National Physical Laboratory

Beam at NPL
UK Nuclear Academics Meeting
8th September 2021

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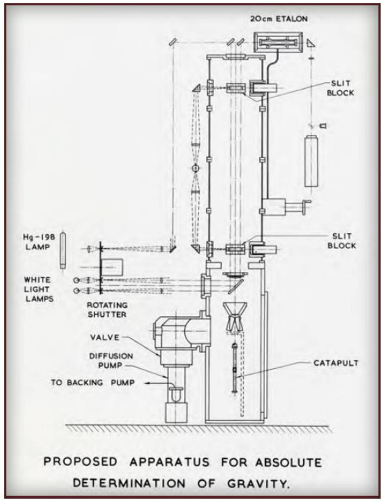
What is the NPL?

- The National Physical Laboratory (NPL) is the UK's National Measurement Institute, and is a world-leading centre of excellence in developing and applying the most accurate measurement standards, science and technology available

- Approximately 950 staff

Neutron Metrology



1960

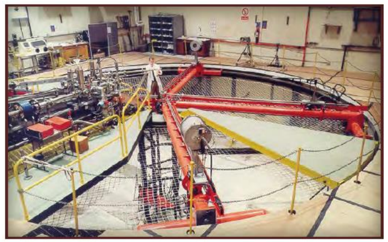
Absolute determination of g

In 1960 a new more, accurate determination of acceleration due to gravity (g) was made by NPL.

A more precise knowledge of the value of the acceleration of free fall (i.e. the acceleration due to gravity) was demanded in various applications and the problem was attacked simultaneously by a number of scientific nations.

NPL's approach was a symmetrical free motion method, in which a glass ball was timed in upward and downward passages in a vacuum across two horizontal planes separated by a vertical distance of about a metre. The planes were defined by a pair of slits, the ball serving to focus light from one slit onto the other. Distances were measured interferometrically, and time measured by NPL's standard frequency service.

The new value for g was found to be 9.8118177 metres per second squared, lower than the previously determined figure.



1962

3.5 MV Van de Graaff accelerator installed

This picture shows the experimental area of the Van de Graaff accelerator facility.

The Van de Graaff is used to accelerate beams of protons or deuterons that are directed on to selected target materials on the end of an evacuated flight tube, thereby producing neutron fields by nuclear reactions. Voltages of up to 3.5 MV are generated, providing beam energies of up to 3.5 MeV (mega electron volts). A 3.5 MeV proton has a velocity of about a tenth of the velocity of light. The neutron fields, which have energies from a few keV to 20 MeV according to which nuclear reaction is utilised, are used mainly to calibrate monitors used for radiological protection.

1960

1962

3.5 MV van der Graaff accelerator installed at NPL in 1962.

This is / has been used for (mainly) for the production of well-characterised neutron 'beams' with energies ranging from ~20 keV to ~20 MeV.

'Building 47' at NPL includes a large area scattering room.

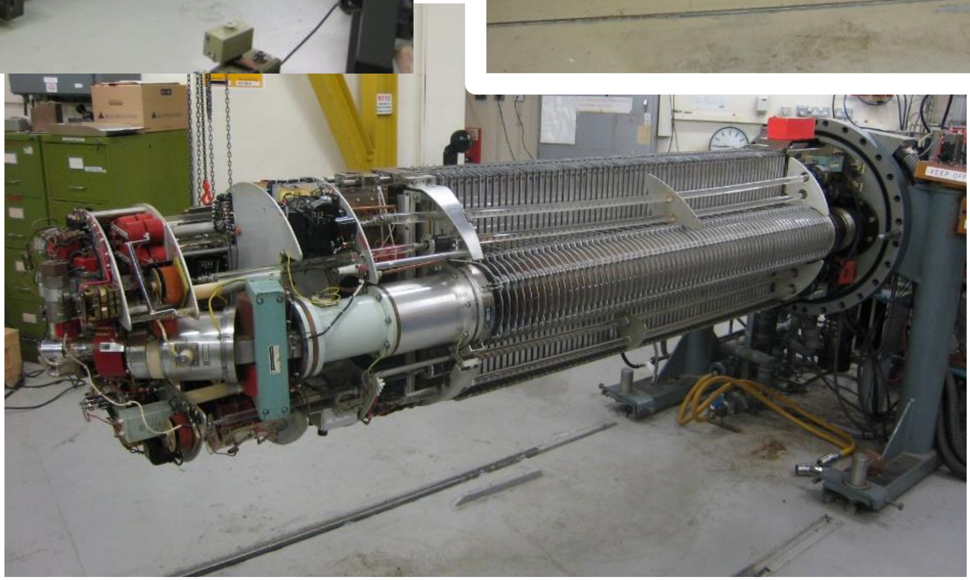
http://www.npl.co.uk/science-technology/neutron-metrology/

Neutron irradiation capabilities

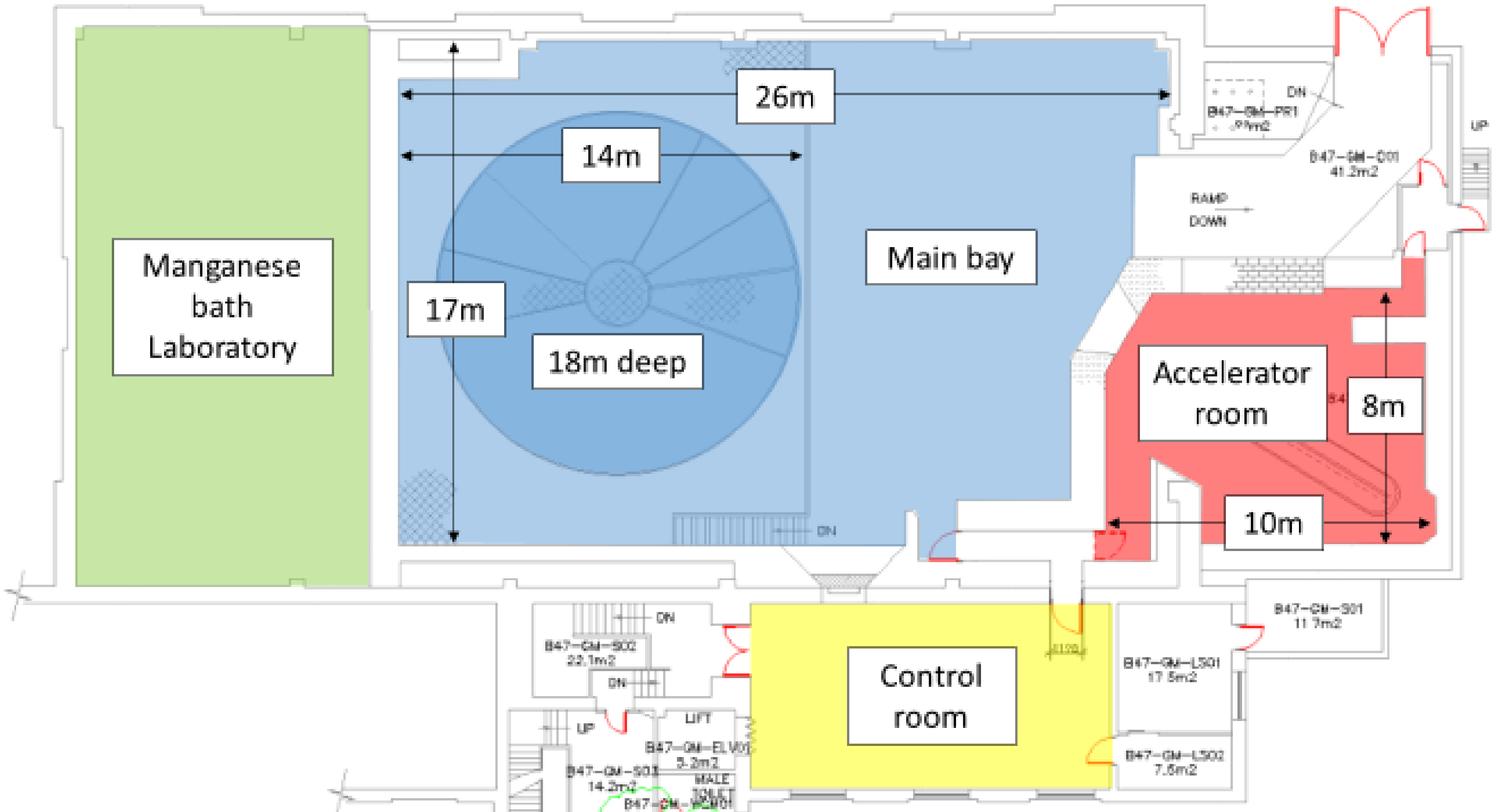
- Accelerator based neutron sources

Nuclear Metrology Group (NMG) houses a 3.5 MV Van der Graaff.

Protons and deuterons to energies between 880 keV to 3.5 MeV.



Neutron facility ('Building 47')



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Plans for neutron metrology at NPL

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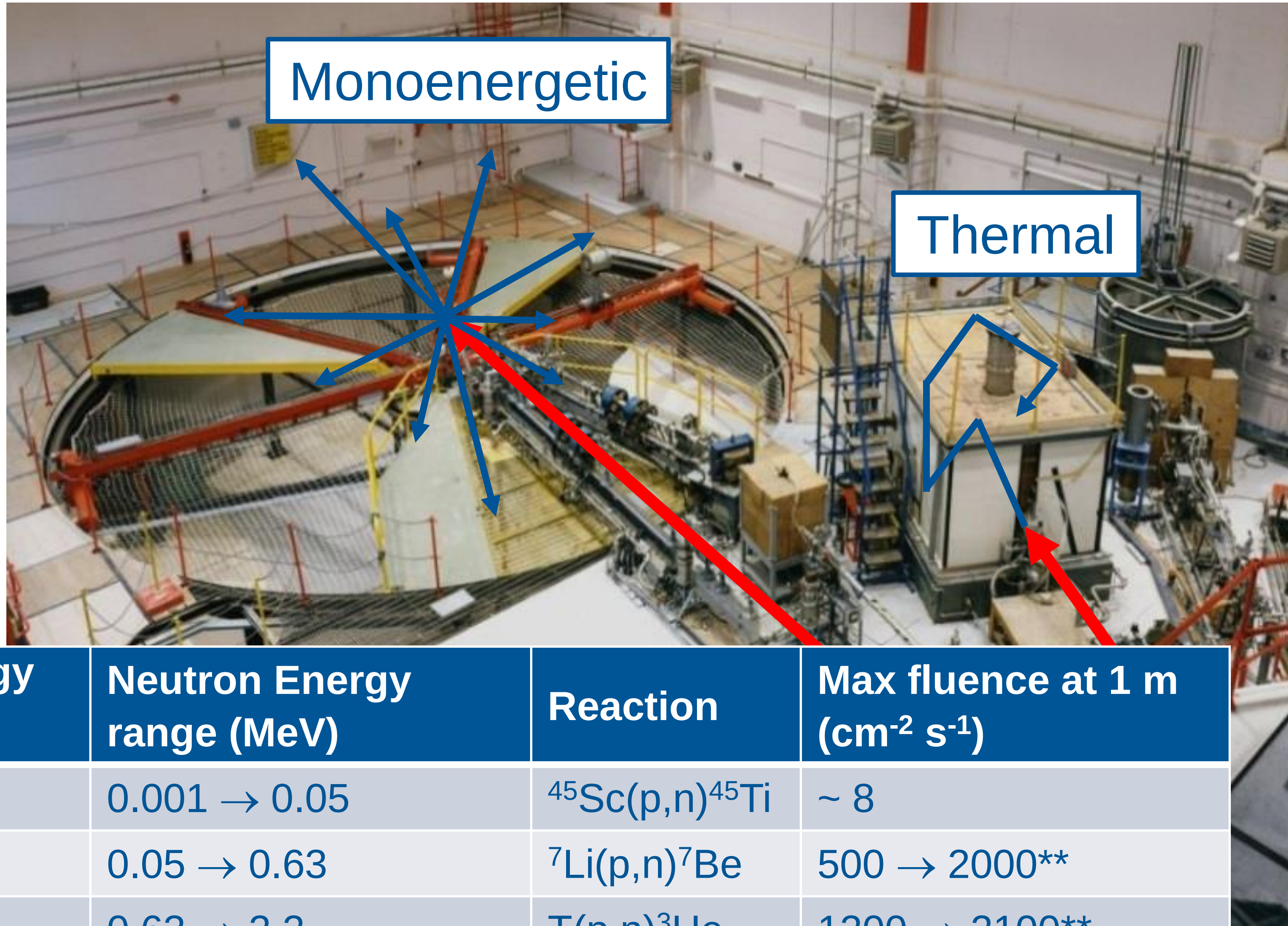
Neutron irradiation capabilities

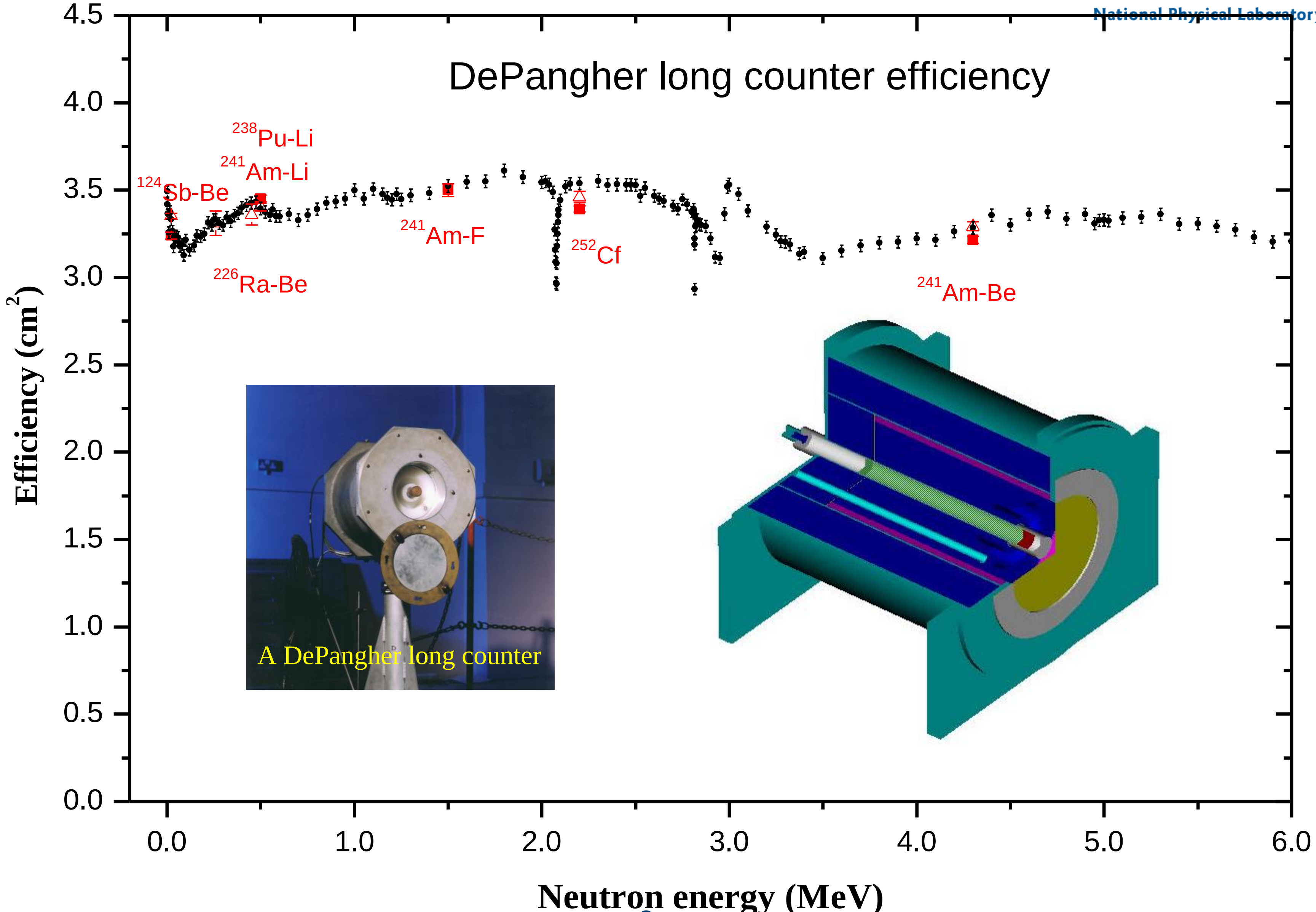


Beam Energy (MeV)*	Neutron Energy range (MeV)	Reaction	Max fluence at 1 m ($cm^{-2}\ s^{-1}$)
2.905-2.945	$0.001 \rightarrow 0.05$	$^{45}Sc(p,n)^{45}Ti$	~ 8
1.925-2.355	$0.05 \rightarrow 0.63$	$^{7}Li(p,n)^{7}Be$	$500 \rightarrow 2000$**
1.450-2.985	$0.63 \rightarrow 2.2$	$T(p,n)^{3}He$	$1200 \rightarrow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

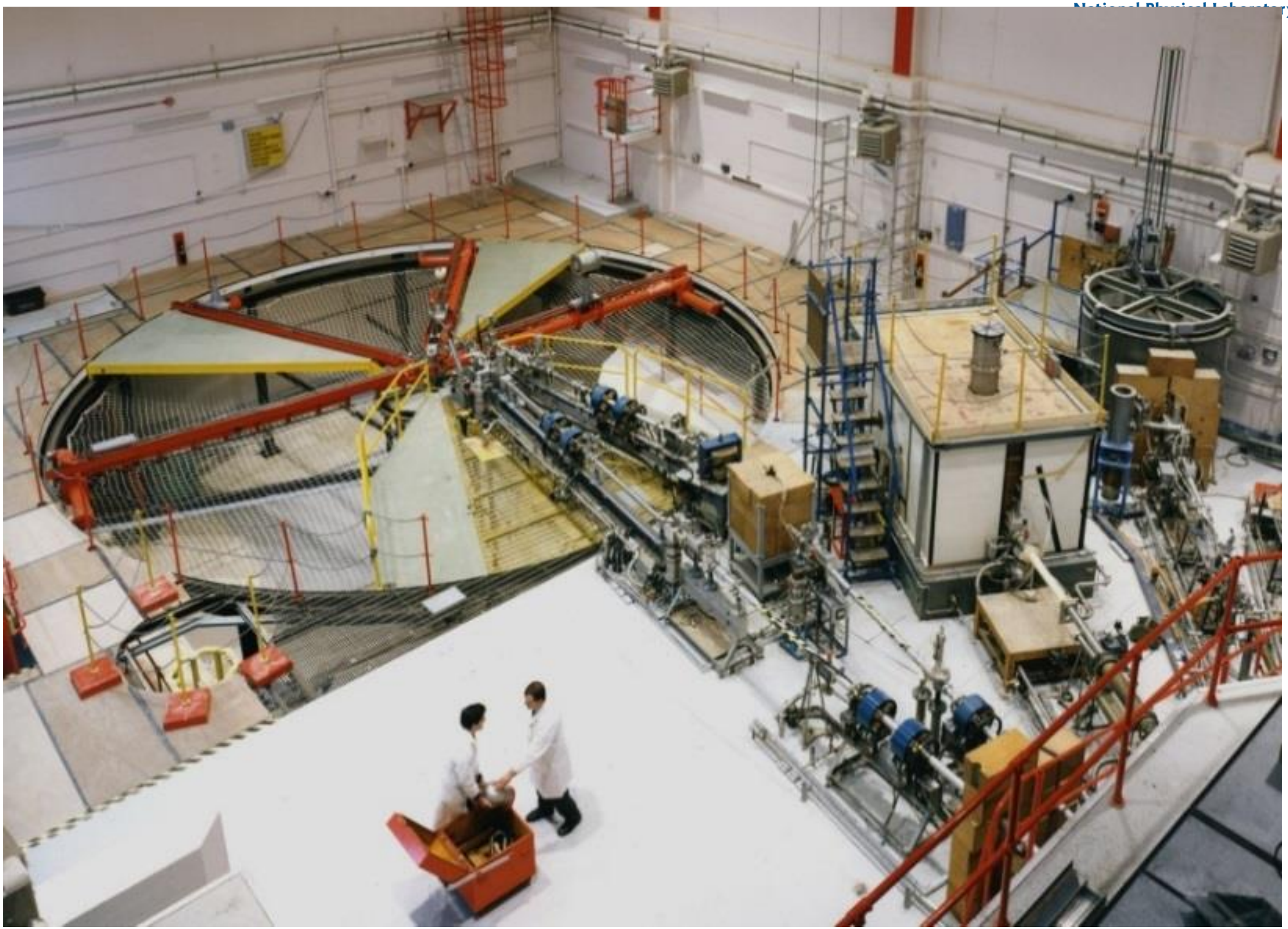
Mn bath and Radioisotope sources

Source	Total output (s^{-1})
^{252}Cf	1.8×10^2 - 6.4×10^7
$^{252}Cf / D_2O$	5.1×10^7
^{241}Am-Be	3.0×10^3 - 3.2×10^7
^{241}Am-B	4.2×10^5
^{241}Am-F	1.3×10^5
^{241}Am-Li	2.1×10^5

Measuring monoenergetic fluences

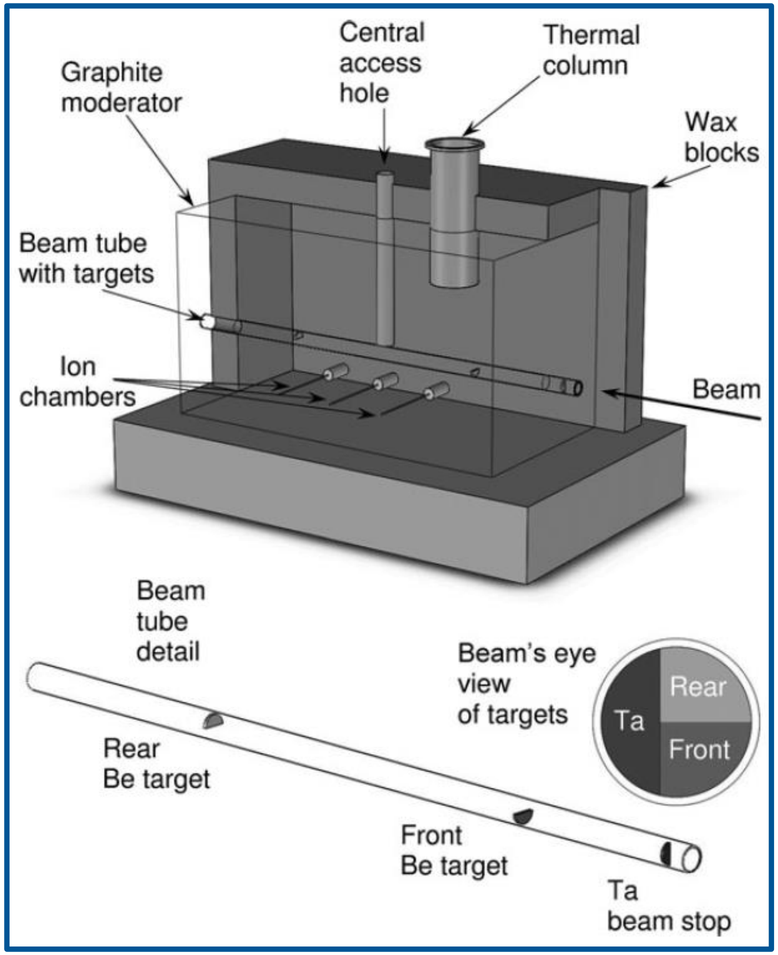


Neutron irradiation capabilities – Thermal Pile



Thermal neutron standards

- **Thermal neutron fluence standards: ~10^7 cm^{-2} s^{-1} in a 12 cm diameter hole.**
- **~10^4 cm^{-2} s^{-1} over an area of about 30 cm diameter in the column**



Can irradiate U targets for standardised noble gaseous radioactive (Kr, Xe) sources

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Journal of Environmental Radioactivity

journal homepage: www.elsevier.com/locate/jenvrad

Production and measurement of fission product noble gases

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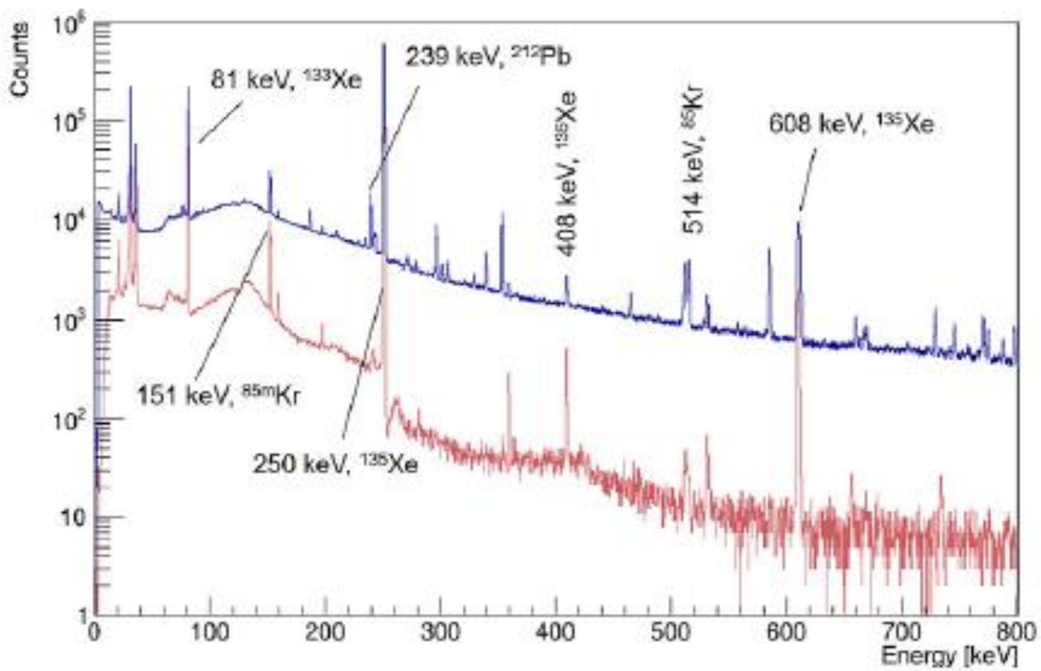

Table 3

Nuclide identification from a peak search of the γ-ray spectrum from Extraction 1 using the full acquisition (t = 170,731 s).† X-rays from Xe/Cs minus Ge fluoresence (escape peak). The relative γ-ray intensity is the full energy peak integral divided by the simulated γ-ray detection efficiency, decay-corrected to the start of the acquisition relative to the 250 keV ^{135}Xe peak (see Eq. (1)).

Fitted Energy (keV)	Parent Nucleus	Signature Type	γ-ray emission probability (%)	Rel. γ-ray Intensity (RGI) ($\times$ 1000)	Comment
20.4	Xe/Cs†	e^--X	–	–	Multiplet
30.7	Xe/Cs X K_α	e^--X	–	–	Multiplet
35.3	Xe/Cs X K_β	e^--X	–	–	Multiplet
80.9	^{133}Xe	$\beta-\gamma$	37.3(4)	47.4(7.1)	81.0 + 79.6 keV
122.8	^{88}Kr	$\beta-\gamma$	0.20(1)	0.807(12)	
129.1	^{85m}Kr	$\beta-\gamma$	0.30(8)	4.73(71)	
151.4	^{85m}Kr	$\beta-\gamma$	75.2(8)	38.1(5.7)	
158.6	^{135}Xe	$\beta-\gamma$	0.29(1)	2.40(36)	
196.6	^{88}Kr	$\beta-\gamma$	26(1)	4.42(67)	
233.4	^{133m}Xe	γ	10.1(2)	0.65(98)	
240.6	^{88}Kr	$\beta-\gamma$	0.25(1)	0.78(12)	
250.2	^{135}Xe	$\beta-\gamma$	90.0(3)	1000(7)	
305.1	^{85m}Kr	$\beta-\gamma$	14.0(4)	5.32(80)	^{85m}Kr > ^{85}Kr
358.5	^{135}Xe	$\beta-\gamma$	0.22(1)	1.94(29)	
390.0	^{88}Kr	$\beta-\gamma$	0.64(5)	0.87(14)	
407.7	^{135}Xe	$\beta-\gamma$	0.36(2)	5.83(88)	
438.9	^{88}Rb	$\beta-\gamma$	0.015(4)	1.35(21)	
451.1	^{85m}Kr	$\beta-\gamma$	0.011(4)	0.88(14)	
454.4	^{135}Xe	$\beta-\gamma$	0.004(1)	0.55(9)	
514.3	^{85}Kr	γ	0.43(1)	4.76(72)	^{85}Kr > ^{85}Rb
526.4	^{135m}Xe	γ	80.6(6)	35.5(5.4)	
530.3	^{133}I	$\beta-\gamma$	87(2)	2.81(42)	
608.3	^{135}Xe	$\beta-\gamma$	2.9(1)	81.4(1.2)	^{214}Bi Interference
731.9	^{135}Xe	$\beta-\gamma$	0.055(4)	0.39(6)	
834.9	^{88}Kr	$\beta-\gamma$	13(2)	6.75(10)	
898.2	^{88}Rb	$\beta-\gamma$	14.4(2)	1.73(27)	
1836.5	^{88}Rb	$\beta-\gamma$	22.8(1)	5.07(78)	

(n,f) Cross-section measurements

- ^{235}U(n,f), ^{238}U(n,f), ^{237}Np(n,f), ^{242}Pu(n,f)
- Monoenergetic neutrons: E_n = 0.565 up to 2.4 MeV
- Fluence measurement → NPL long counter
- Fission detector → TFGIC
- 2 measurements: absolute and relative

EPJ Web of Conferences **211**, 03009 (2019) https://doi.org/10.1051/epjconf/201921103009
WONDER-2018

Absolute cross section measurements of ^{238}U(n,f) and ^{237}Np(n,f) in the neutron energy range 1-2.4 MeV

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PHYSICAL REVIEW C **95**, 024606 (2017)

Absolute cross section measurements of neutron-induced fission of ^{242}Pu from 1 to 2.5 MeV

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The absolute neutron-induced fission cross section of ^{242}Pu was measured at five energies between 1 and 2.5 MeV at the low-scatter neutron measurement facility of the National Physical Laboratory, UK. The measurements are part of an effort to reduce uncertainties of nuclear data related to fast spectrum reactors. The neutron-induced fission results are in good agreement with the Evaluated Nuclear Data File/B-VII.1 but disagree with several recent measurements near the resonance-like structure around 1.1 MeV. Within the same experimental campaign, the spontaneous fission half-life of ^{242}Pu was measured and it is in good agreement with previous results.

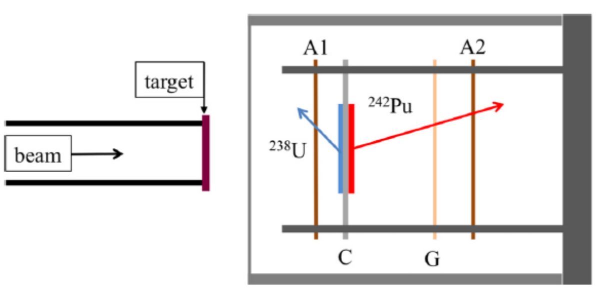

FIG. 1. Schematic drawing of the ionization chamber, beam line, and neutron producing target. The cathode (C), the grid (G), and the two anodes (A1, A2) are shown inside the chamber.

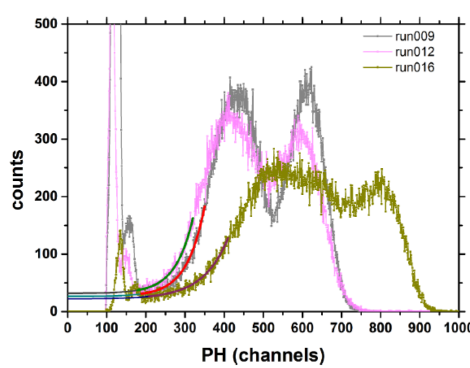

FIG. 2. Anode spectra from several ^{242}Pu spontaneous fission runs. Alpha particles are visible below channel 200. Exponential fits on the low-energy side of the spectrum are displayed with solid lines.

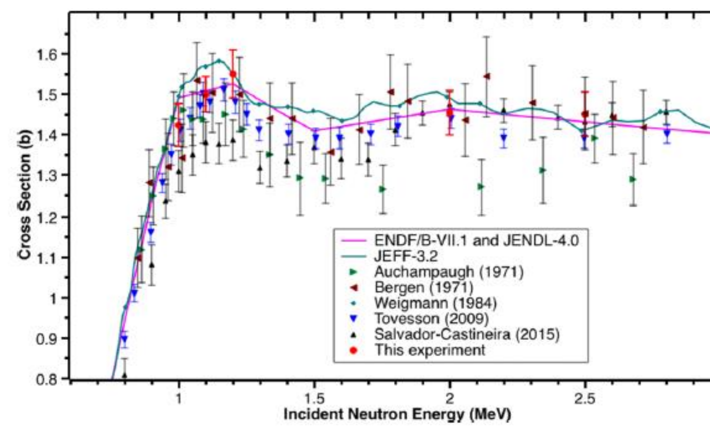

FIG. 3. Overview of the experimental data and evaluated nuclear data for the neutron-induced fission cross section of ^{242}Pu. JEFF-3.2 evaluation follows the data of Weigmann *et al.*

Other ‘beams’ at NPL – ICP-MS Analysis for Radioactive species

NPL
National Physical Laboratory

- Dr. Ben Russell (SRS) – ICP-MS leader at NPL et al.,
- Atom counting and isotope ratios for radioactive species.
- Research includes
  - (a) Isotope analysis of long-lived radioisotopes in nuclear fuel waste inc. minor actinides.
  - (b) Determination of radioactive lifetimes of very long-lived species (e.g. ^{231}Pa ; ^{238}U etc.)
  - (c) Atoms counting for standardisation of (pre-clinical) medical isotopes (e.g. ^{155}Tb)

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SCIENTIFIC REPORTS

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Chemical Purification of Terbium-155 from Pseudo-Isobaric Impurities in a Mass Separated Source Produced at CERN

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Ben Webster[1,2], Peter Ivanov[1], Ben Russell[1], Sean Collins[1], Thierry Stora[3], Joao Pedro Ramos[3,4], Ulli Köster[5], Andrew Paul Robinson[1,6,7] & David Read[1,2]

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Application of plasma mass spectrometry for half-life measurement of medium and long-lived radionuclides

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ICP-QQQ in the Nuclear Metrology Group

- Operating since September 2015
- Measurement of medium and long-lived radionuclides (>30 years) as a rapid alternative to decay counting techniques
- Expands number of radionuclides measurable compared to decay counting techniques alone
- Tandem mass spectrometry design and integrated reaction cell reduces or removes need for relatively time-consuming offline chemical separation
- 8 PhD students, 11 Masters Placement students
- > 30 publications

Applications

Application	Radionuclides currently measurable	Industry need
Actinides	^{231}Pa, ^{232}Th, ^{237}Np, ^{235}U, ^{236}U, ^{238}U, ^{239}Pu, ^{240}Pu, ^{241}Am, ^{243}Am	Fuel reprocessing, decommissioning, NORM
Medium-lived radionuclides	^{90}Sr, ^{151}Sm, ^{226}Ra, ^{63}Ni	Waste characterisation and decommissioning
Isotope ratios	$^{135}Cs/^{137}Cs$, $^{129}I/^{127}I$, $^{239}Pu/^{240}Pu$	Nuclear forensics
Long-lived, low abundance radionuclides	^{129}I, ^{93}Zr, ^{99}Tc	Decommissioning, long-term waste monitoring
Stable analogues of short-lived nuclides	Rare earth elements	Nuclear medicine- rapid development and validation of procedures
Material characterisation	Various (recent examples ^{226}Ra and ^{99}Tc)	Reference material characterisation, separation materials e.g. resins, graphene. nanomaterials
Radionuclide standards	Nuclides with half-life >30 years	High purity mass spectrometry standards for validation

Summary

- NPL van der Graaff facility provides traceable neutron fluxes in the energy regimes from ~ keV up to ~20 MeV.
- Can be used for research / measurements into e.g. (n,f) cross-sections on actinide targets etc.
- Provides neutron beam for graphite moderated thermal pile.

- Other 'beam' studies at NPL using ICP-MS (QQQ) for Radioactive Isotope atom counting.
- External research in collaboration with UK nuclear structure physics community includes
  a) ^{238}U(n,f) spin distributions in fission (LICORNE, France)
  b) RIB nuclear data studies at e.g. CERN-ISOLDE; GSI-FAIR (Germany); RIBF-RIKEN (Japan).