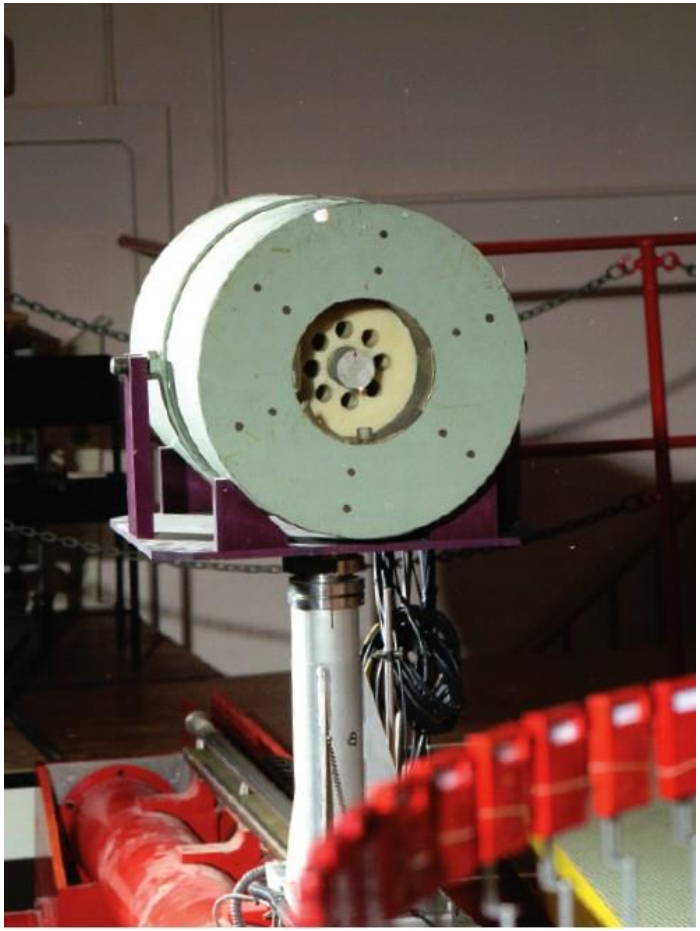
Neutron irradiation capabilities



Beam Energy (MeV)*	Neutron Energy range (MeV)	Reaction	Max fluence at 1 m (cm^{-2} s^{-1})
2.905-2.945	0.001 → 0.05	$^{45}Sc(p,n)^{45}Ti$	~ 8
1.925-2.355	0.05 → 0.63	$^{7}Li(p,n)^{7}Be$	500 → 2000
1.450-2.985	0.63 → 2.2	$T(p,n)^{3}He$	1200 → 2100
0.880-2.740	4 → 6	$D(d,n)^{3}He$	~ 850
0.880-2.550	13 → 19	$T(d,n)^{4}He$	~ 620

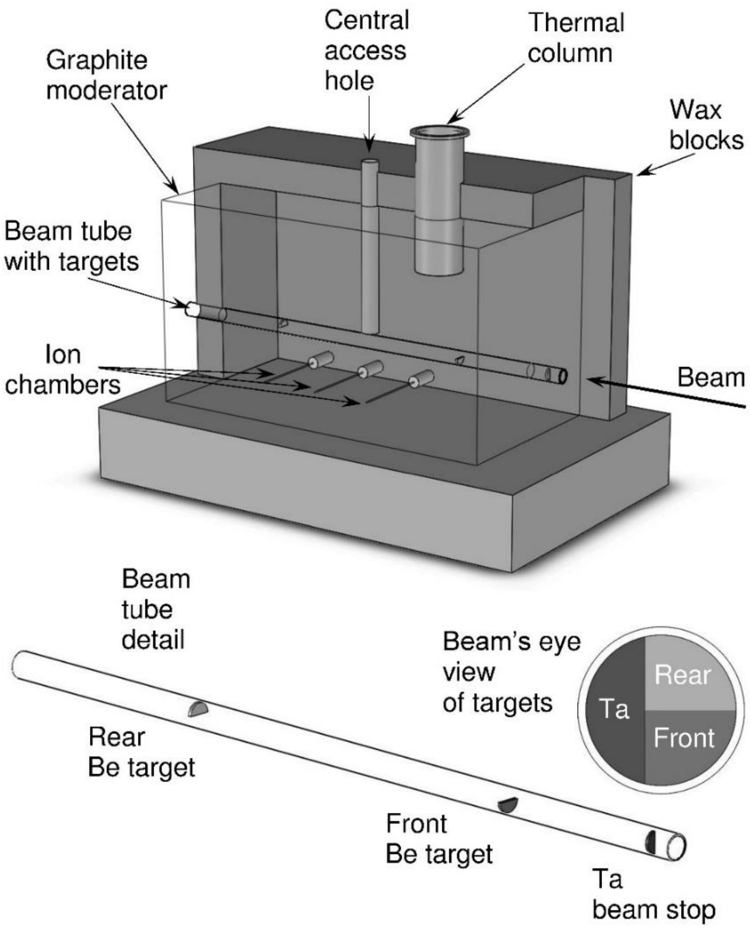
Neutron Fluence

- Measured using a Long Counter (BF_3 counter inside a cylindrical moderator).
- The efficiency, about 11 counts per (neutron per cm^2), varies relatively little with energy.
- Efficiency established by (e.g.) using neutron sources with accurately known output (measured in NPL Mn bath).
- Provides a calibration of the beam current monitor.



Thermal Pile

	Beam Current (μA)	Central access hole	Thermal column
Field geometry		Isotropic	Collimated beam
Max fluence rate ($cm^{-2}s^{-1}$)	80	1.2×10^7	4.0×10^4

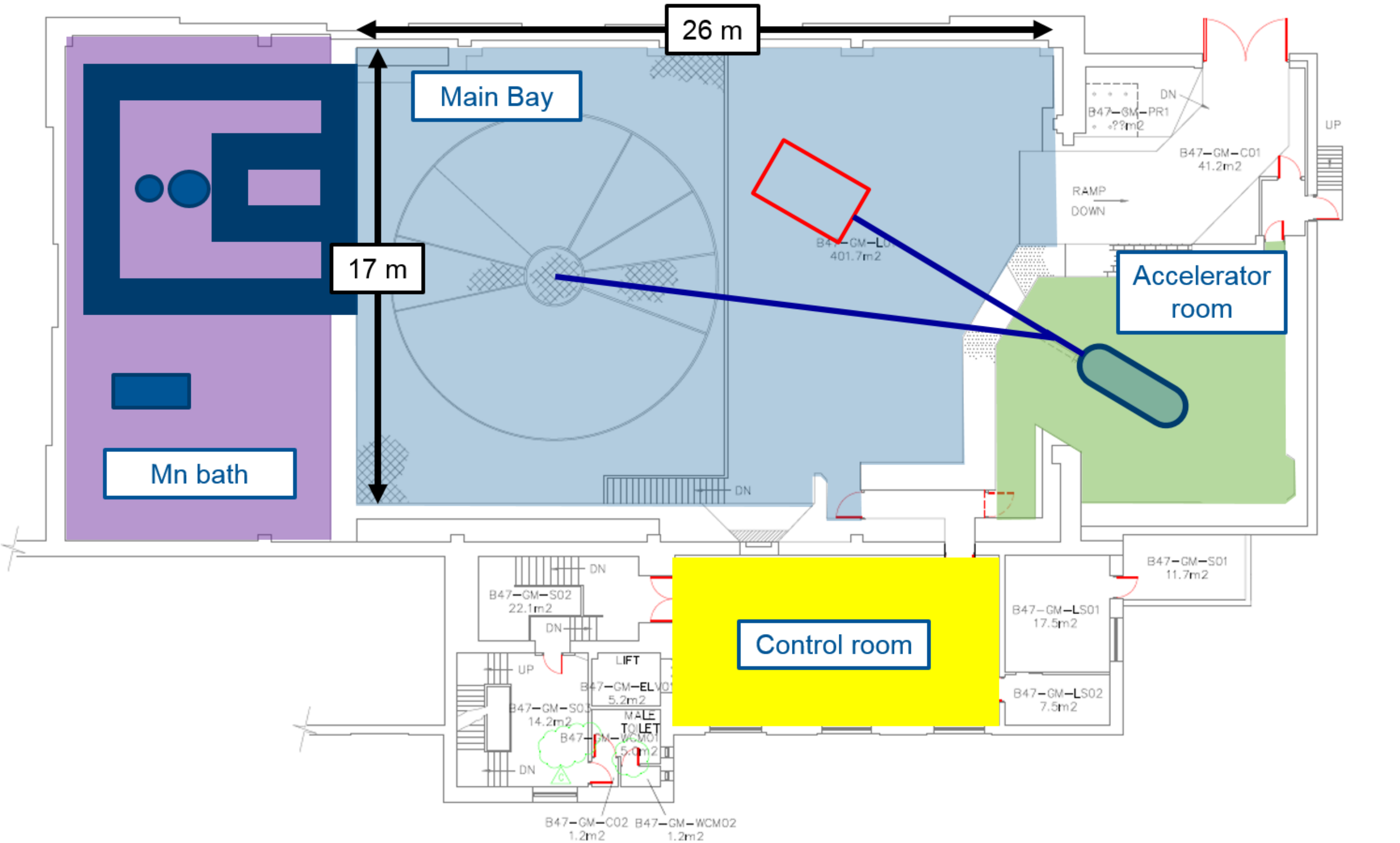


Graphite block:

2.8 m x 1.4 m

1.6 m tall

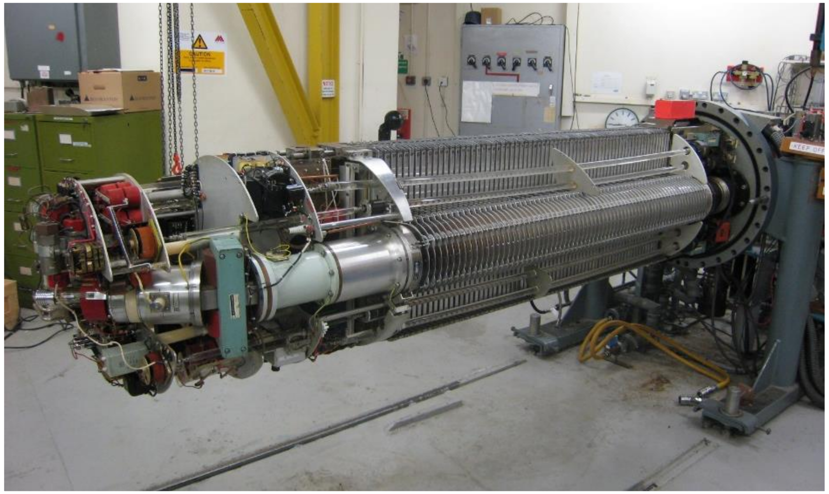
Neutron Facility



Accelerator Replacement

- The accelerator is over 50 years old and becoming unreliable
- Many of the component parts are obsolete and irreplaceable
- The machine is kept going by the knowledge and experience of a very small team - 2 people!

Therefore, we need a new machine!



Solution

- Stakeholder engagement → Optimal solution

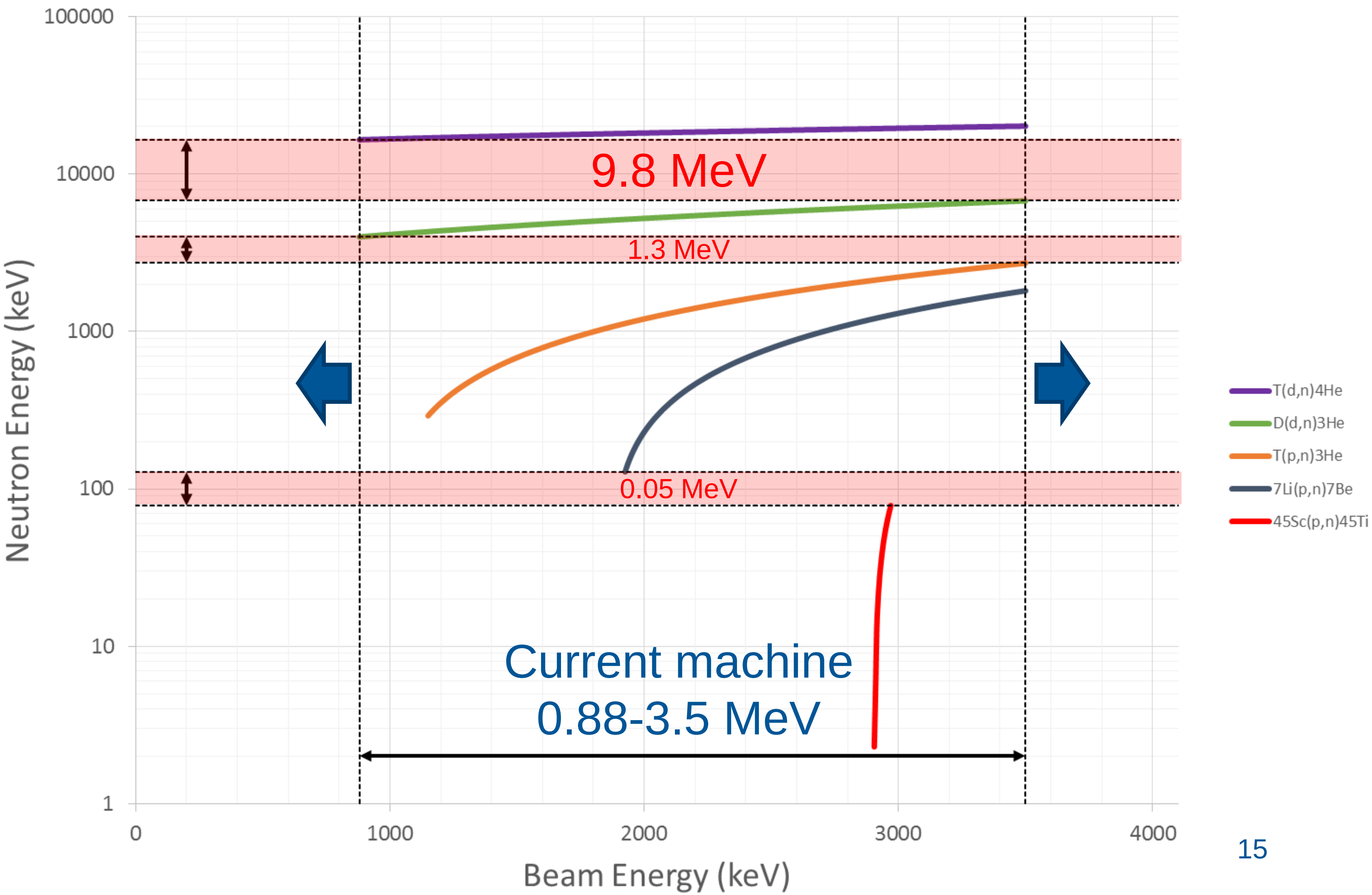
2MV TVdG

- ↑ I_{beam} = ↑ fluence ✓
- Energy range ↑ ✓
- ↑ Reliable = ↑ uptime ✓
- Pulsed ✓

T-shaped design
Current max = 200 µA

Coaxial design
High Current > 1 mA

Benefits for neutron production



Benefits for neutron production

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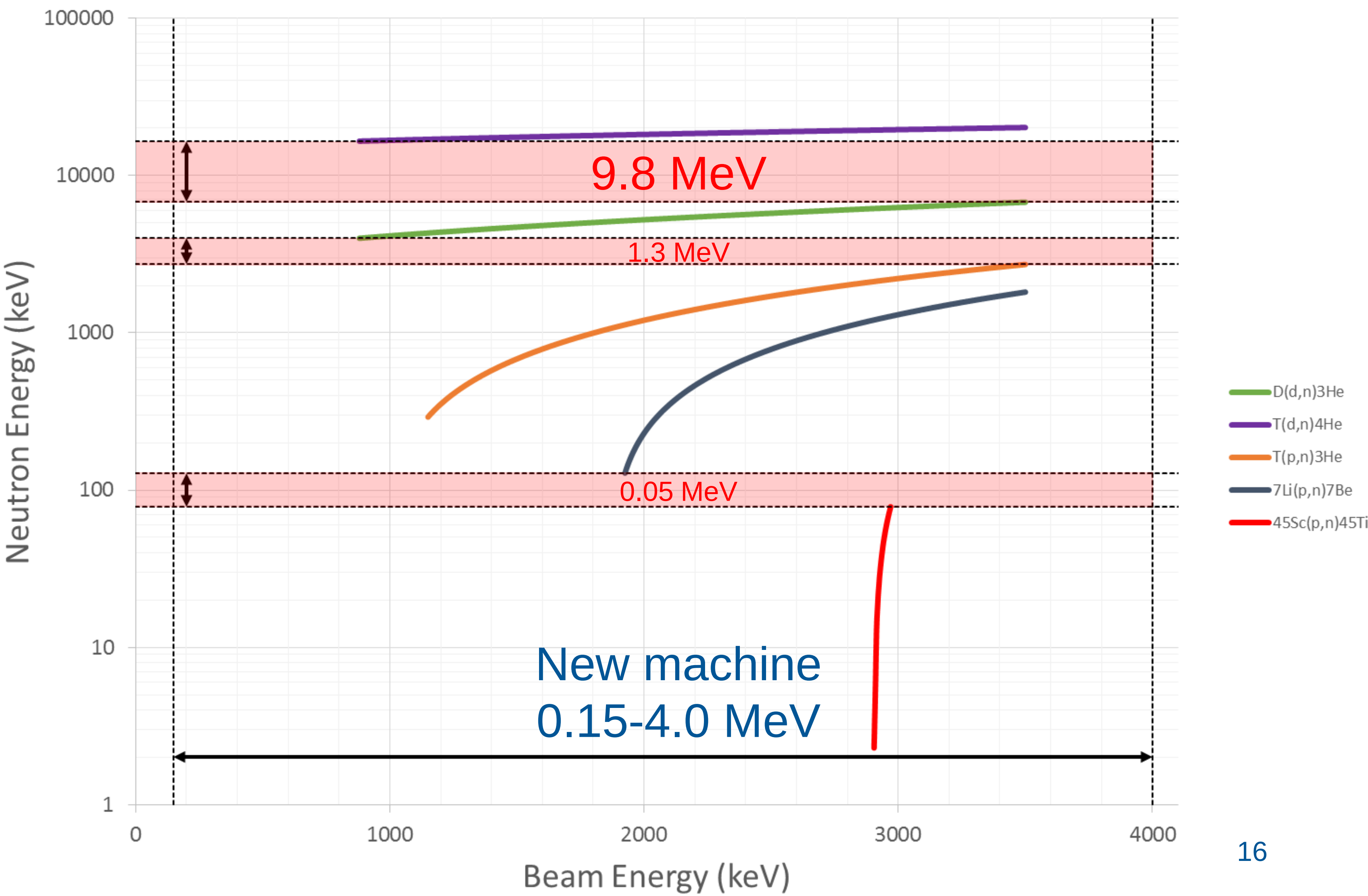
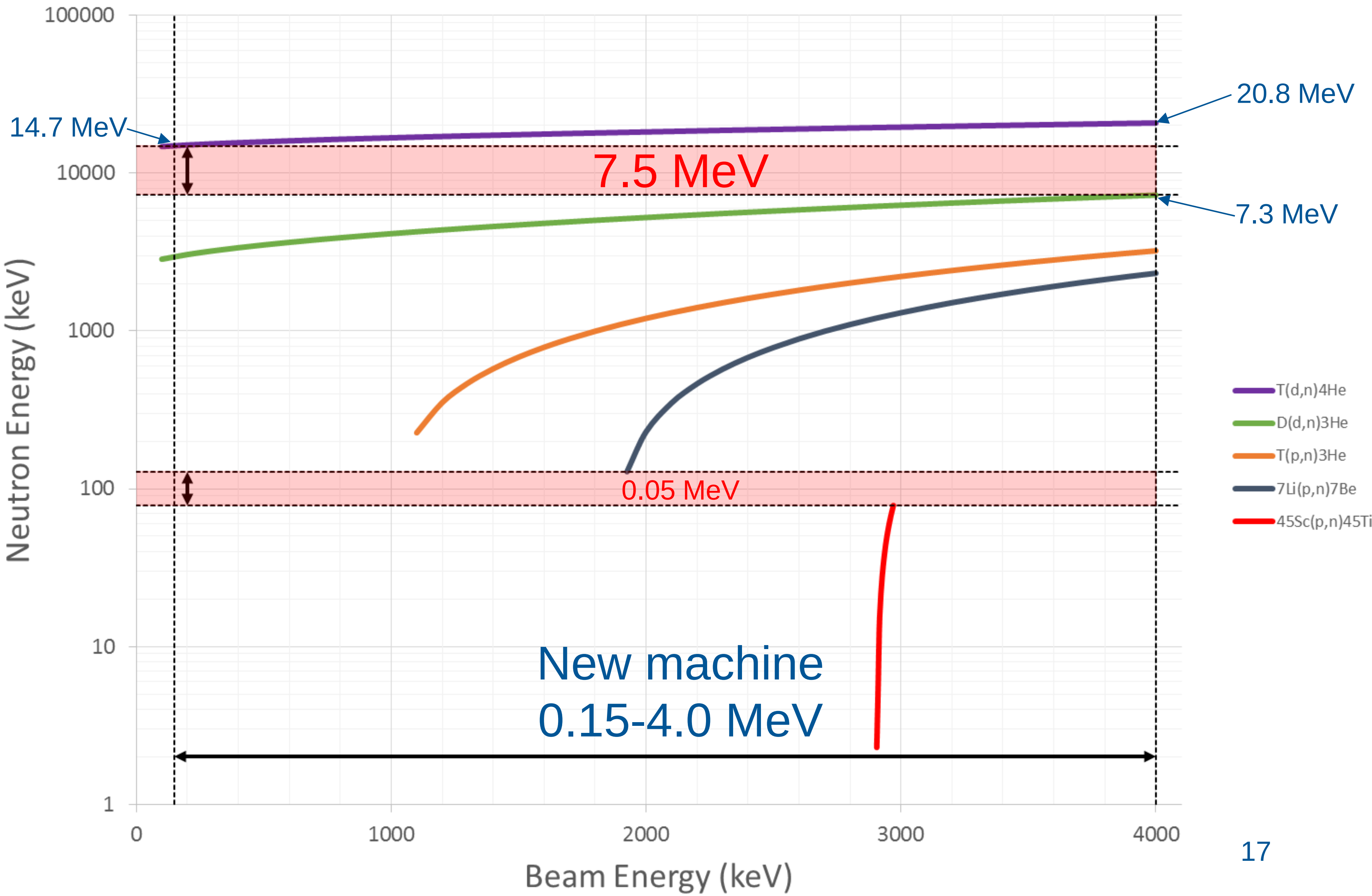
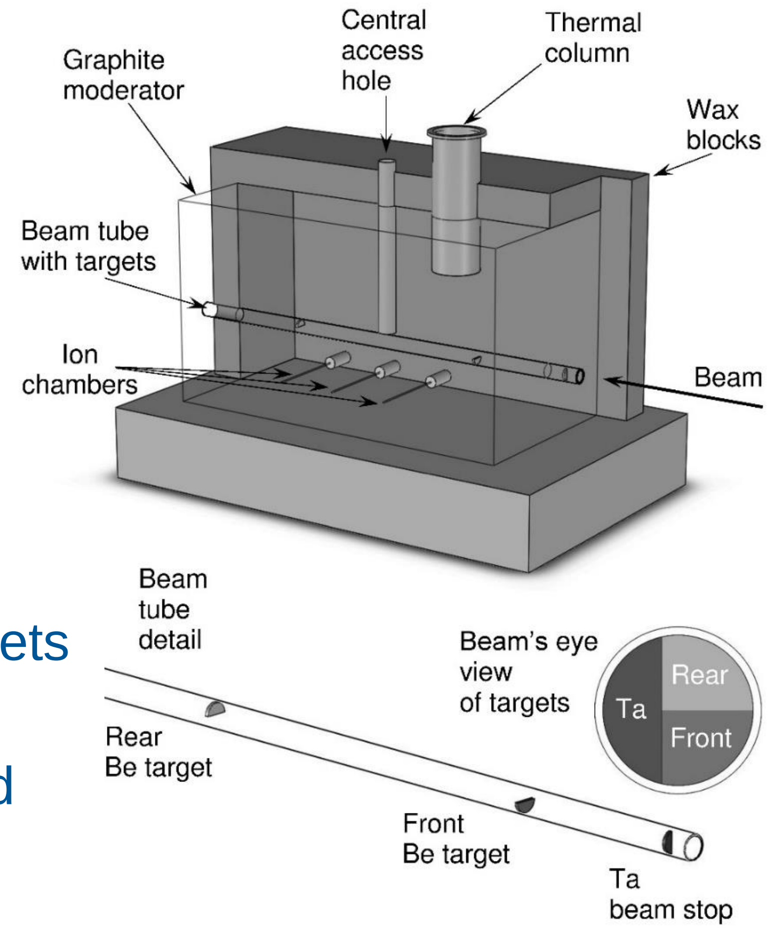


Benefits for neutron production



Thermal Pile - Benefits

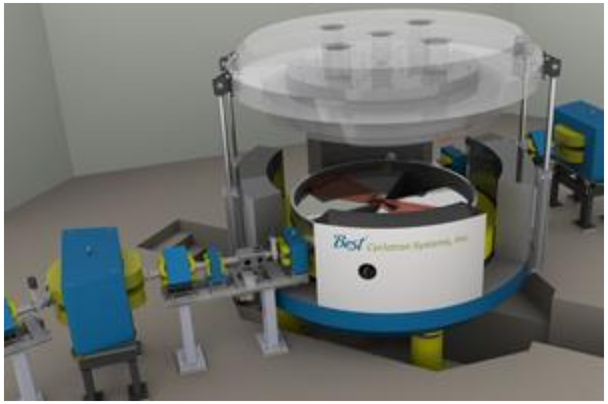
	Beam Current (μA)	Central access hole	Thermal column
Field geometry		Isotropic	Collimated beam
Max fluence rate ($cm^{-2}s^{-1}$)	80	1.2×10^{7}	4.0×10^{4}
	1000	1.5×10^{8}	5×10^{5}

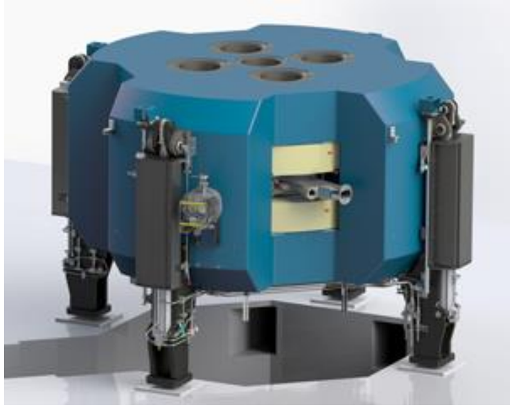


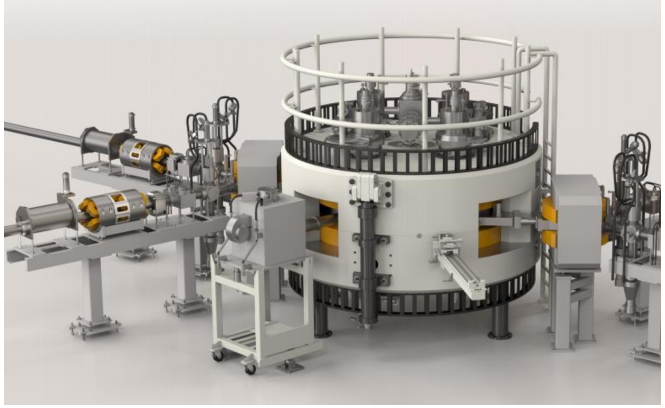
- Substantial work required to redesign targets to withstand extra beam power
- Higher energy + thick target = higher yield
- Redesign could yield even higher yields, reflector material/more shielding?

Opportunity for expansion

- Nuclear Metrology is working in the growth area of radiopharmaceutical standardisation → looking to expand
- Seize this opportunity to explore the options of co-locating another accelerator
- This would accelerate the already planned expansion into this work

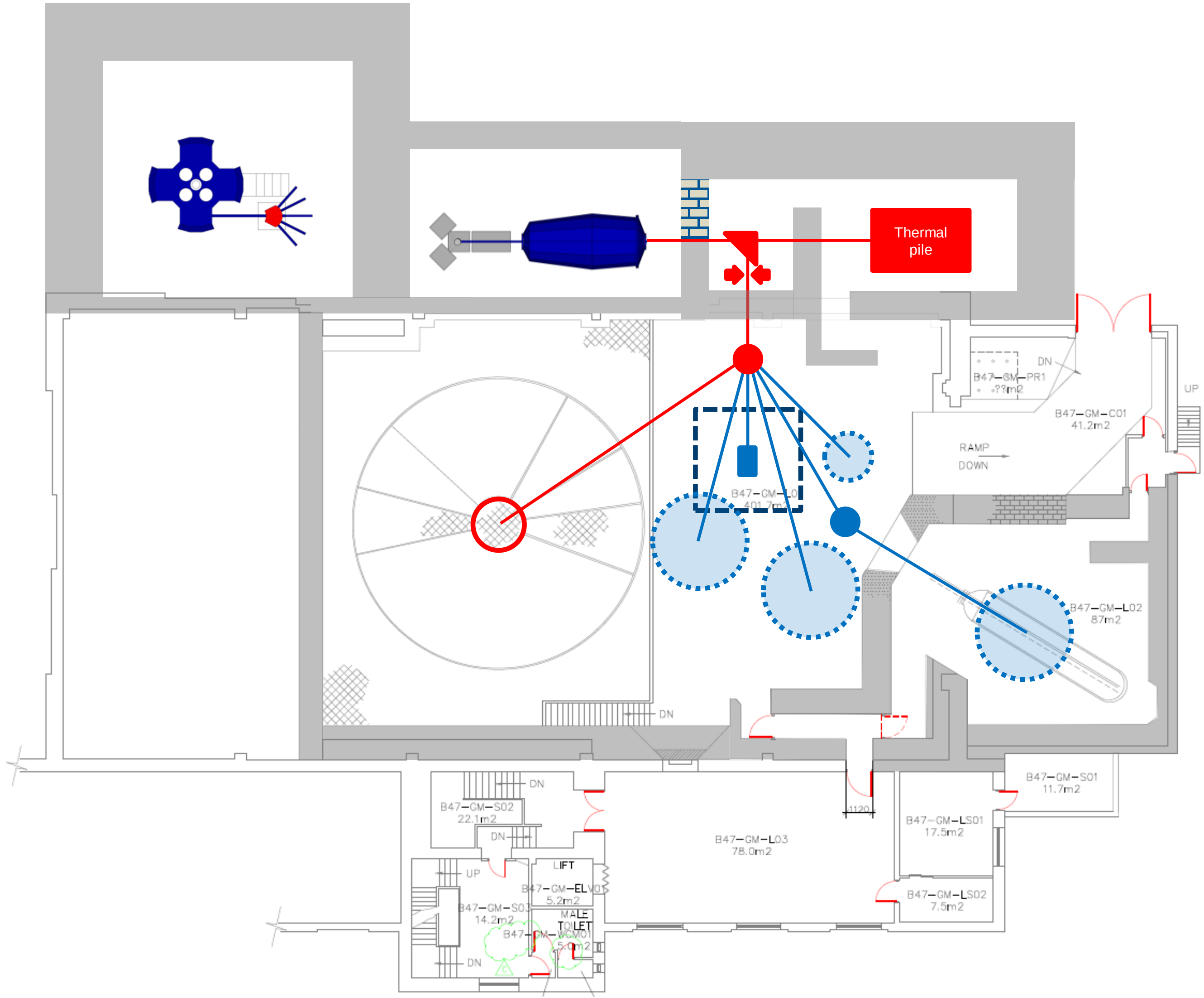






- Other areas: Radiation biology, nuclear structure

Proposed Layout



Possible new research themes

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- Neutron cross section measurements/Nuclear Data
- Neutron hardness
- Neutron Activation Analysis
- Neutron imaging

Neutron work

- Radiation Biology
- Production of novel medical isotopes

@ NPL

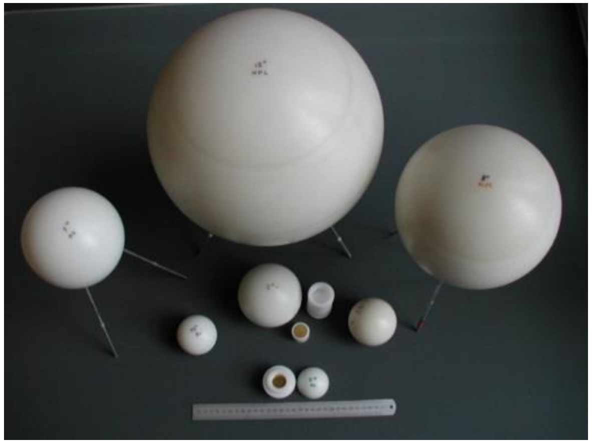
- Academic access - Nuclear Astrophysics or Structure
- Accelerator component development

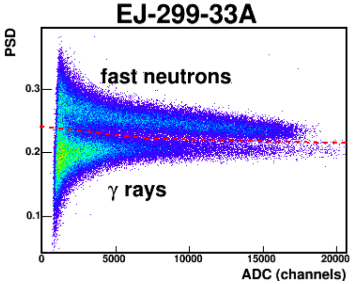
- Teaching and Education – PhD/MSc projects

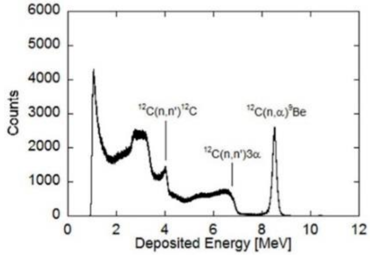
Neutron Spectrometry

Broad range, thermal to GeV, but poor resolution – Bonner Spheres – based on moderation

- **Active** system – ^{3}He proportional counter
- **Passive** system – Au activation foils
- **Extended range** BS (high-Z layer) -> higher E range





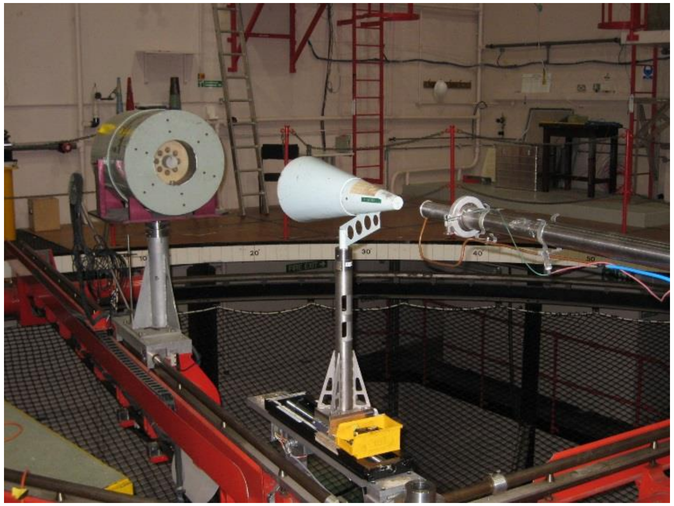


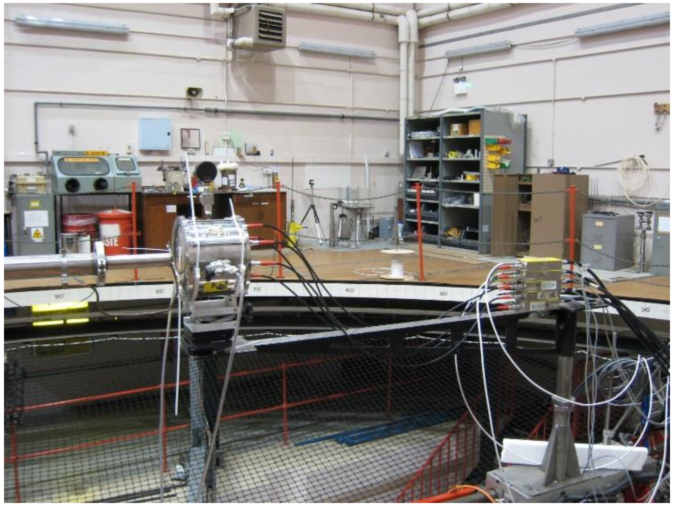
Limited range, high resolution

- **Scintillators**: liquid (NE213), CLYC, plastic – Fast response, Pulse Shape Discrimination
- **Proton Recoil Counters** – 50 keV to 1.5 MeV
- **Diamond detector** – Well defined peak at neutron energy

Cross section measurements

- Two campaigns under CHANDA (2016 and 2017)
- $^{235}U(n,f)$, $^{238}U(n,f)$, $^{237}Np(n,f\ )$ and $^{242}Pu(n,f)$
- Monoenergetic neutrons:
  E_n = 0.565, 0.9, 1.0, 1.1, 1.2, 1.8, 2.0 and 2.4 MeV
- Fluence measurement → NPL long counter
- Fission detector → TFGIC
- 2 measurements: absolute and relative





Neutrons in Proton Therapy

Secondary neutrons are produced by the interaction of the primary protons with the matter

Unwanted dose to the patient

Secondary cancer risk?

Dose to the workers?

Implanted Cardiac Devices?

There are two kind of secondary neutrons:

External neutrons

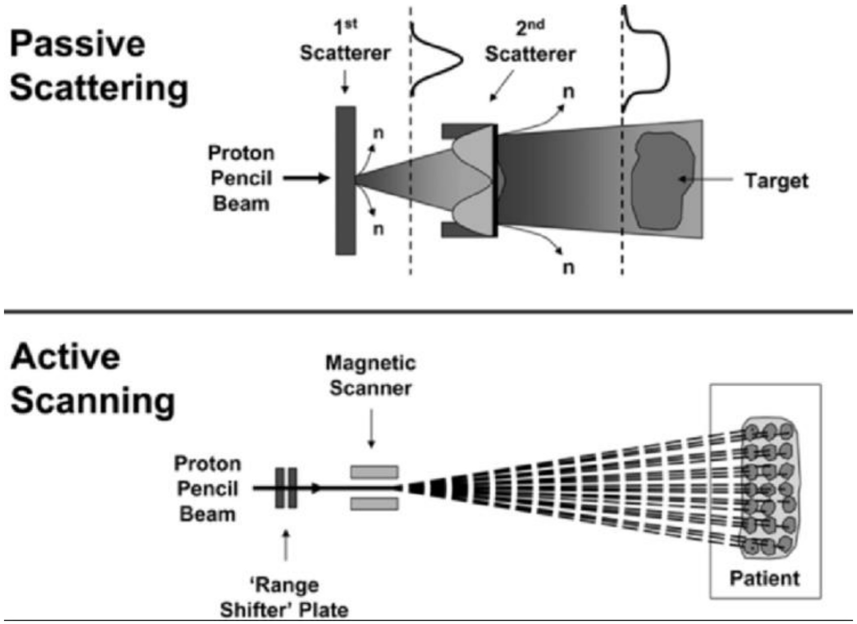
Produced in the interaction of the protons with the **beam delivery system**

Worse in Passive scattering

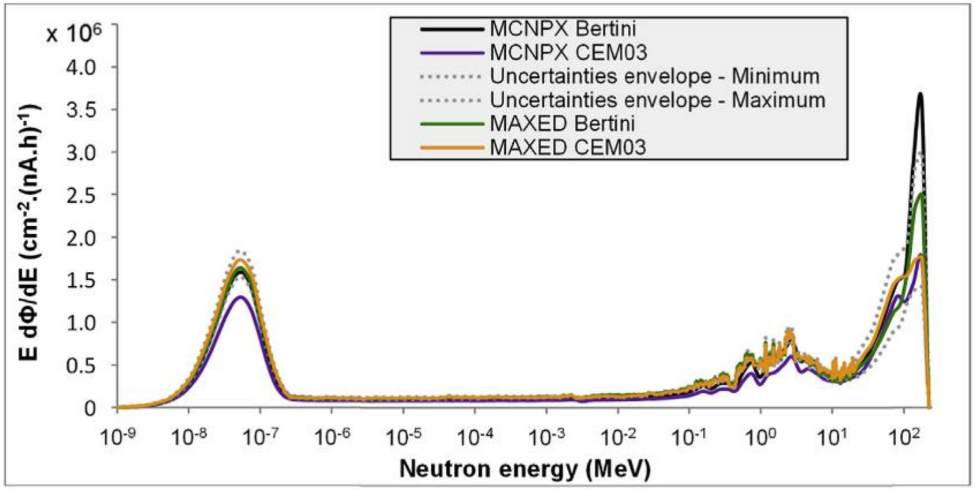
Internal neutrons

Produced **inside the patient**

Impossible to avoid



Experimental Challenges



Wide Energy Range

- No survey instrument with good response over the whole range
- We need spectroscopic information!
- Difficult to validate response matrix at very high energy
- Simulations rely on physics models

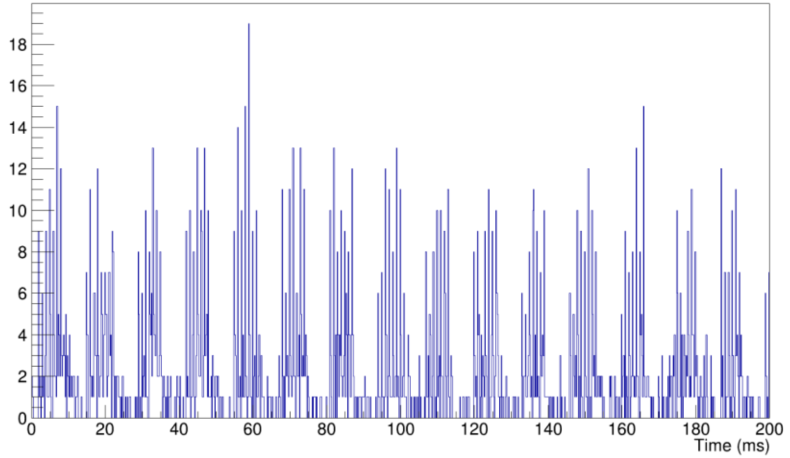
Beam delivered by cyclotrons, synchrotrons, cyclo-synchrotrons -> Pulsed structure

Pulsed structure

Very high intensity in narrow time window

Detectors require time to process every single event

-> Dead Time



Proton Therapy in the UK

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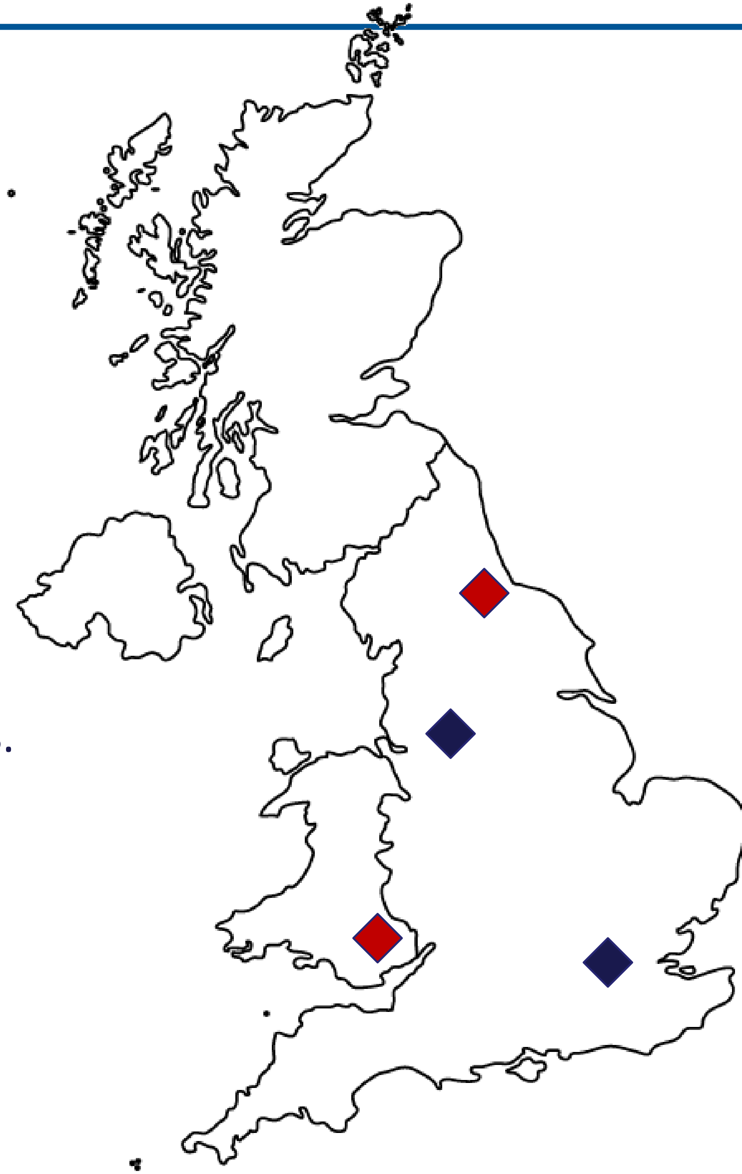
Good contacts with public centres
- Christie, Manchester. First treatment in 2018.
  NDA in place, measurements out the room soon
- UCLH, London. First treatment in 2020.

CHRISTIE'S
TOWARDS A FUTURE WITHOUT CANCER

uclh NHS

Good contacts with private centres
- Rutherford, Newport. First treatment in May 2018.
  Preliminary measurements performed
  Collaboration with NPL Dosimetry Group
  New measurements soon

Rutherford Cancer Centres



Next Steps

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Measurements at Christie, Manchester

- Neutron dose **outside** the shielding
- Hazard for workers
- Possibly measurements inside the room

CHRISTIE'S
TOWARDS A FUTURE WITHOUT CANCER

Measurements at Rutherford, Newport

- Neutron dose in and out of the room
- Collaboration with NPL Dosimetry Group

Rutherford Cancer Centres

EURADOS WG9

- Measurement in **Krakow** (Sep 18)
- Measurements in CCB cyclotron
- Dosemeters, survey instrument, ERBSS

EURADOS

TECHNICAL DEVELOPMENT

- Development of BSS read out in **current mode** with POLIMI (accepted EMPIR)

POLITECNICO MILANO

- **Validation of BSS response function at high energy** with (quasi)monoenergetic beams (iThemba?)

National Physical Laboratory

Thank you for listening!

Who are our customers?

NPL
National Physical Laboratory

The NPL NMG provides industry, academia, and defence with well characterised monoenergetic neutron fields from 0.001 eV to 19 MeV and high intensity thermal fields.

High Intensity Facility

- Plans for a facility are being developed based on $^{9}Be(d,n)^{10}B$ reaction
- MCNP6 used to model potential shielding solutions
- Theoretical fluence for radiation hardness testing for electronic devices

  1 MeV-equivalent fluence rate in Si = 1.45×10^{6} neutrons cm^{-2} s^{-1}

  (3 MeV Ds, 20 uA beam current, d = 1 m)
- Theoretical dose rates for overload testing radiation protection devices

  H*(10) rate = 1.7 Sv *h*$^{-1}$ *(3 MeV Ds, 20 uA beam current, d = 1 m)*