UK Nuclear Physics Update (2022)

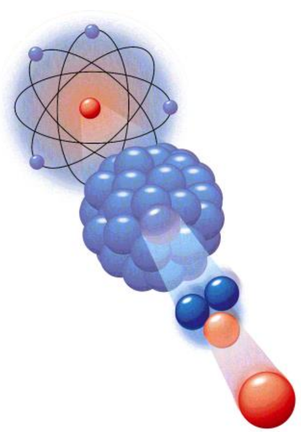
- **UK Nuclear Physics Science include:**
  - Nuclear Structure and Nuclear Astrophysics
  - Hadronic Physics
  - Nuclear Theory
- **(Industrial) UK Nuclear Data Network**
- **NUclear SECurity Network ; Early Diagnosis Network.**
- **Public Engagement & Outreach**
- **Applications and Innovation**

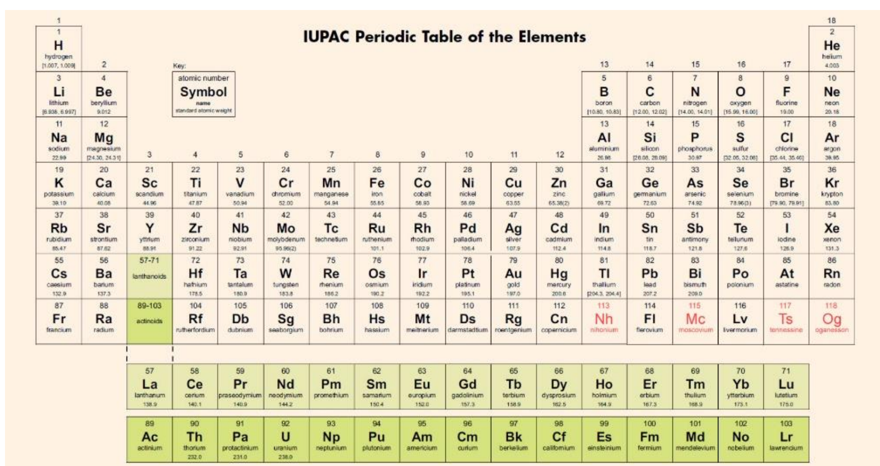
Core UKRI funding comes via STFC (tensioned vs Particle Physics and Astronomy).

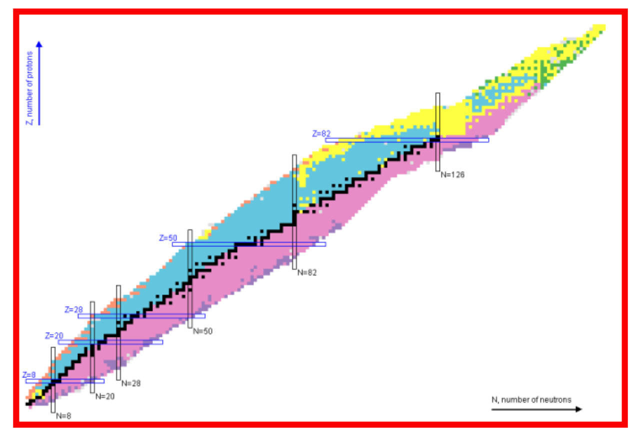
Paddy Regan: p.regan@surrey.ac.uk

Some ‘Big’ Physics Questions?

1) What are the fundamental building block of matter ?
2) How can you see ‘inside’ an atomic nucleus / nucleons?
3) Where & when were the stable elements formed?
4) How do we measure very long / short radioactive decays?
5) What are some of the applications of nuclear science?







Size of the UK community

- There are ~70 academics / faculty staff @ 11 institutions carrying out nuclear physics research
  - Includes recent appointments via ERF, UKFLF, RS Fellows.
  - Almost all are University-based researchers
- 90 PhD Research students across the community
  - ~ 50 funded by STFC quota plus a few iCASE etc.
- Nuclear Physics Advisory Panel (Chair R.Page Liverpool)

https://sites.google.com/view/stfccancerdiagnosis

STFC Cancer Diagnosis Network+

Welcome to the STFC Cancer Diagnosis Network+

The Science and Technology Facilities Council (STFC) Cancer Diagnosis Network+ (CDN) is a multidisciplinary community with academic, clinical and industry members aiming to collaboratively address clinical challenges in the diagnosis of cancer. The Network+ is built upon four themes:

1. Early diagnosis
2. Precision and quantitative imaging
3. Multimodal techniques
4. Data science techniques applied to imaging and bioinformatics

The CDN ultimately seeks to enable researchers with expertise and knowledge developed through the STFC core science programmes and at STFC national facilities and laboratories to address one of the most important societal and economic global challenges of this century. The CDN therefore hosts multidisciplinary challenge led workshops and provides funding for scoping studies, proof of concept projects and PhD studentships to translate STFC innovations into clinical impact. There are also opportunities for Early Career Researchers to apply for travel awards to attend conferences and events, placements and MSc level training in medical physics and bioinformatics.

Science and Technology Facilities Counci | UNIVERSITY OF LIVERPOOL | University of Glasgow | ICR The Institute of Cancer Research | Loughborough University

UK Academic Network in Nuclear Security and Non-proliferation Skills

The STFC Nuclear Security Science Network (NuSec)

- **Novel imaging techniques, including compact gamma & neutron imaging systems; cosmic ray muon imaging of large objects.**
- **Radiation detection, detector development, digital pulse processing; new materials for radiation detectors.**
- **Advanced detection methods for nuclear fuel cycle monitoring.**
- **Robotics and remote inspection technologies.**
- **Non-proliferation technologies.**

For further information, see: www.nusec.uk/

Consortium for Enabling Technologies & Innovation

NuSec Nuclear Security Science Network

UKRI Science and Technology Facilities Council

University of Surrey

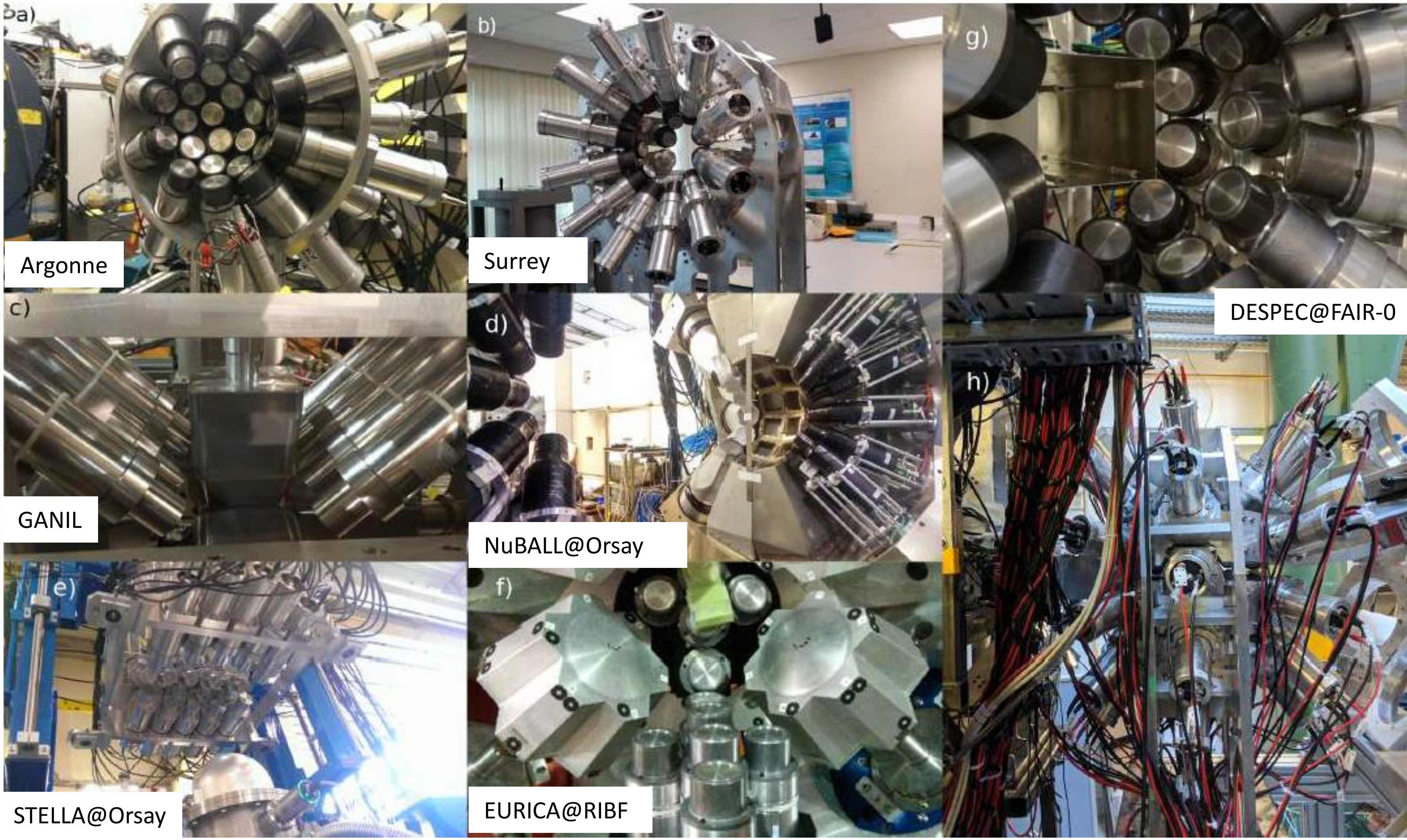
The Nuclear Physics Strategy document

- Scope and range of Physics
- Current projects
- Future projects
- Other issues
- 10 year horizon

- Last revision Oct 2019

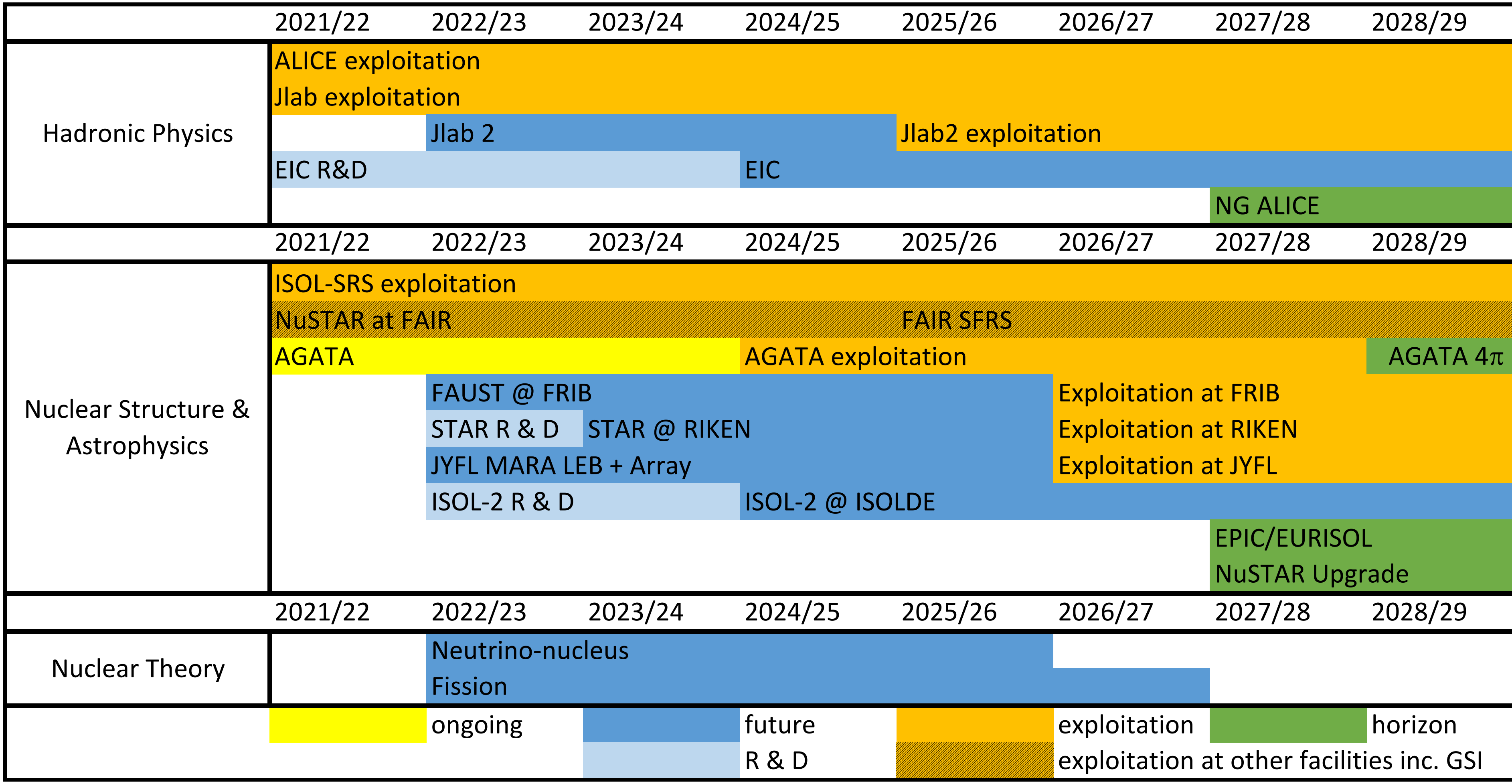
https://stfc.ukri.org/about-us/how-we-are-governed/advisory-boards-panels-committees/nuclear-physics-advisory-panel/

Design build and commission precision instrumentaton (e.g. AGATA; J-LAB; ALICE at CERN; NuSTAR at FAIR….) and used them for UK 'buy in' at labs around the world…



M. Rudigier, Zs. Podolyák, P.H. Regan et al.
Nuclear Inst. and Methods in Physics Research, A 969 (2020) 163967

Roadmap for existing projects and future opportunities



Update needs Nuclear Physics Forum discussion

STFC Postgraduate 'Summer' School in Nuclear Physics 2022

Held at University of Sheffield (27th March – 3rd April 2022)

58 PhD student attendees, *all residential* (STFC-funded students, other students, international students and industry)

- Well received event following isolation during lockdowns
- First in-person talk for many students
- Intense programme of lectures, tutorials etc (see below)

Science and Technology Facilities Council

Institute of Physics

Organised by

Daniel Doherty – University of Surrey

Marina Petri – University of York

With thanks to

ORTEC | AMETEK

<u>Programme</u>

Nuclear Structure (Seweryniak, Crawford, Flanegan, Gezerlis)

Nuclear Astrophysics (Lotay, Kankeinan)

Reactions (Cortina, Diaz-Torres)

Hadron Physics (Hen, Bashkanov)

Applications (Harkness-Brennan, Watts)

Hands-on Tutorials - Nuclear Theory, Geant4, Data Analysis Techniques

Student Talk Sessions

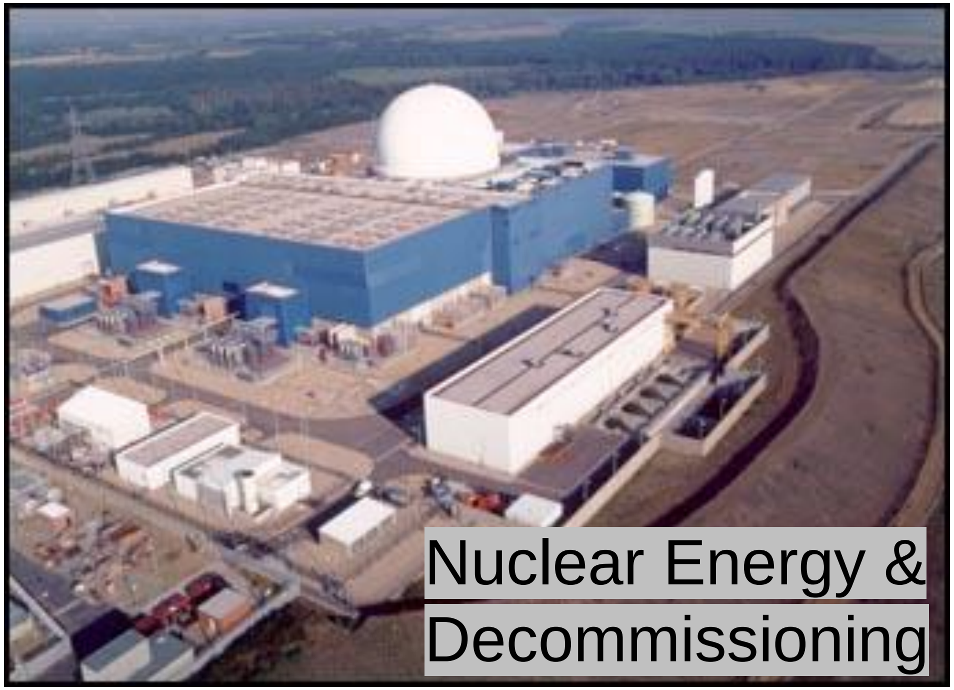
Public Engagement (Diget)

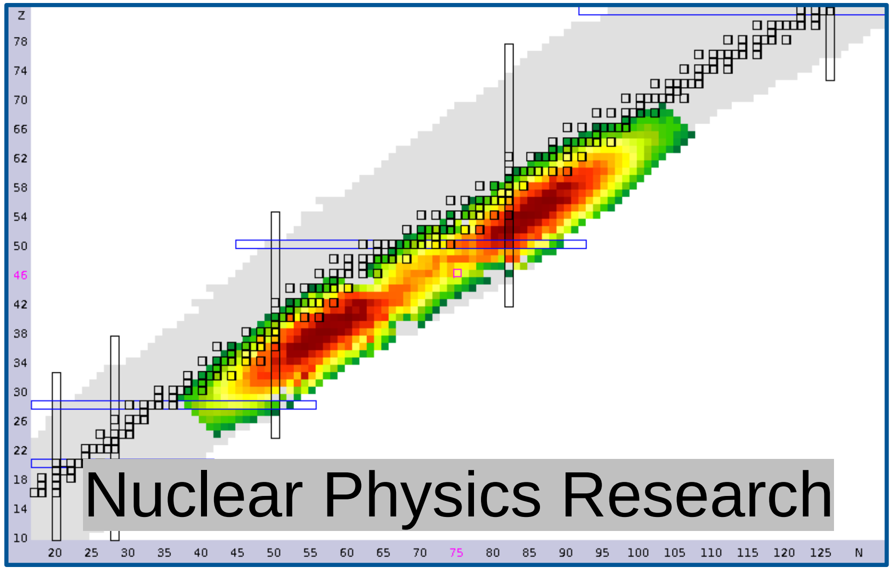
Career Session

Career's Panel

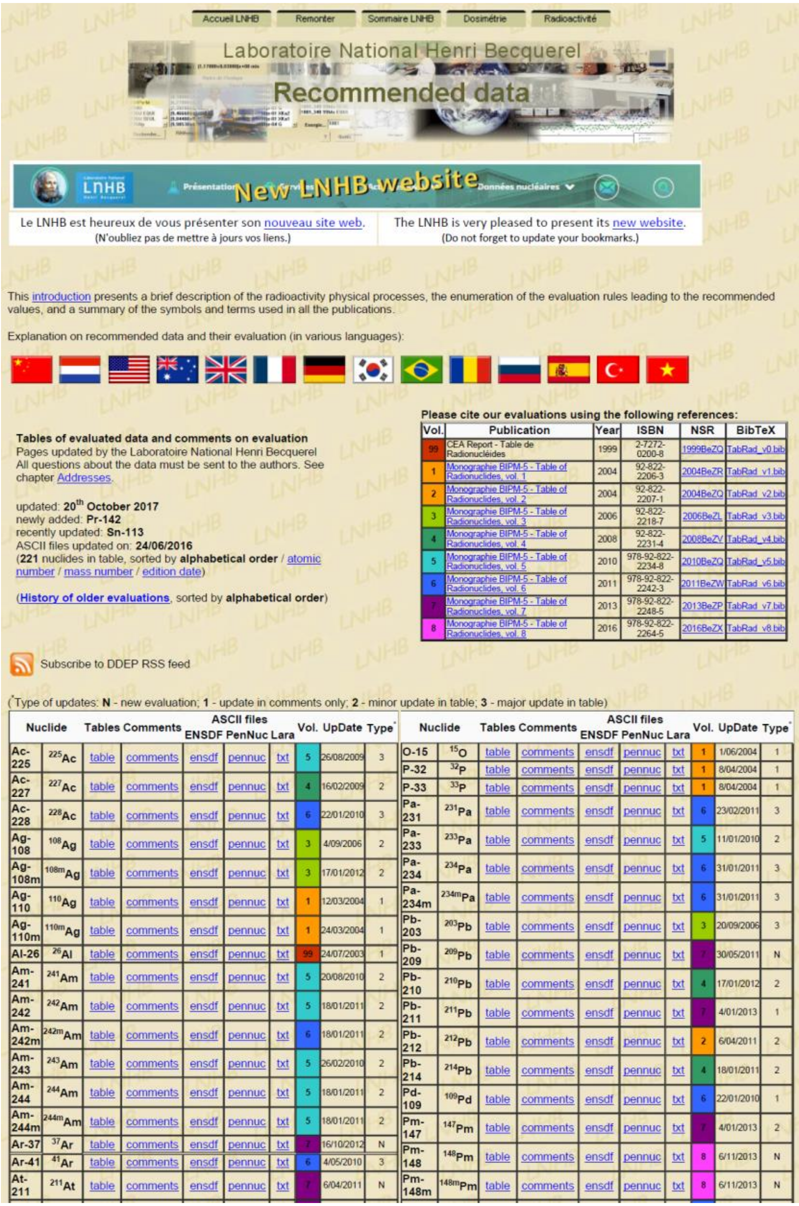
Organisers with Kayleigh Gates (Glasgow), winner of best 2nd year student talk

Impact from UK nuclear physics





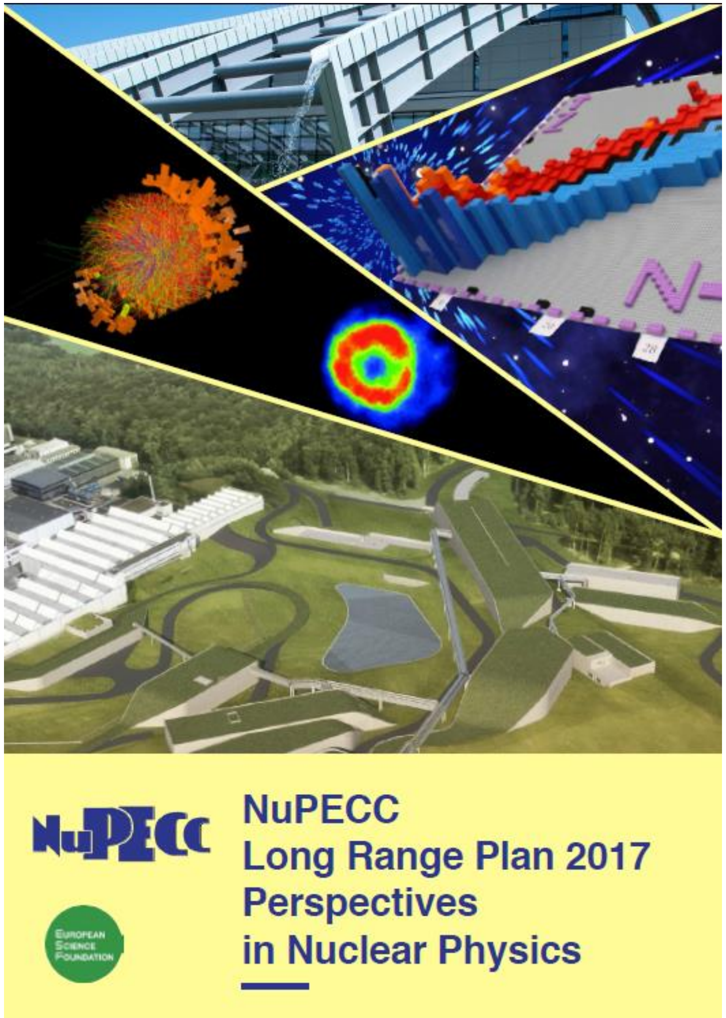
Evaluated nuclear (decay) data underpins many areas.



https://www.nndc.bnl.gov/nudat2/

http://www.nucleide.org/DDEP.htm

Most recent (2017) NuPECC Long Range plan.
Chapter 6. APPLICATIONS AND SOCIETAL BENEFITS



- Energy production: fission, fission.
- Health applications
  - therapy; imaging; radioisotope production; theranostics, etc.
- Radioprotection / health physics.
- Environmental radioactivity, space applications, climate science.
- Cultural Heritage science.
- Nuclear security; counter terrorism; Nuclear forensics.
- Materials science, nanotechnology.

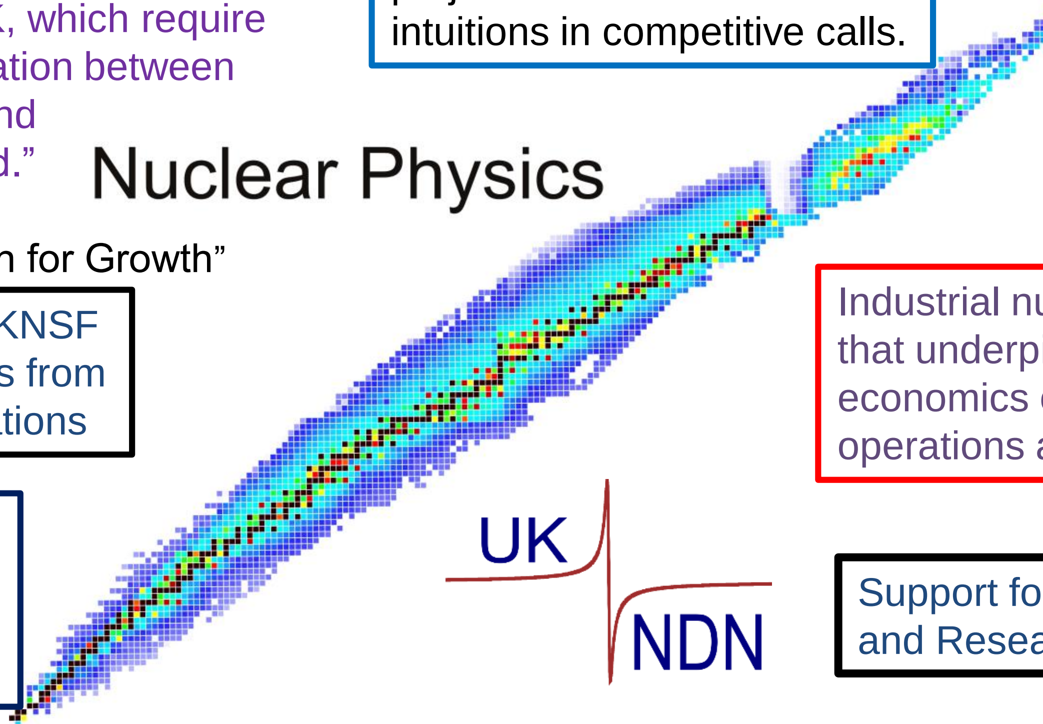
http://www.esf.org/fileadmin/user_upload/esf/Nupecc-LRP2017.pdf

UK Nuclear Data Network+ (UKNDN)

"The revitalisation of the nuclear power industry offers important economic opportunities for the UK, which require unprecedented cooperation between government, industry and academia to be realised."

Government's "Our Plan for Growth"

Funded 16 nuclear-data projects at 11 research intuitions in competitive calls.



UK Membership
n_TOF @CERN

Supports UKNSF
76 members from
36 organizations

Industrial nuclear data are those that underpin the safety and economics of industrial nuclear operations and processes.

Community Detectors:

- STEFF @ n_TOF
- $LaBr_3$ Array
- FIFI2

UK NDN

Support for PhD studentships and Research travel funding

NPL National Physical Laboratory · National Nuclear Laboratory · Manchester 1824 The University of Manchester · University of Surrey · University of York

Primary standard of radioactivity standard for ^{60}Co using γ-γ energy coincidences with NANA

Applied Radiation and Isotopes 134 (2018) 290–296

ELSEVIER

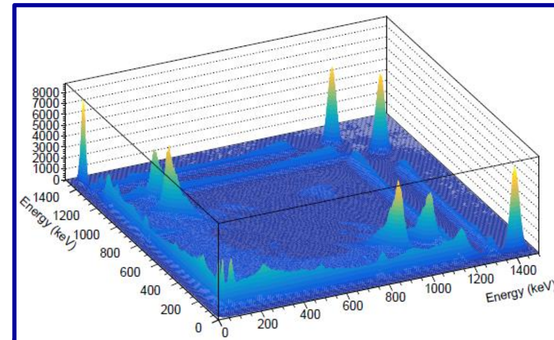
Applied Radiation and Isotopes

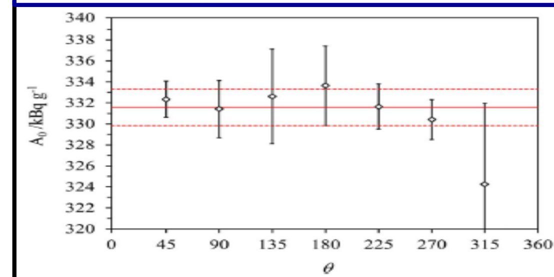
journal homepage: www.elsevier.com/locate/apradiso

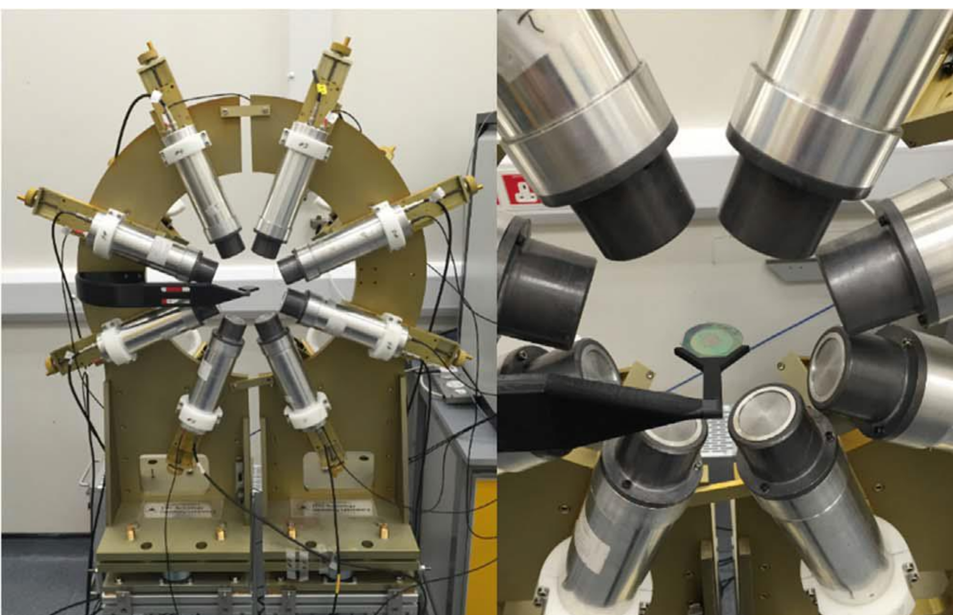
Investigation of γ-γ coincidence counting using the National Nuclear Array (NANA) as a primary standard

S.M. Collins[a,b,*], R. Shearman[a,b], J.D. Keightley[a], P.H. Regan[a,b]

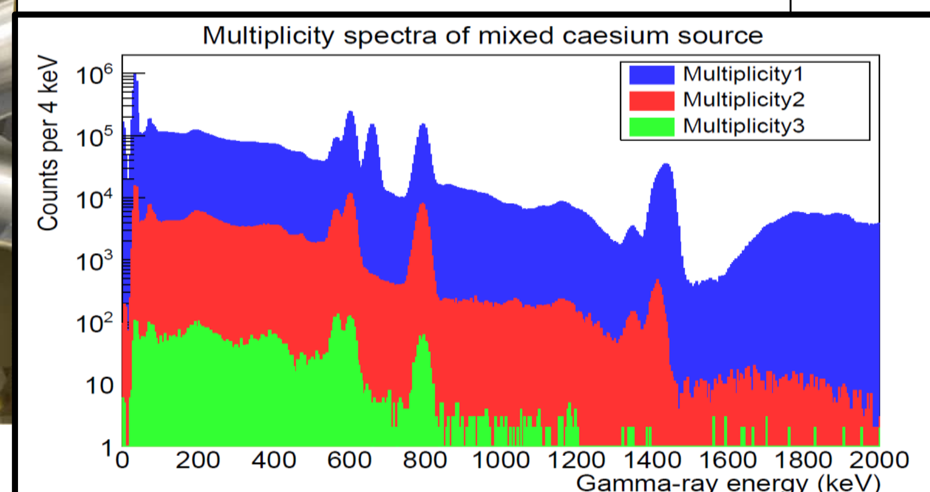
[a] National Physical Laboratory, Hampton Road, Teddington, Middlesex TW11 0LW, United Kingdom
[b] Department of Physics, University of Surrey, Guildford GU2 7XH, United Kingdom







Standardisation technique	A_0 /kBq g^{-1}	$u(A_0)$ /kBq g^{-1}
NANA γ-γ coincidence counting	330.8	± 1.0
4π(LS)- γ DCC	330.92	± 0.86



PHYSICAL REVIEW LETTERS **124**, 192701 (2020)

Advances in the Direct Study of Carbon Burning in Massive Stars

G. Fruet,[1,2] S. Courtin,[1,2,3,*] M. Heine,[1,2,†] D. G. Jenkins,[4] P. Adsley,[5] A. Brown,[4] R. Canavan,[6,7] W. N. Catford,[6] E. Charon,[8] D. Curien,[1,2] S. Della Negra,[5] J. Duprat,[9] F. Hammache,[5] J. Lesrel,[5] G. Lotay,[6] A. Meyer,[5] D. Montanari,[1,2,3] L. Morris,[4] M. Moukaddam,[6] J. Nippert,[1,2] Zs. Podolyák,[6] P. H. Regan,[6,7] I. Ribaud,[5] M. Richer,[1,2] M. Rudigier,[6] R. Shearman,[6,7] N. de Séréville,[5] and C. Stodel[10]

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[4]*University of York, York YO10 5DD, United Kingdom*
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[6]*Department of Physics, University of Surrey, Guildford GU2 7XH, United Kingdom*
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[8]*NIMBE, CEA, CNRS, Université Paris-Saclay, CEA Saclay F-91191 Gif sur Yvette, France*
[9]*Centre de Sciences Nucléaires et de Sciences de la Matière (CSNSM), Université Paris Sud, UMR 8609-CNRS/IN2P3, 91405 Orsay, France*
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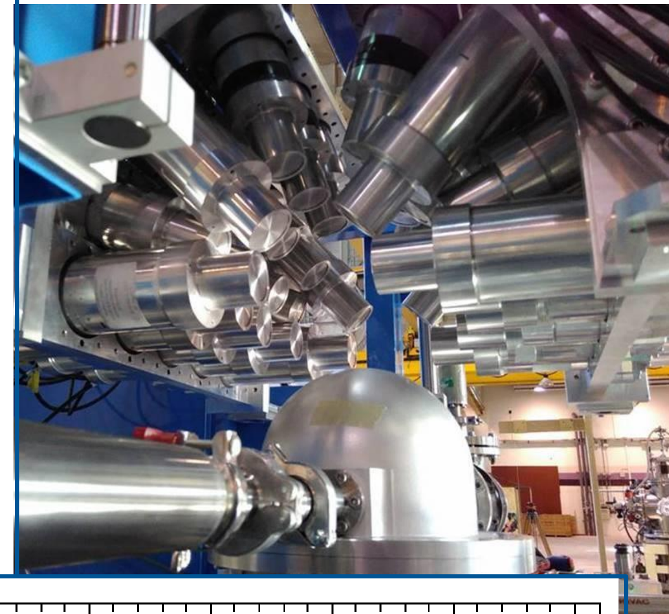
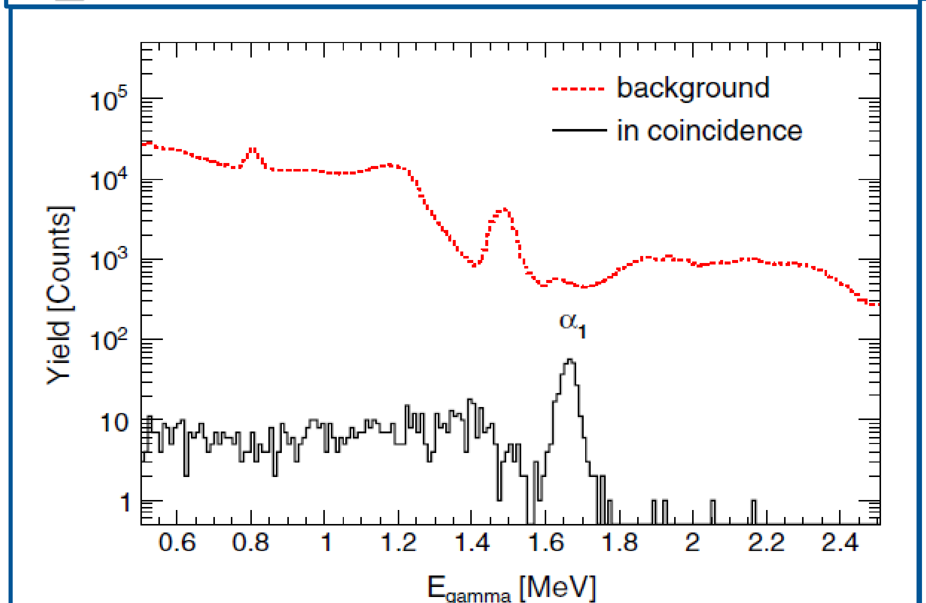
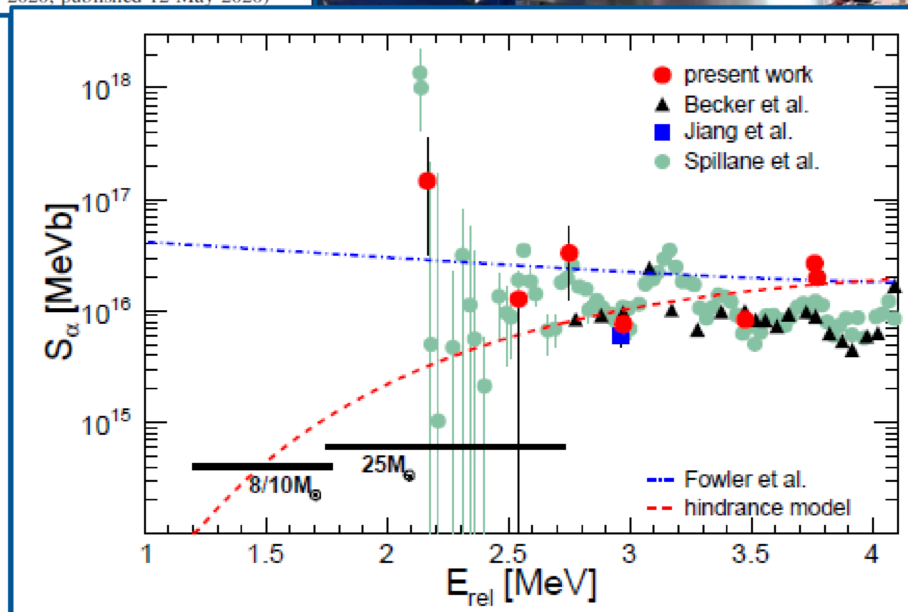
(Received 30 July 2019; revised manuscript received 27 September 2019; accepted 21 February 2020; published 12 May 2020)





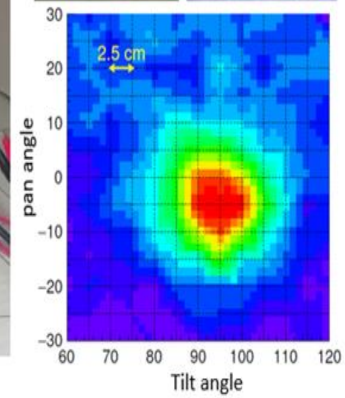


Understanding of the creation of Ne and Na in stellar burning. NANA detectors measure ^{12}C+^{12}C nuclear fusion probability.

Nuclear Data for Nuclear Power Generation.

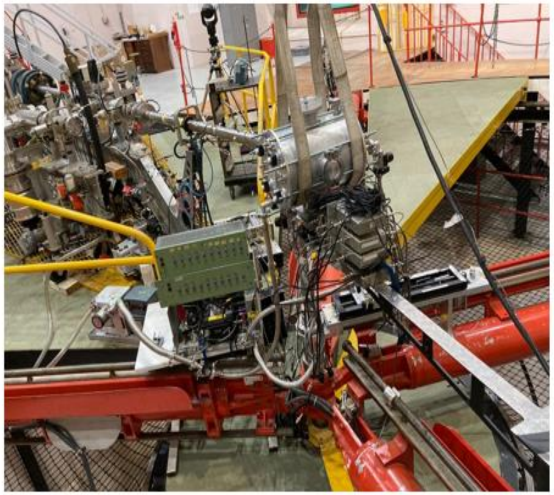
National Physical Laboratory

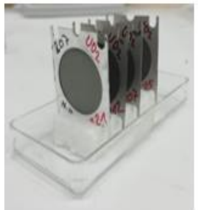
- Design and construction of detector setup for alpha emitters in **Sellafield** Special Nuclear Material stores.
- Work was carried out in B47, enabling use of strong neutron sources e.g. ^{252}Cf.
- Applications for safety, security and decommissioning.

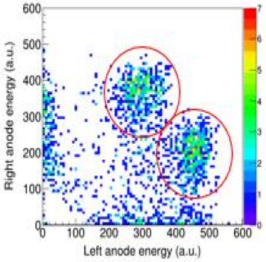


- Testing of novel ion chamber design with **U.Manchester** and **NNL**, along with investigation of ^{236}U cross sections.
- Support for **Advanced Fuel Cycle Programme**.

Giuseppe Lorusso & Michael Bunce







University of Manchester: STEFF @ n_TOF

Spectrometer for Exotic Fission Fragments: *A.G. Smith, T. Wright, N. Sosnin, S. Bennett, et al.*

Goal:

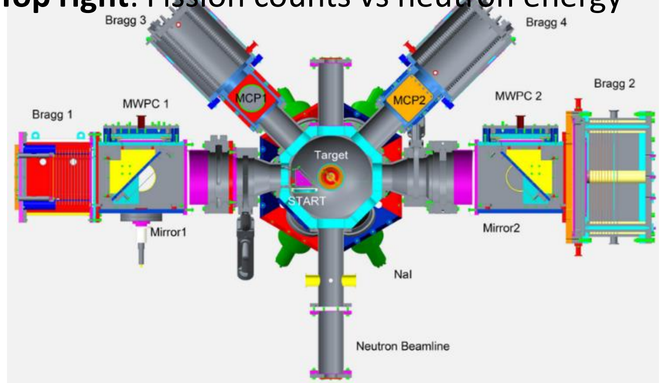
- Provide data for NEA HPRL entry on ^{235}U and ^{239}Pu Prompt Fission γ-Rays (average energies and multiplicities)

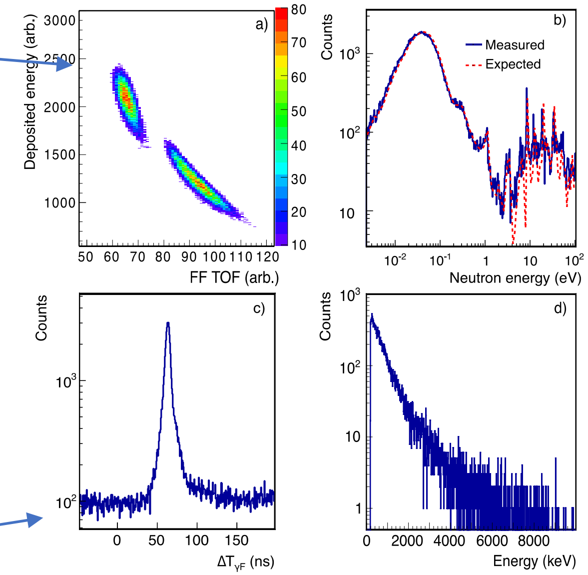
Realisation:

- Measure fission with *2E2v* device STEFF and corresponding γs with NaI and $LaBr_3$ detectors

Top left: Fission fragment time-of-flight vs energy

Top right: Fission counts vs neutron energy



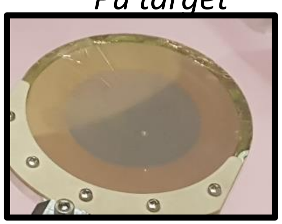


Bottom left: γ-ray counts vs fission time

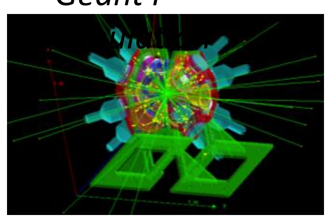
Top right: Fission γ-ray energy spectrum

^{235}U target

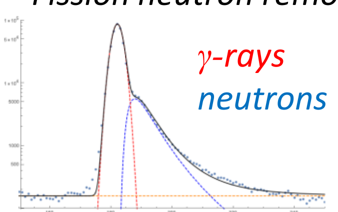
^{239}Pu target



Geant4



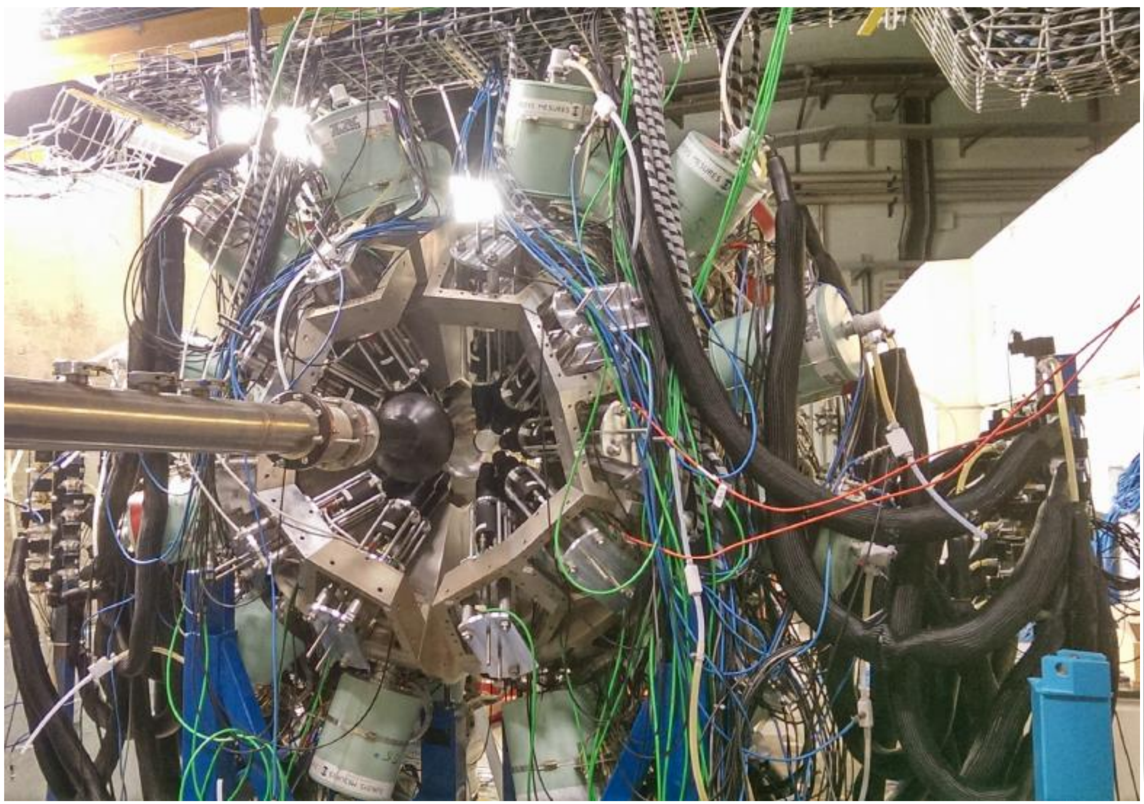
Fission neutron removal

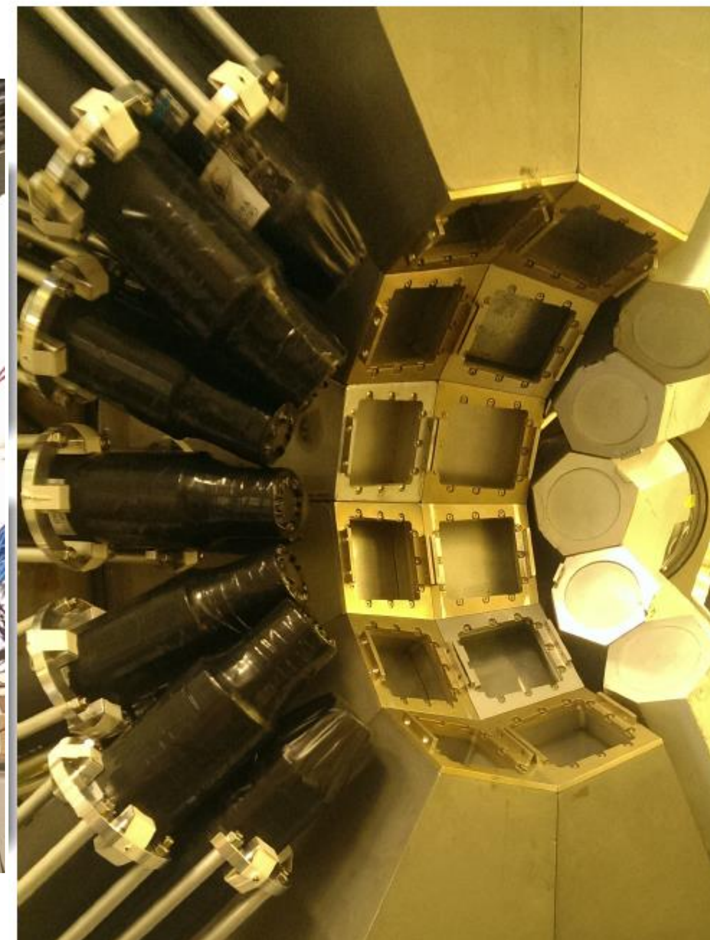


N. Colonna et al., "The fission experimental programme at the CERN n TOF facility: status and perspectives", *Eur. Phys. J. A (2020) 56: 48. DOI: http://dx.doi.org/10.1140/epja/s10050-020-00037-8*

ν-Ball at IPN-Orsay: 'Hybrid' HPGe –$LaBr_3$ combined array.

- **20 $LaBr_3$ detectors** with from FATIMA -time resolution ~250 ps
- **24 HPGe clover detectors** with BGO shielding for Compton Suppression
- **10 coaxial HPGe detectors** with BGO shielding
- **FASTER Digital DAQ;** 500 MHz sampling for the $LaBr_3$ detectors; 125 MHz sampling for the HPGe and BGO detectors
- Internal **pulse shape analysis**



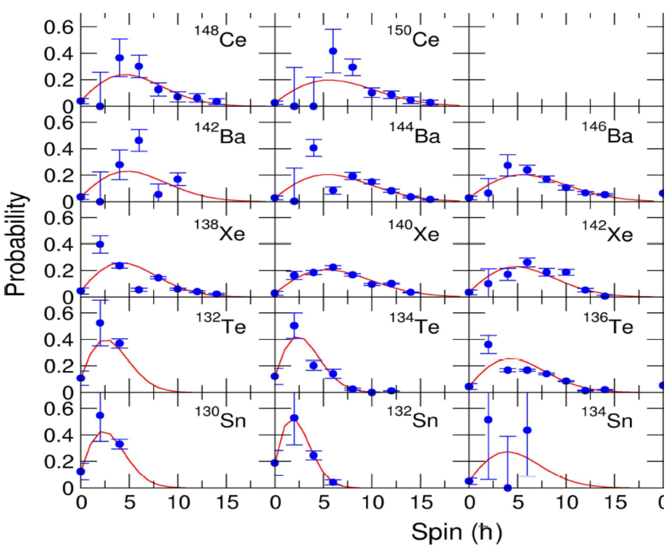


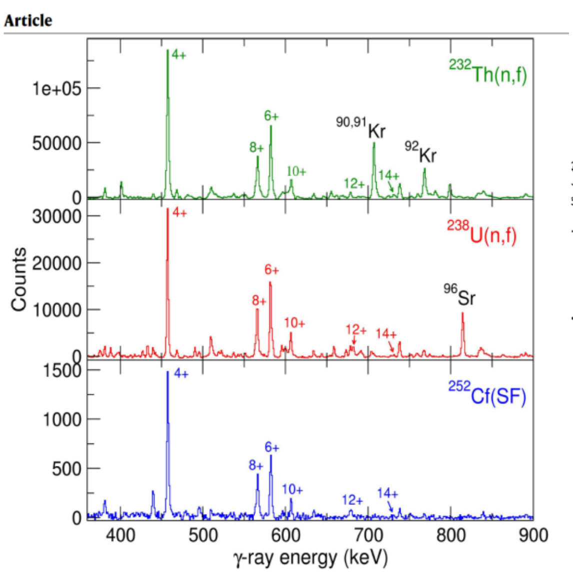
NuBall – Attacking an 80 year problem
The generation of angular momentum in nuclear fission

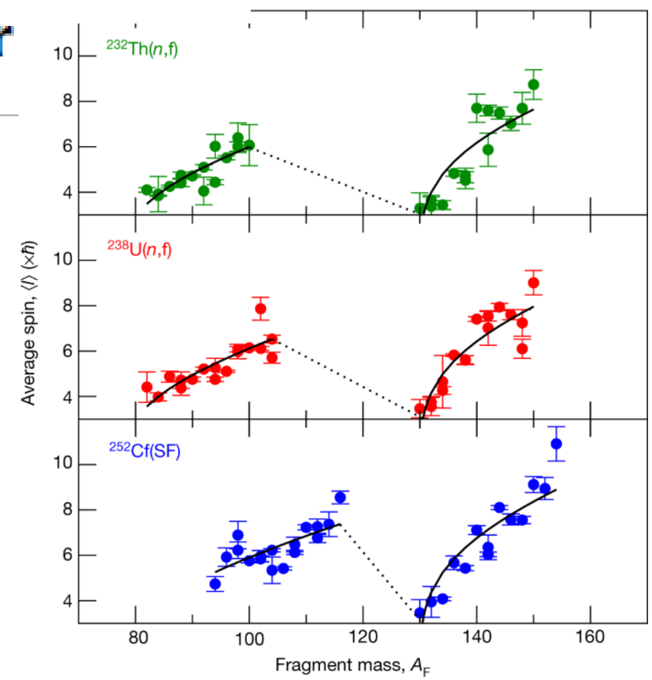
- Fast-neutron fission on Th and U targets.
- Measure the angular momentum of fragments.
- Precision high-resolution ID of the coincident gamma cascades.
- The angular momentum between fragment pairs NOT correlated!
- Huge challenge to understanding of the nuclear fission process.

Article 566 | Nature | Vol 590 | 25 February 2021

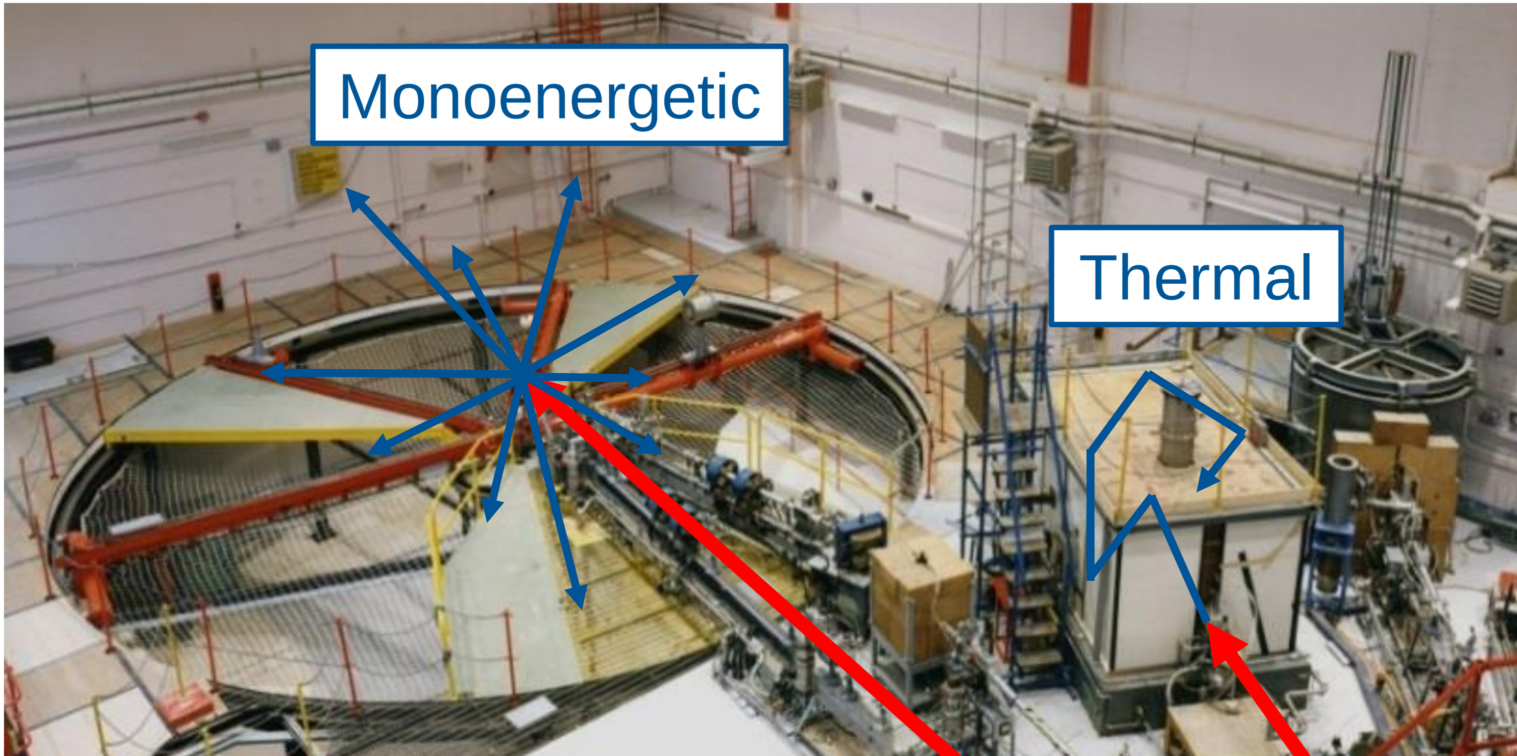
Angular momentum generation in nuclear fission







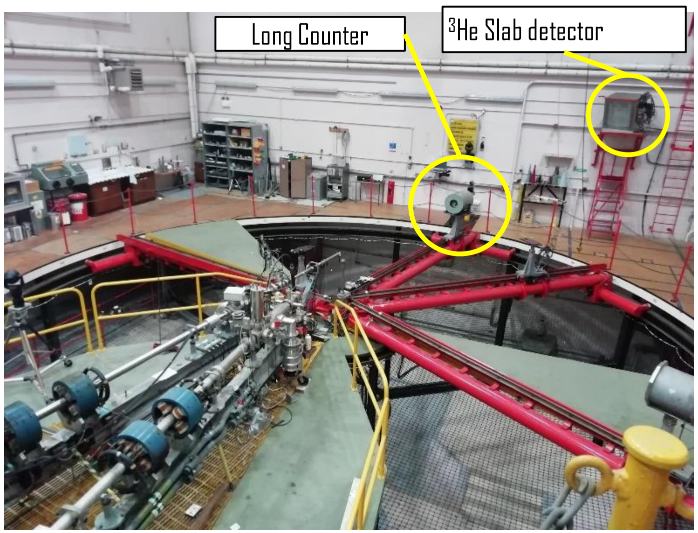
UK-based Neutron irradiation capabilities



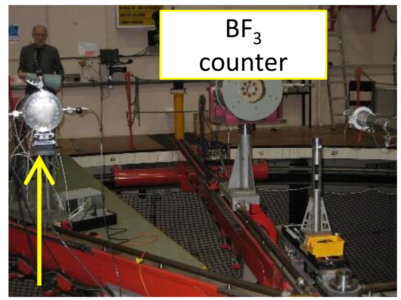
Beam Energy (MeV)*	Neutron Energy range (MeV)	Reaction	Max fluence at 1 m (cm^{-2} s^{-1})
2.905-2.945	0.001 → 0.05	$^{45}Sc(p,n)^{45}Ti$	~ 8
1.925-2.355	0.05 → 0.63	$^{7}Li(p,n)^{7}Be$	500 → 2000**
1.450-2.985	0.63 → 2.2	$T(p,n)^{3}He$	1200 → 2100**
0.880-2.740	4 → 6	$D(d,n)^{3}He$	~ 850
0.880-2.550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

Toward ^{237}Np(n,f) and ^{238}U(n,f) reference cross sections

- NPL Low scattering area 18m x 18m x 26m
- Well known neutron fluence (within 2%)

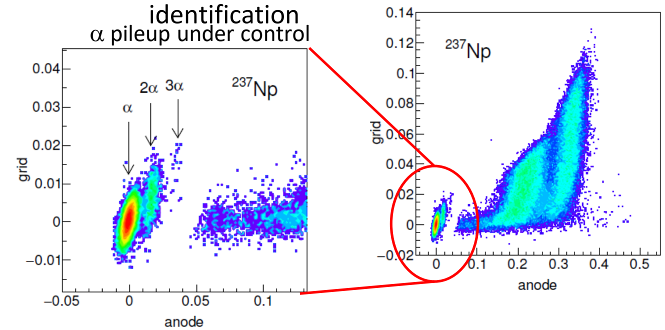


Neutron Flux measurement



TFGIC and targets from JRC (Geel)

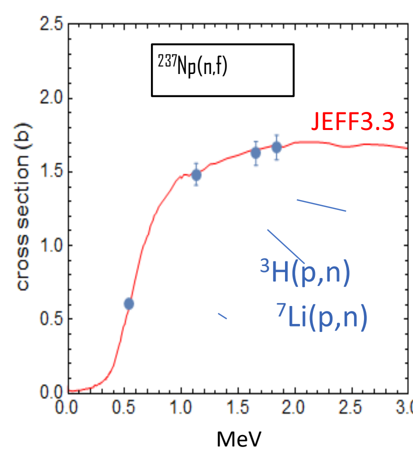
Fission events identification

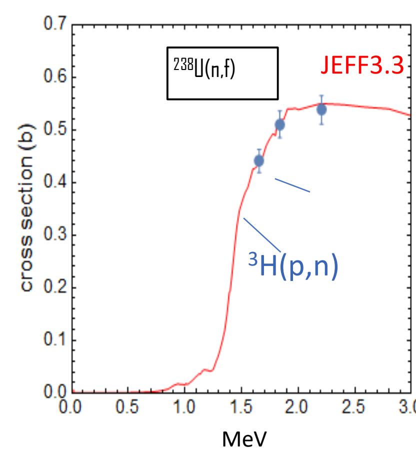


Results are promising, agree with current libraries, more work needed to:

- Improve reproducibility of the fission target position
- reduce error bars and more energies for ^{238}U → more neutrons needed (working on this with AFCP)

- 2/3 of the GEN-IV reactors are fast reactors
- Fast ^{237}Np(n,f) ^{238}U(n,f) are better reference cross section than ^{235}U(n,f)
- NPL absolute cross section will contribute the evaluation effort toward making ^{237}Np and ^{238}U standards





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

Journal of Environmental Radioactivity 238–239 (2021) 106733

ELSEVIER

Journal of Environmental Radioactivity

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

Production and measurement of fission product noble gases

Matthew A. Goodwin [a,b,*], Steven J. Bell [c], Richard Britton [d], Ashley V. Davies [a], Marc Abilama [c], Sean M. Collins [b,c], Robert Shearman [c], Patrick H. Regan [b,c]

[a] AWE Aldermaston, Reading, Berkshire, RG7 4PR, UK
[b] Department of Physics, University of Surrey, Guildford, GU2 7XH, UK
[c] National Physical Laboratory, Teddington, Middlesex, TW11 0LW, UK

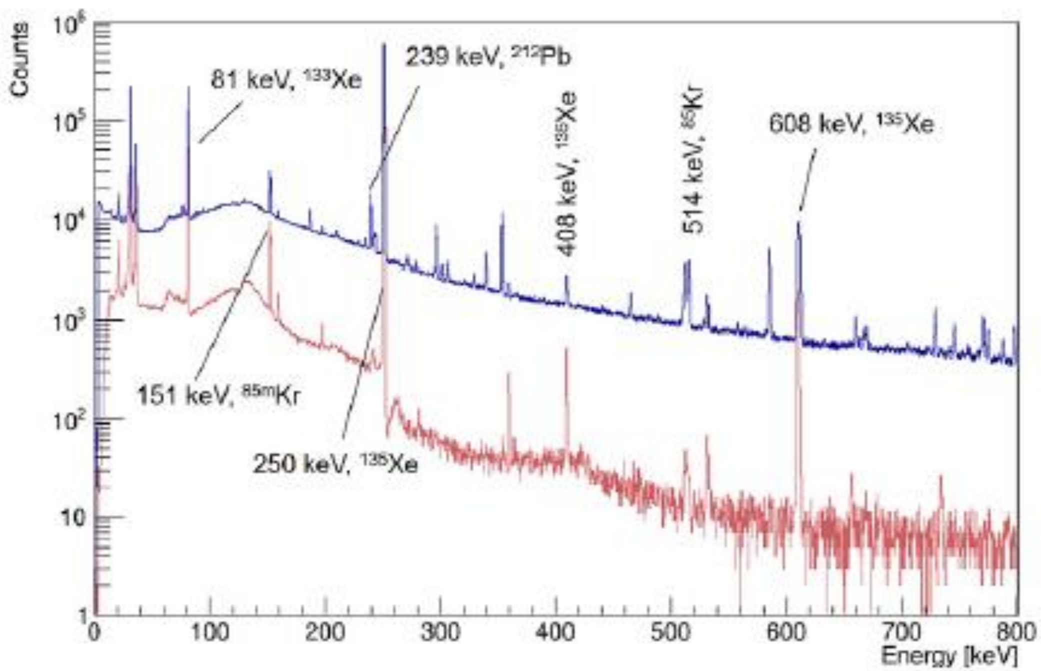


Table 3

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) (× 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)	

UK NP Radioactive Gas Metrology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Production and measurement of fission product noble gases

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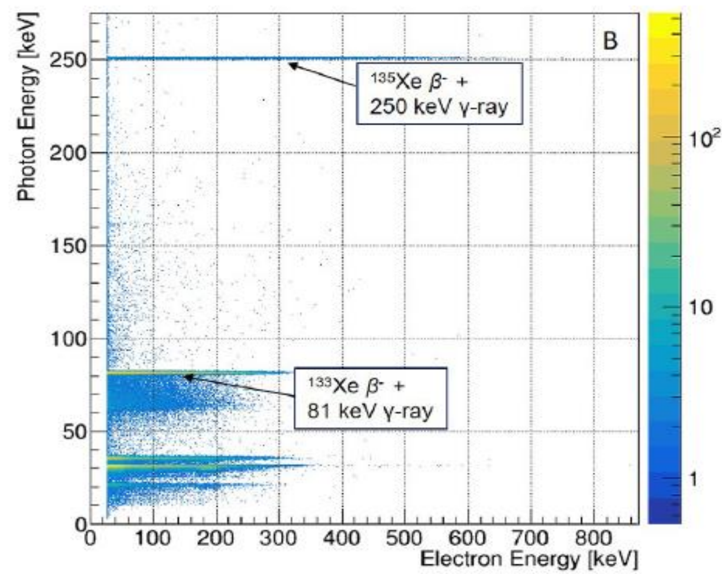
UK Nuclear expertise in

A) Neutron activation facility & source prep;

B) Gas metrology, transport and engineering;

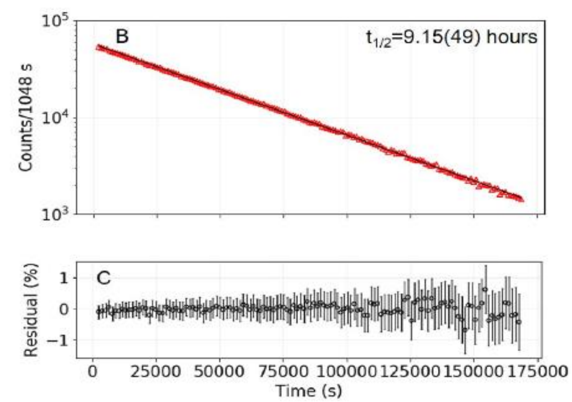
C) Gamma-ray and electron spectrometry;

D) Nuclear data analysis and interpretation.



Clear, direct impact in:

1) **Energy & Environment**: standardisations of **radioactive Krypton**. Real time signatures **for reactor criticality** .



2) **Security & Resilience:** New methodologies developed in collaboration with AWE & **CTBTO** for **radioactive Xenon** weapon signatures.

UK Nuclear Physics

Next community meeting ~Jan 2023