CLS Grid
Technical Considerations

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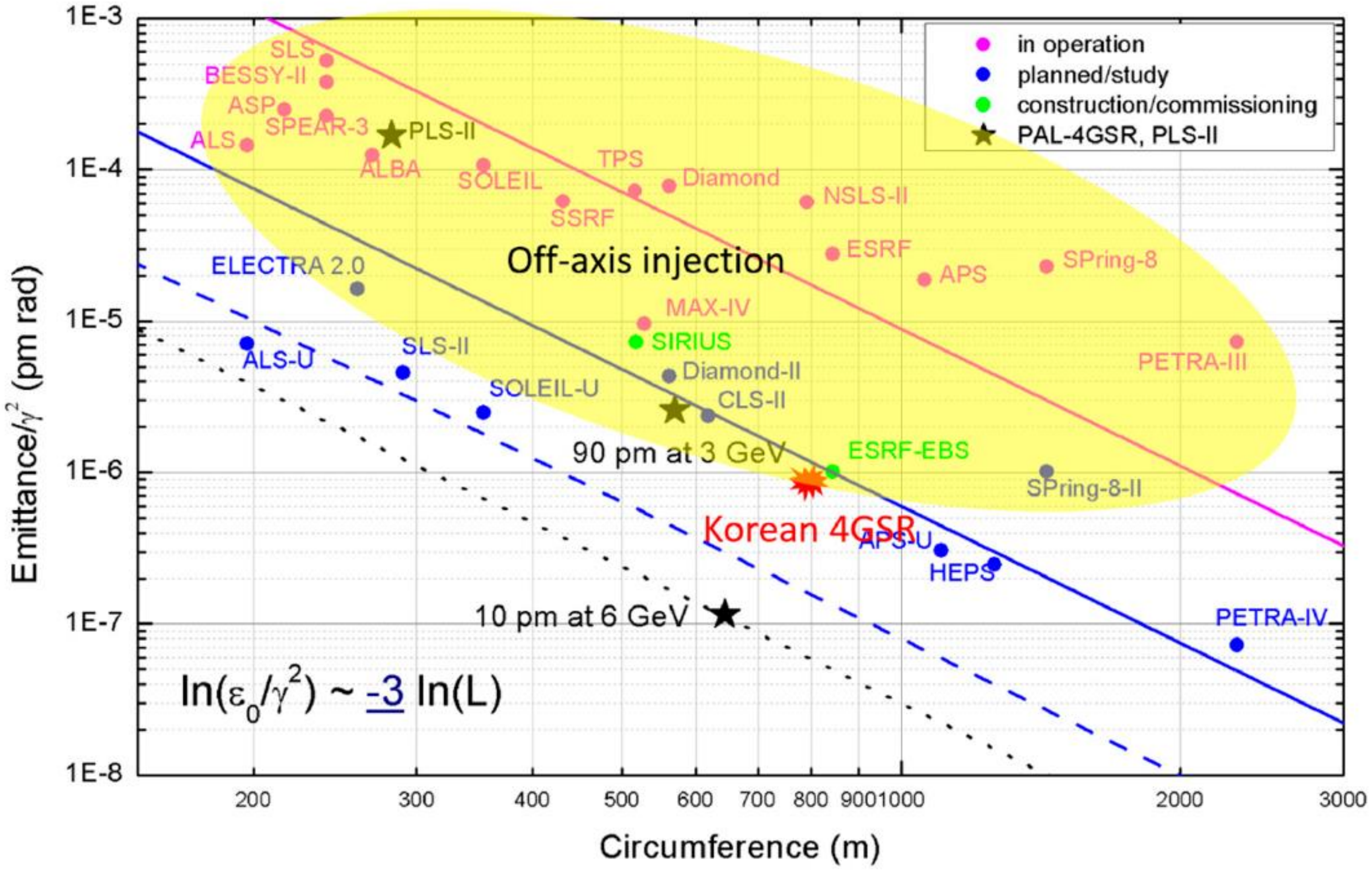
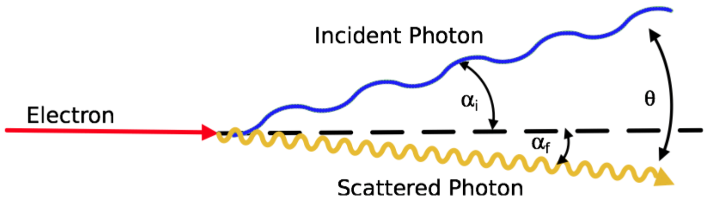
3rd and 4th Generation Synchrotrons

Science and Technology Facilities Council



Oh et al. https://doi.org/10.3390/app112411896

One Option for CLS-Grid



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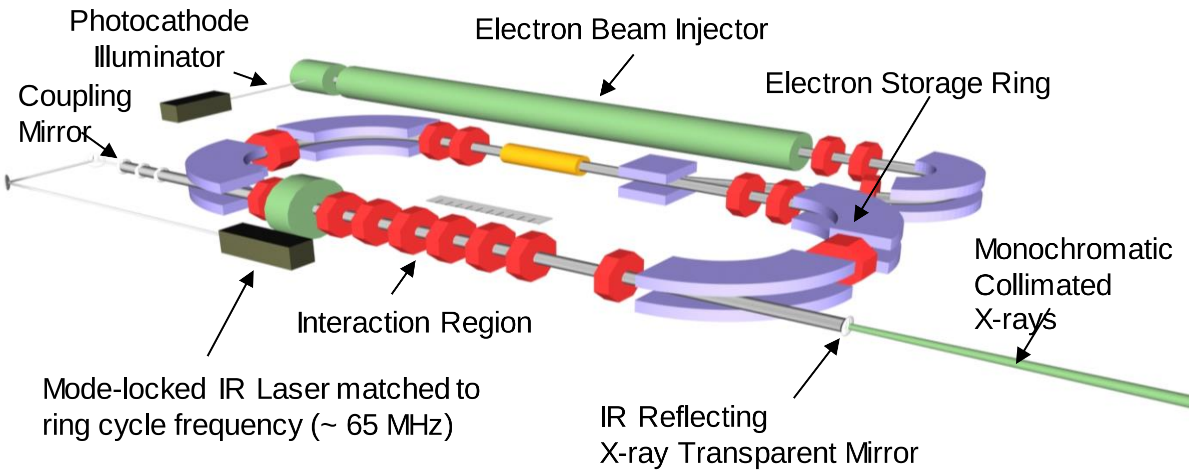
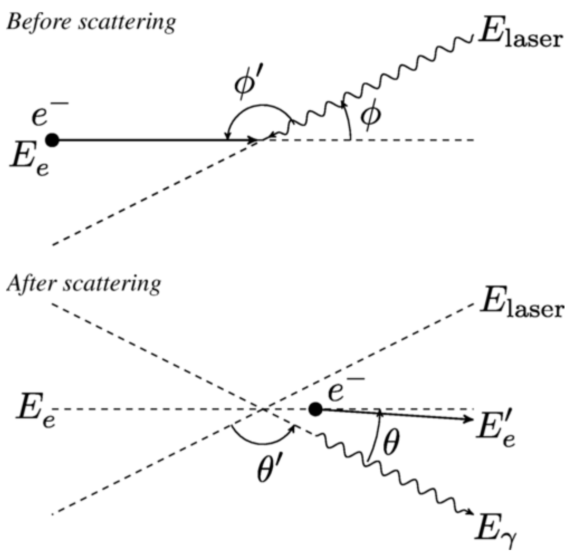


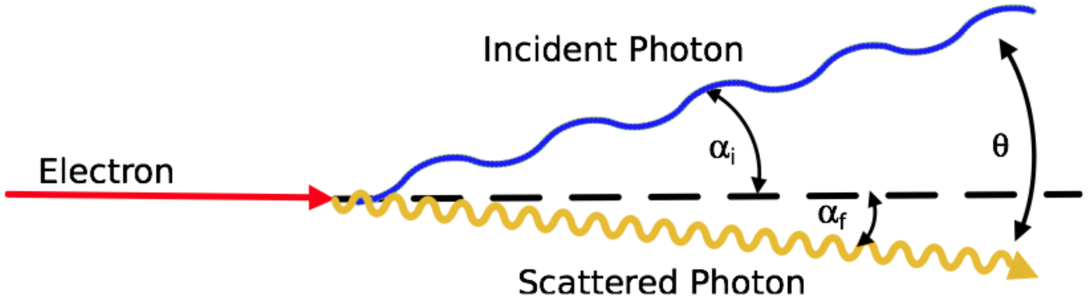
- CLS – commercially available since 2015 (Munich CLS)
- Recent developments extending the envelope of performance
- Hardware cost ~£10-15M for the source
- In the hard X-ray range (30-90keV or 60-180keV) competitive with synchrotron light

ICS	Electron Energy (MeV)	λ_{las} (μm)	Laser Energy (mJ)	X Energy (keV)	X Flux	Bandwidth	Rep. Rate (Hz)
CLS [8]	25–45	1	5	8–42	$5{\cdot}10^2$–$5{\cdot}10^3$	3%	$65{\cdot}10^6$
MUCLS [9]	25–45	1	5	8–42	$5{\cdot}10^2$–$5{\cdot}10^3$	3–5%	$65{\cdot}10^6$
ThomX [28]	50	1.03	1.4–$2.6{\cdot}10^{-3}$	45	10^5	10%	$65{\cdot}10^6$

Petrillo et al., https://doi.org/10.3390/app13020752

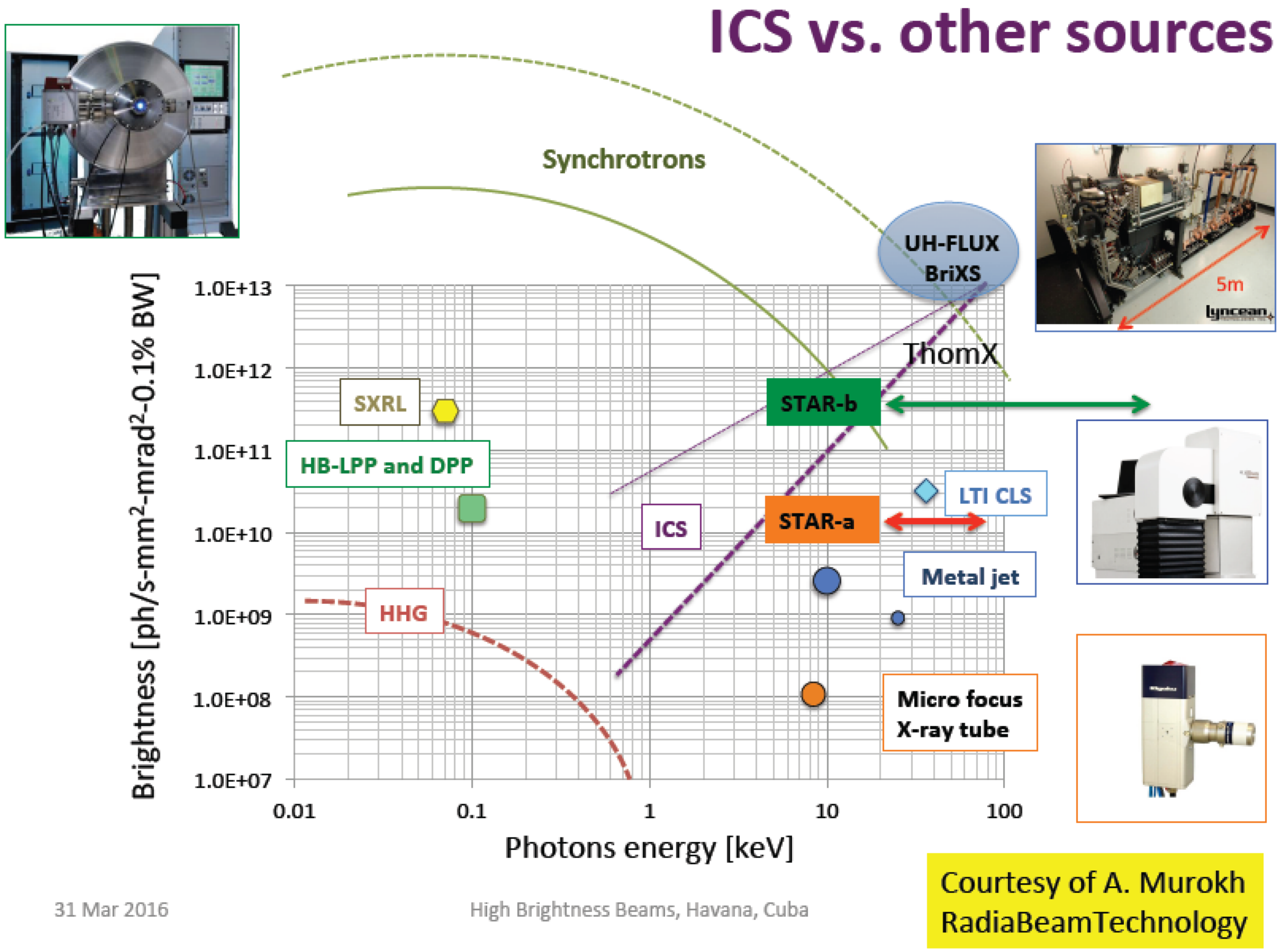
One Option for CLS-Grid

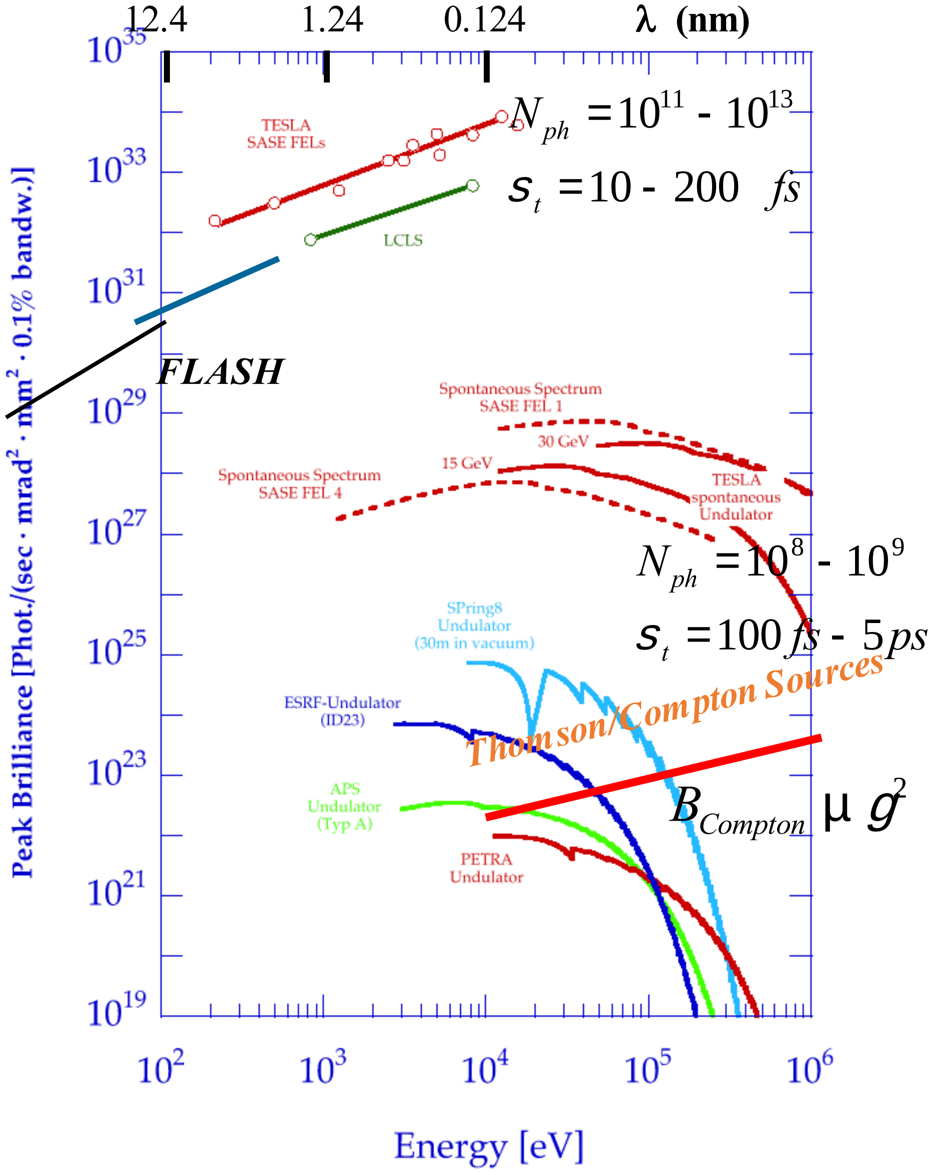




Deitrick et al., https://doi.org/10.1103/PhysRevAccelBeams.24.050701

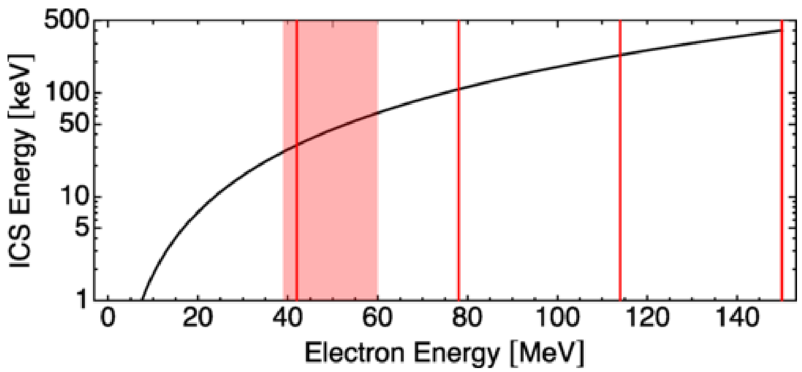
3rd and 4th Generation Synchrotrons

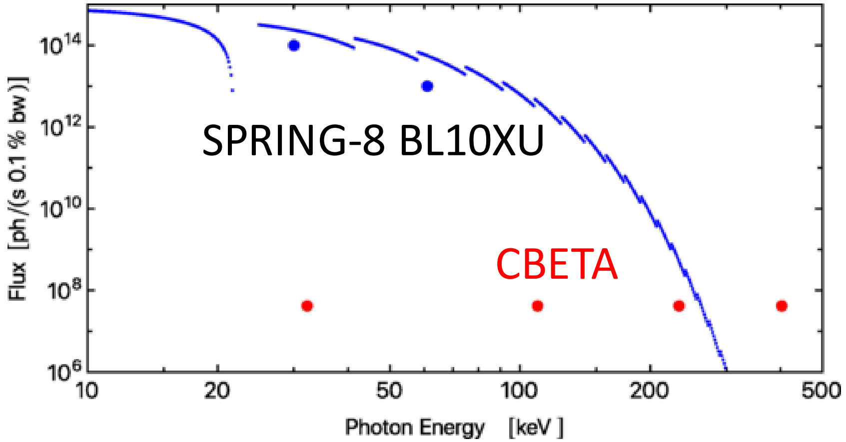


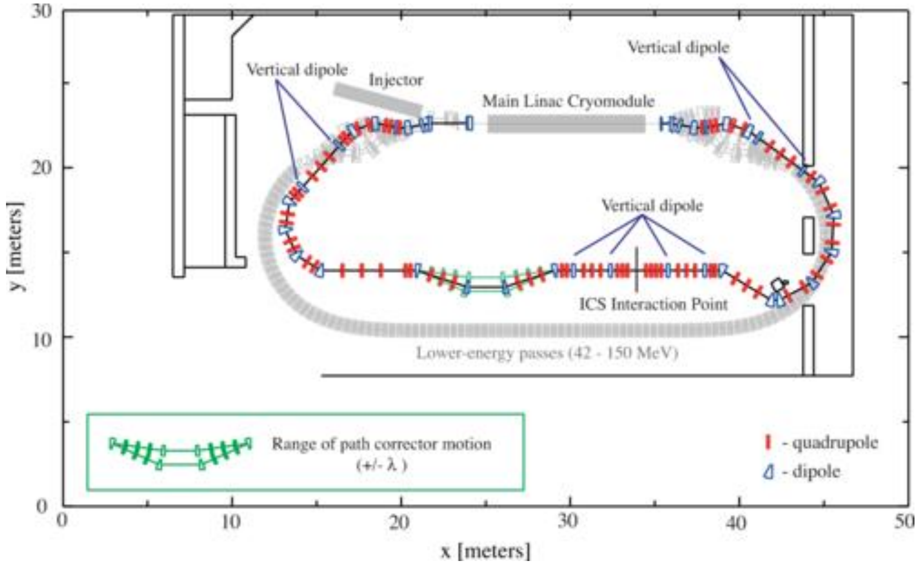


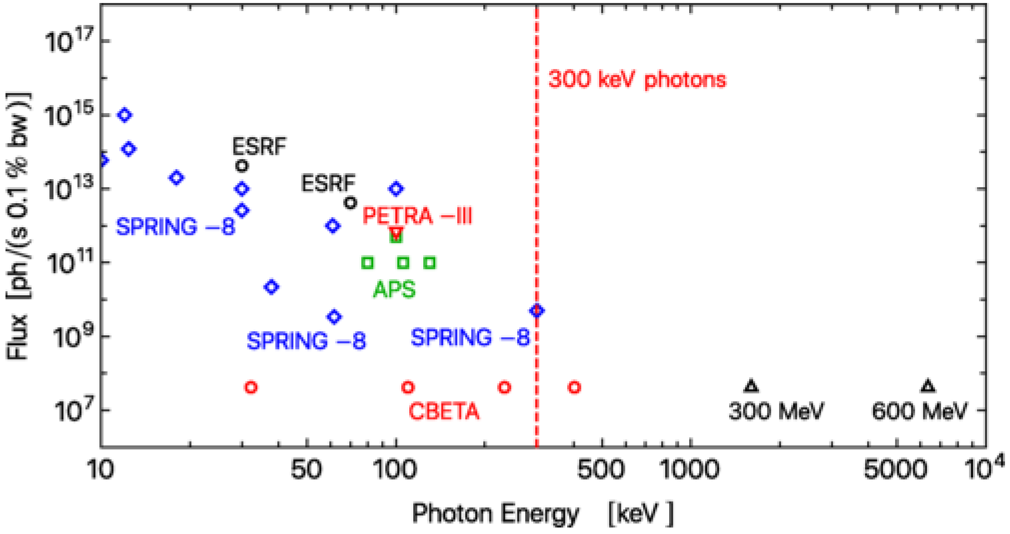
ICS @ CBETA

Aim: examine whether a CBETA ERL might be a competitive replacement for the Cornell CHESS synchrotron light source









doi:10.18429/JACoW-IPAC2019-TUPGW085
doi:10.18429/JACoW-IPAC2021-THPAB009
https://doi.org/10.1103/PhysRevAccelBeams.24.050701

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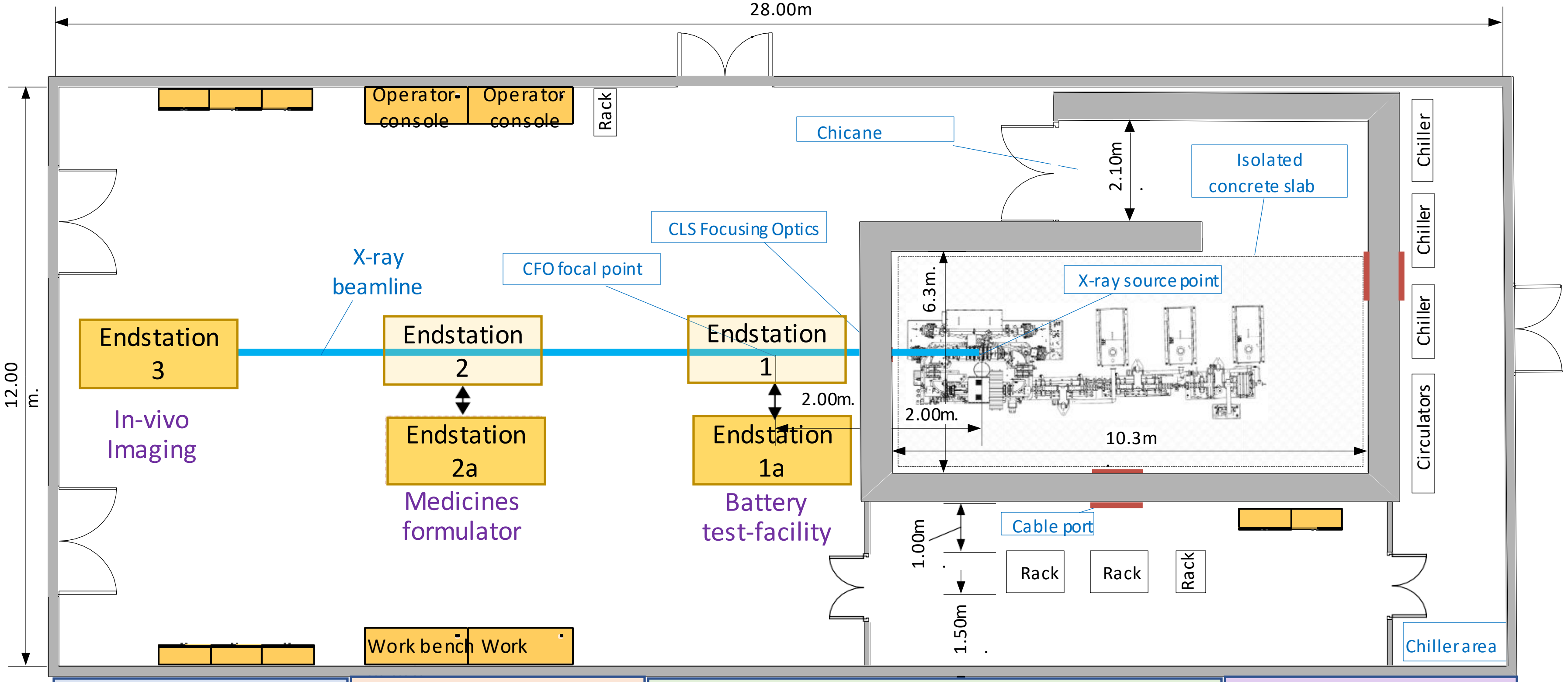
Compact light sources: what might a node look like?



Construction will use STFCs life cycle analysis of sustainable construction, operation and decommissioning

(Design based on existing facilities)

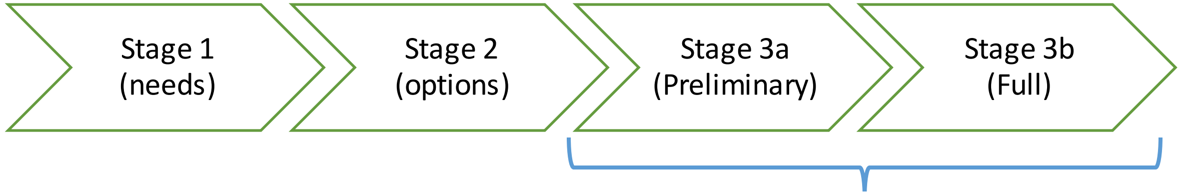
Battery assembly suite	Electron microscopy/ spectroscopy	Materials for Net Zero engineering test facility	In-vivo/Ex-vivo bio-facility

Training centre	Medicines formulation small-scale production plant

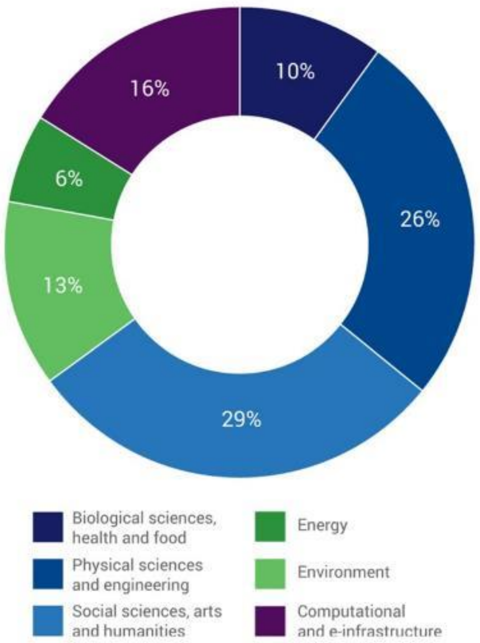
Business offices on second storey

UKRI, STFC, ASTeC and Infrastructures

- STFC Strategic Framework:
  - ‘giving priority to infrastructures that support the science mission needs’
  - ‘ensure that critical technologies are developed for future infrastructures’
  - ‘provision and operation of research facilities in… …any area of UKRI’s activity’
- UKRI Infrastructure Fund:
  - ‘aimed at supporting significant investments that enable a step change in research and innovation infrastructure’
  - New build, upgrades, or decommissioning
  - Full Project or Preliminary Activity



Infrastructure Fund eligibility



Over **500** nationally and internationally significant infrastructures

A breadth of expertise: **92%** work across more than one topic domain

Three quarters work with UK business and **42%** with public policy organisations

Infrastructures employ just under **25,000** staff

- UKRI Infrastructure Projects:
- 32 Full Projects
- 9 Preliminary Activities – ASTeC pivotal in 1/3 of PAs
- Total investment 481M 2022-2025
- Includes projects such as DIAMOND-II, SKAO, Hyper-K

- Accelerator Science and Technology Centre (100 staff)
- Science and Technology Facilities Council (1900 staff)

- ‘Coordinates research and development of national infrastructures’

Additional Material

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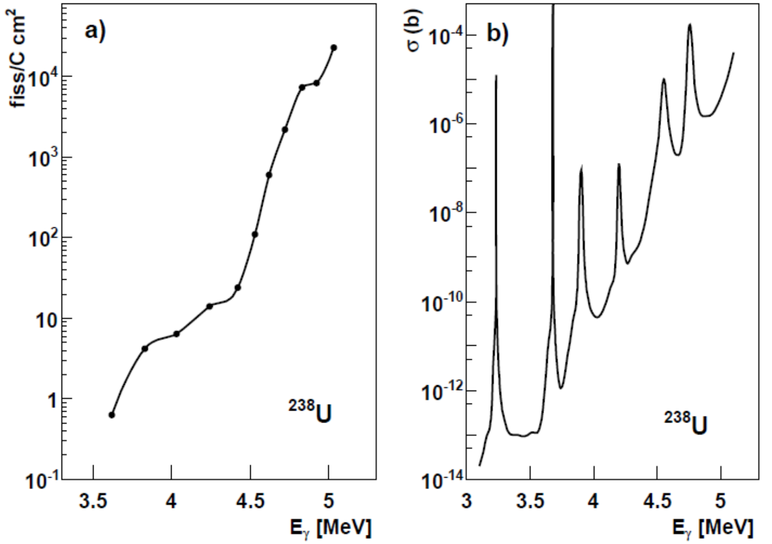
Gammas @ UK-XFEL

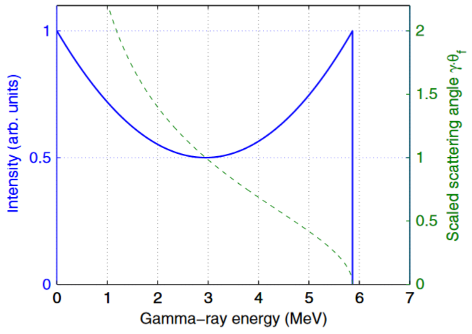
Brem spectra compared to example dipole resonances of I-129 and Cs-135/137

Aim: examine whether there is a case for and design of a 1-100 MeV gamma source for the UK-XFEL project

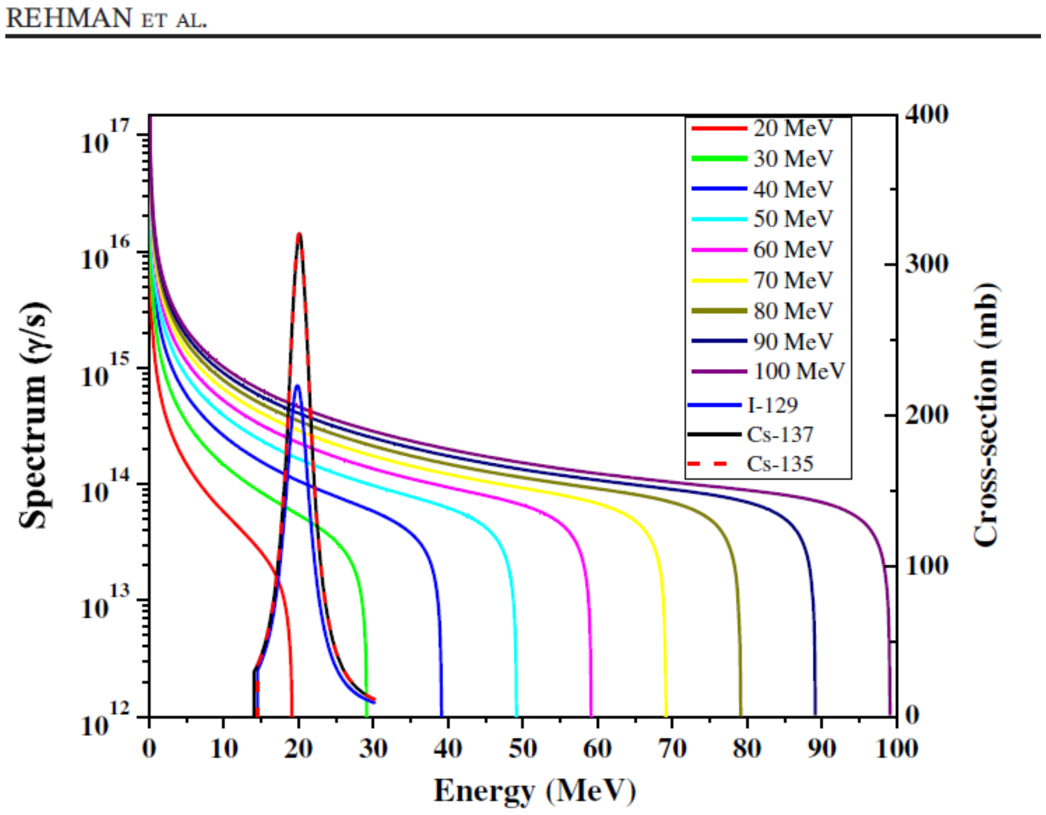
Main points:

Current sources generally based on bremsstrahlung – signal to noise limit and dose limit





"Perspectives for photofission studies with highly brilliant, monochromatic γ-ray beams" P. G. Thirolf et. al., EPJ Web of Conferences **38**, 08001 (2012)



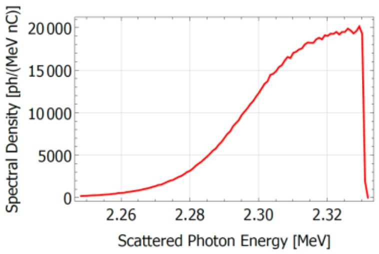
- Gammas also generated by active sources, such as Co-60, these **are** monoenergetic, but have fixed energy, isotropic emission and low flux

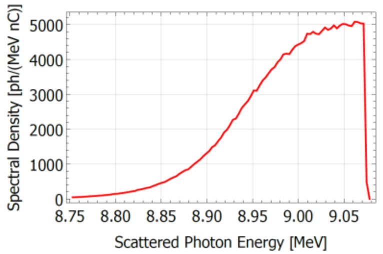
A Gamma Source at UK-XFEL?

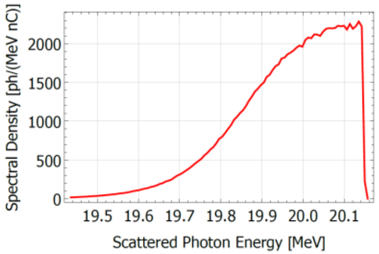
Science and Technology Facilities Council

- What gamma properties can such a source provide? Central energy of gammas is proportional to **square** of electron beam energy, linearly proportional to laser photon energy. E.g. vary electron beam energy from ~500 MeV to 2 GeV – and have perhaps two laser cavities of 1064 / 532 nm gives us variability from ~1 to ~100 MeV

$$E^{\gamma}_{\max} = \frac{4\gamma^2 E_{\text{laser}}}{1 + X}$$

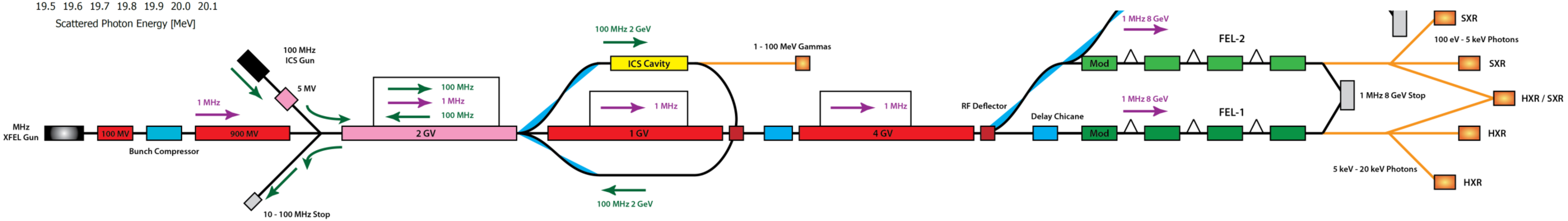




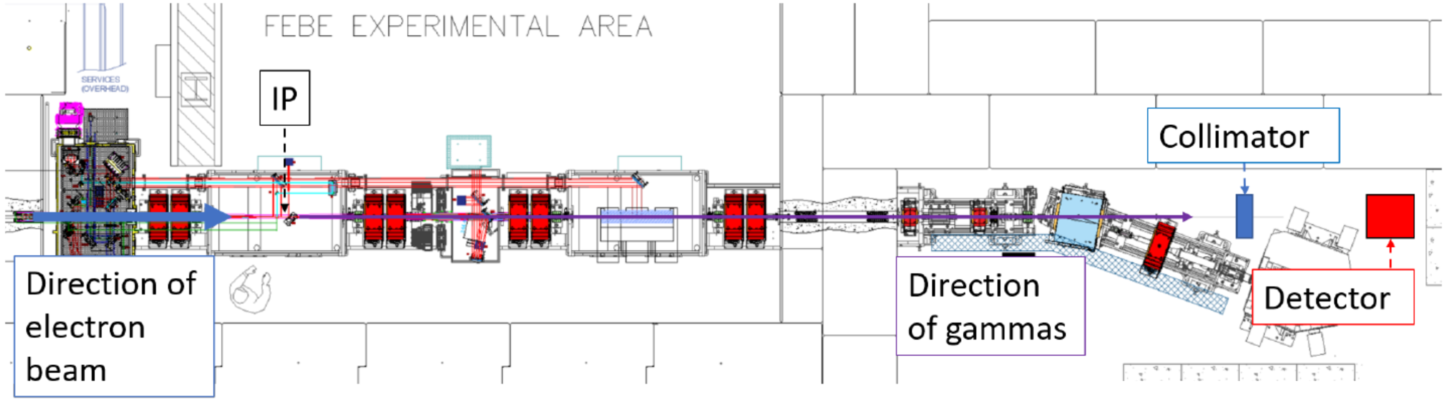


- Dialling the electron energy down to three example energies of 360 MeV, 720 MeV and 1070 MeV results in gammas at 2.3 MeV, 9 MeV and 20 MeV

	Electron Kinetic Energy (MeV)			
	362	717	1072	
γ-ray peak energy	2.33	9.06	20.11	MeV
Baseline				
Source size (x/y)	10.72/10.72	8.00/8.00	6.65/6.65	µm
Uncollimated flux	5.77×10^{10}	6.02×10^{10}	6.08×10^{10}	ph/s
Spectral density	2.48×10^{5}	6.65×10^{4}	3.03×10^{4}	ph/s eV
Average brilliance	5.64×10^{12}	2.05×10^{13}	4.45×10^{13}	ph/s mm^{2}mrad^2 0.1% bw
Peak brilliance*	4.44×10^{18}	1.62×10^{19}	3.50×10^{19}	ph/s mm^2 mrad^2 0.1% bw
0.5% rms bandwidth				
Source Size (x/y)	19.36/12.54	19.35/12.52	19.33/12.50	µm
Collimated flux	1.30×10^{9}	1.29×10^{9}	1.29×10^{9}	ph/s 0.5% bw



Pathway to UK-XFEL Gamma Source – CLARA Demonstrator

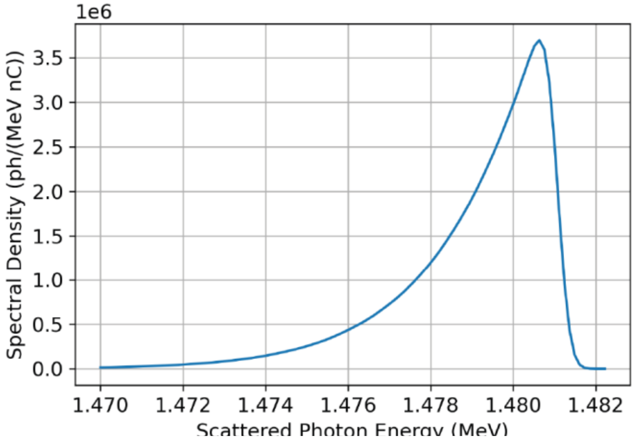


- To build community and gain experience a γ-ray ICS source **demonstration** is proposed at CLARA, Daresbury – this will be **low flux** as CLARA is 100 Hz, not ~100 MHz, but can be done soon ~2026

- Aim is to demonstrate production, detection and characterisation of the spectrum of collimated γ-rays against semi-analytical spectrum simulations in the linear regime.

- Ti:Sa laser (full and reduced power) is baseline, possibility of Nd:YAG system additionally. Electron parameters are widely tuneable, delivering a variety of bunch configurations.

- Gammas collimated by a lead collimator post interaction of mm scale aperture radius place 10m downstream and then detected by a HPGe detector placed beyond that.



Parameter	Value
Collimation angle, θ_{col}	0.070 mrad
Max gamma photon energy, E^{γ}_{max}	1.481 MeV
Source bandwidth, $\Delta E_\gamma / E_\gamma$	3.17 %
Flux at detector	1000 ph/s
Uncollimated flux	5.83×10^5 ph/s

Parameter	Quantity
Wavelength, λ_{laser}	800 nm
Photon energy, E_{laser}	1.55 eV
Pulse energy, E_{pulse}	0.10 J
Number of photons per pulse, N_{laser}	4.03×10^{17}
Repetition rate, f	1 Hz
Rms spot size at the IP, σ_{laser}	45 μm
Crossing angle, ϕ	0 rad
Rms pulse length, τ_{laser}	2.00 ps
Normalised Laser Vector Potential, a_0	8.56×10^{-3}
Rms spectral Bandwidth, $\Delta E_{\text{laser}}/E_{\text{laser}}$	0.03185

Parameter	Quantity
Electron kinetic energy, E_e	250 MeV
Repetition rate, f	1–100 Hz
Bunch charge (typical), eN_e	100 pC
Normalised *rms* emittance, ϵ_N	1 mm-mrad
rms bunch length, $\Delta\tau$	0.73 mm (2.4 ps)
Absolute energy spread, ΔE_e	20 keV
Relative energy spread, $\Delta E_e/E_e$	8.00×10^{-5}
Baseline parameters	
β-function at the IP, β^*	1.23 m
Electron bunch size, σ_{electron}	50 μm

Top: Ti:Sa laser parameters at IP.
Bottom: Electron bunch parameters at IP.

Exemplar: Life and Biomedical Sciences Centre

A medium-resolution CLS imaging facility for in-vivo and ex-vivo research, longitudinal studies, and correlative workflows

Science Challenges:

- Understanding biological organisation and coordination across length scales
- Understanding mechanisms of disease, tissue injury, and repair
- Developing new diagnostic X-ray pathology techniques
- Multiscale correlative workflows

Technical Challenges

- Flexible scheduling for integration within correlative and longitudinal workflows
- Allowing repeat measurements of biological replicates
- establishing direct connections with biomedical, life, and clinical scientists

Ancillary Facilities:

- Electron microscopy (EM)
  - including volume EM
- In-situ/in-operando experimental rigs
- Sample preparation and maintenance/preservation

Adjacency with existing biomedical infrastructure

- research hospitals
- correlative facilities
- biomedical research groups
- expertise in sample preparation

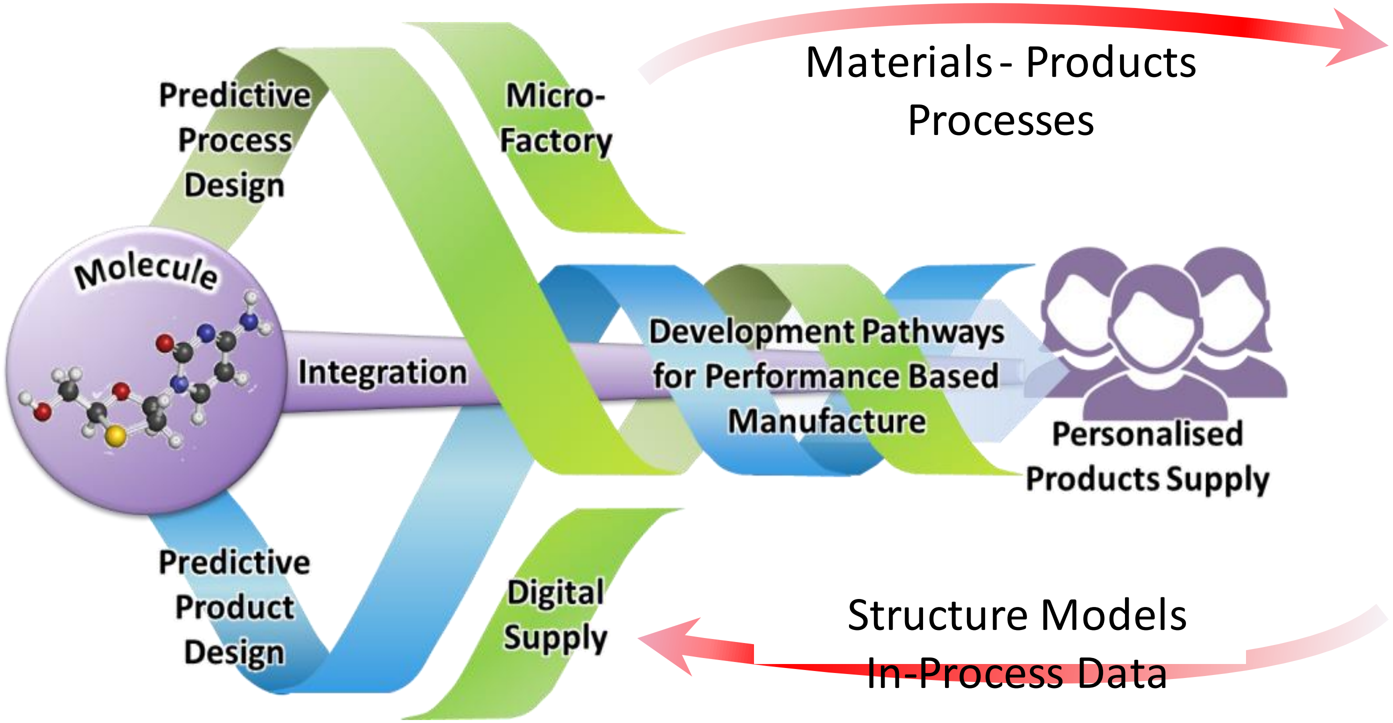
Regional strengths: Crick, Purbright, Edinburgh/Glasgow, North West……..

Exemplar: Advanced Medicines Manufacturing Facility

Technical Challenge

- Endstation with in situ drug manufacturing micro-factory
- Collecting massive datasets

Data-driven
advanced process technologies



At-line (local) – Fast turnaround – Automation
In situ/Operando – Process Equipment

- 4D X-ray imaging – all length & time scales
  Multiple contrast modalities: XRD, XPCI, XPDF, SAXS; ptychography
- X-ray scattering – molecular structure; XRD - XPDF
  noncrystalline phases - melts – solutions – composites
- X-ray spectroscopies – speciation / surface analysis
  Ambient pressure Photoelectron (HAXPES) and absorption spectroscopies (NEXAFS)

Digital Design
Process – Products – Control Systems

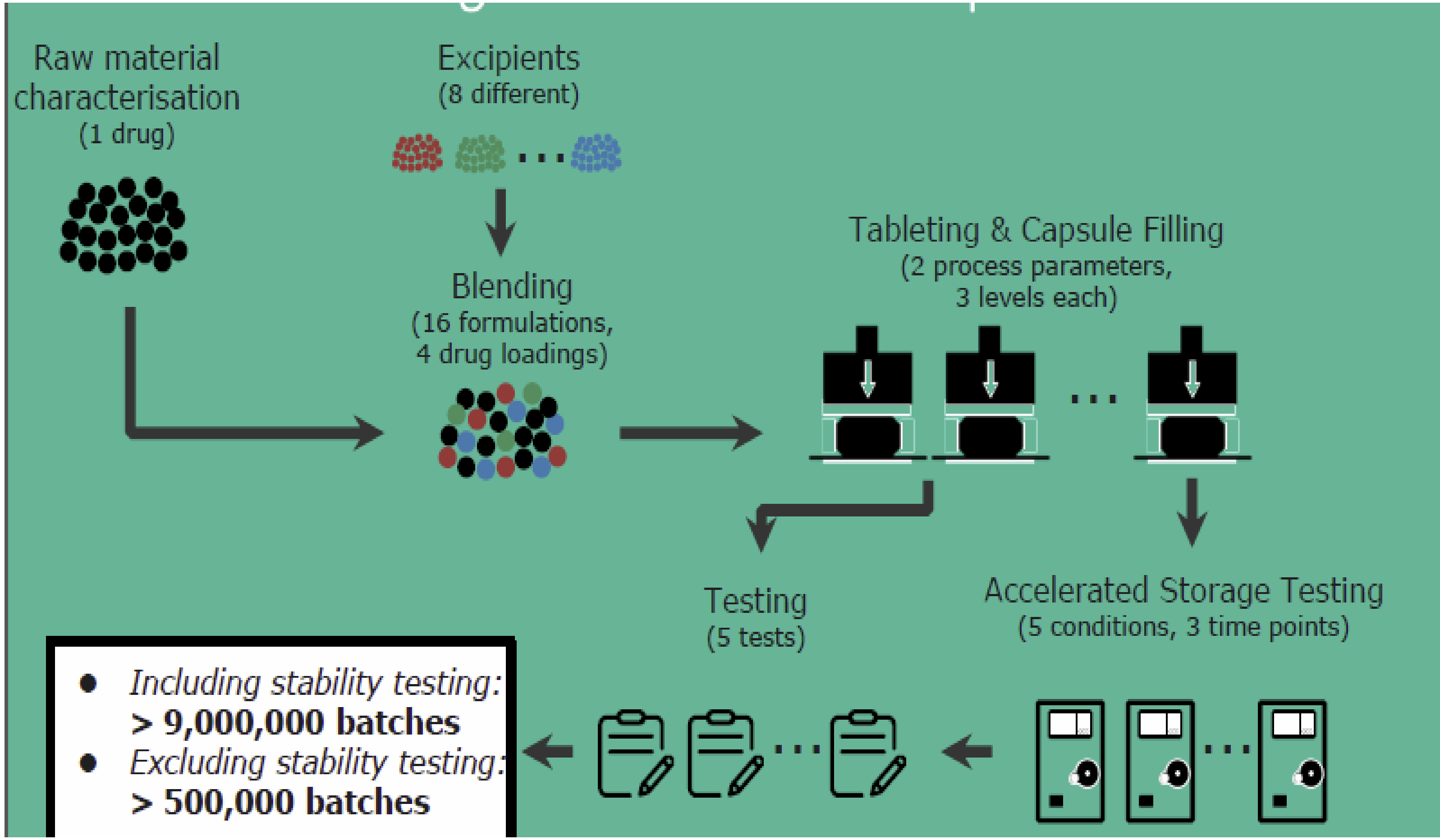
CMAC
FUTURE MANUFACTURING RESEARCH HUB

Strengths in Scotland, North West, South East…

Exemplar: Medicines made smarter campaign

- Making new medicines more quickly requires exploitation of digitalisation methods combined with lots process data
- Installation of in situ processing facilities could provide the large amount of data needed to rapidly accelerate medicine design
- Empower digital design

Scotland, North West, South East…

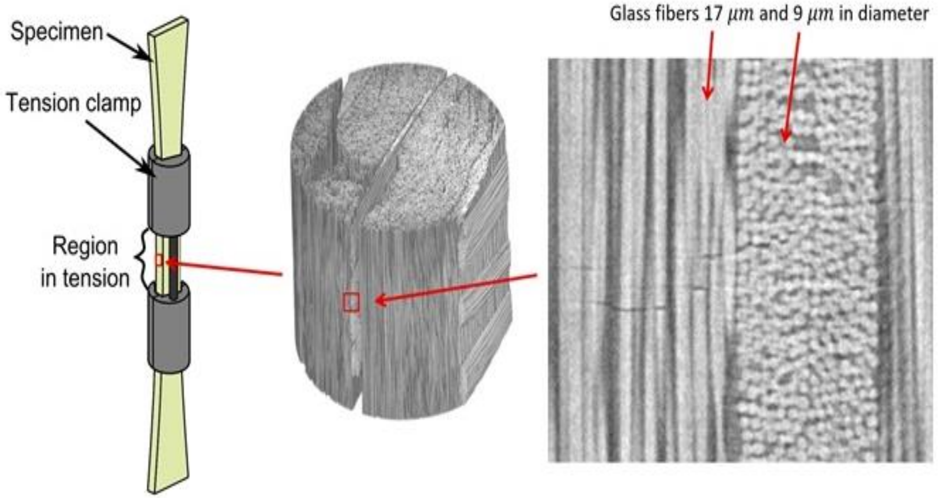


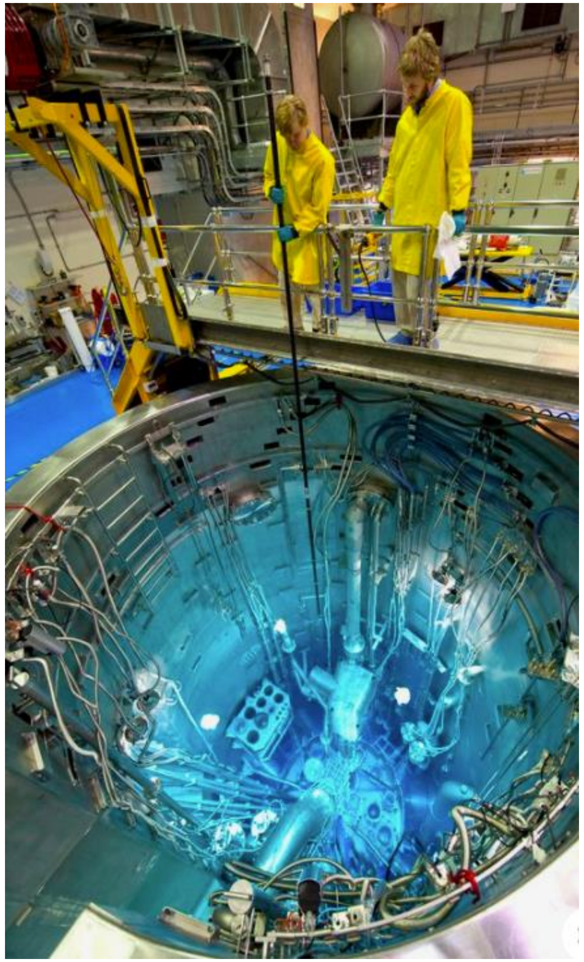
Exemplar: Engineering solutions centre

Challenges: responding quickly to serious unknown unknown events & supporting the 10 point plan for a green industrial revolution:

- Developing new manufacturing processes (additive manufacturing repair of blisks) **Midlands**
- Nuclear fuel research and other restricted materials **Cumbria, Culham, HSE-Buxton….**
- Composites for aerospace and wind turbines, **NE England, N Ireland, N Wales…**
- Catalysts working in extreme environments, **Wales, North East, North West**…

Solutions: fast access, strong industry engagement, multiparametric process development access, secure areas



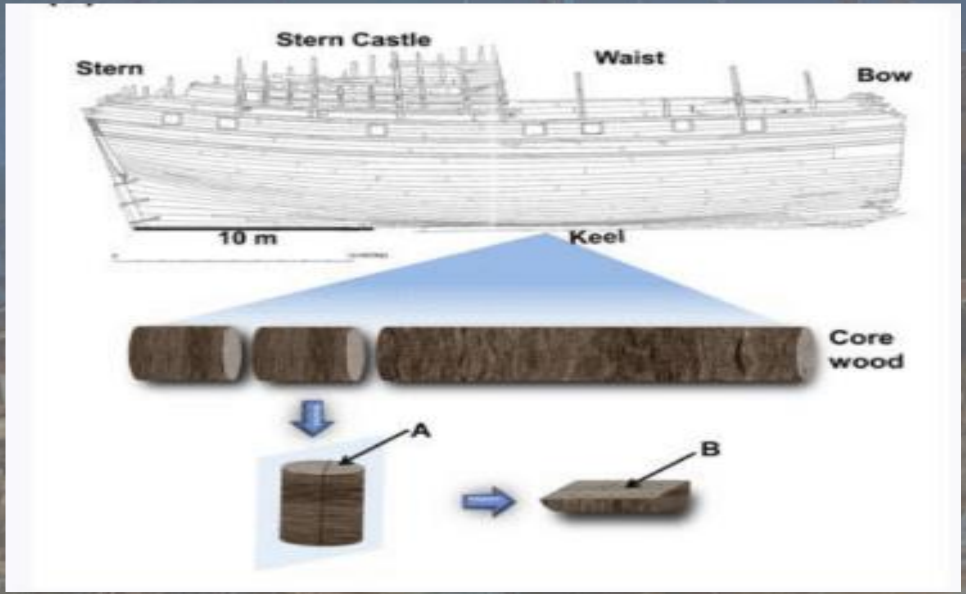


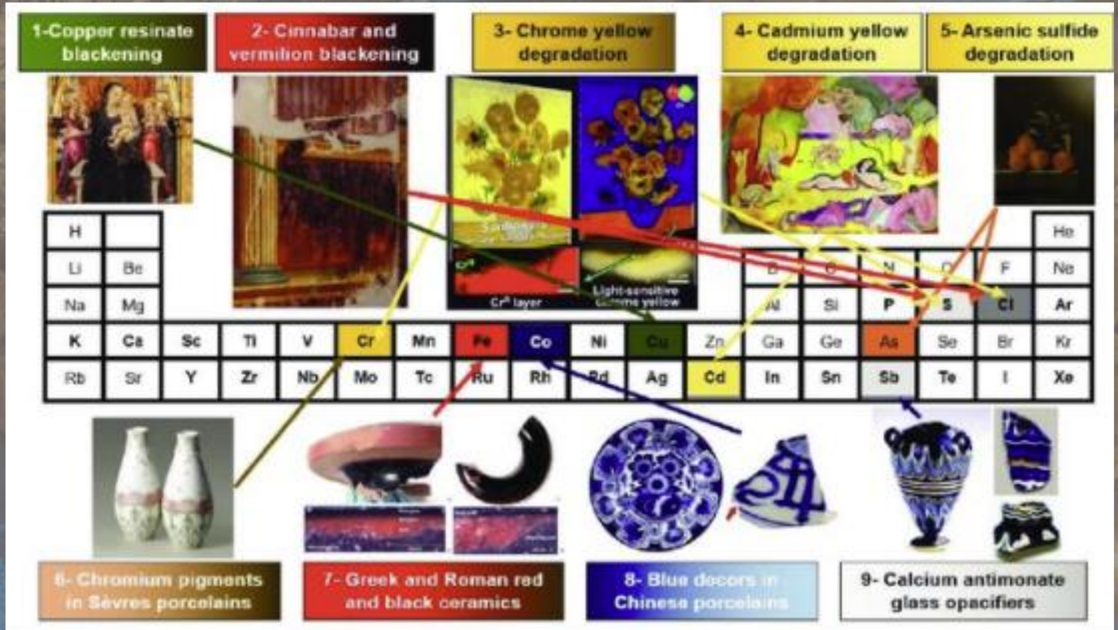
Exemplar: Cultural heritage analysis hub

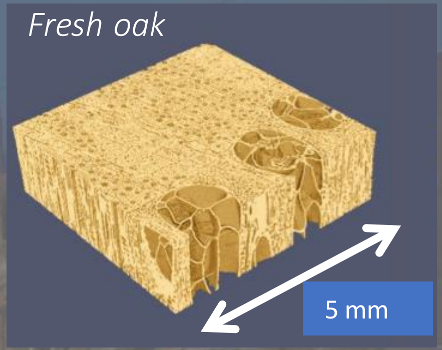
Challenges:

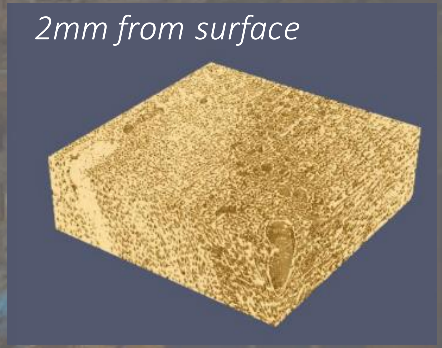
- Specialist technical expert support and sample stewardship
- Testing/developing conservation treatments
- Digitising rare artefacts
- Revealing inside information by 3D X-ray imaging
- Chemical (diffraction, spectroscopy, micro-fluorescence) analysis of natural and man made artefacts

- Link to RICHeS ……









Cultural and Natural Heritage at the ESRF: Looking Back and to the Future, 2019, Synchrotron Radiation News 32(6):34-40

Exemplar: Understanding our environment

Science challenges: Tracking the response of our environment to external factors for

- agriculture/soil health,
- Critical materials mining/extraction
- sub-surface energy storage/exploitations (O&G, CCS, H_2, geothermal, nuclear),
- seismicity, subsidence, landslides, volcanic risk, planetary evolution, remdiation

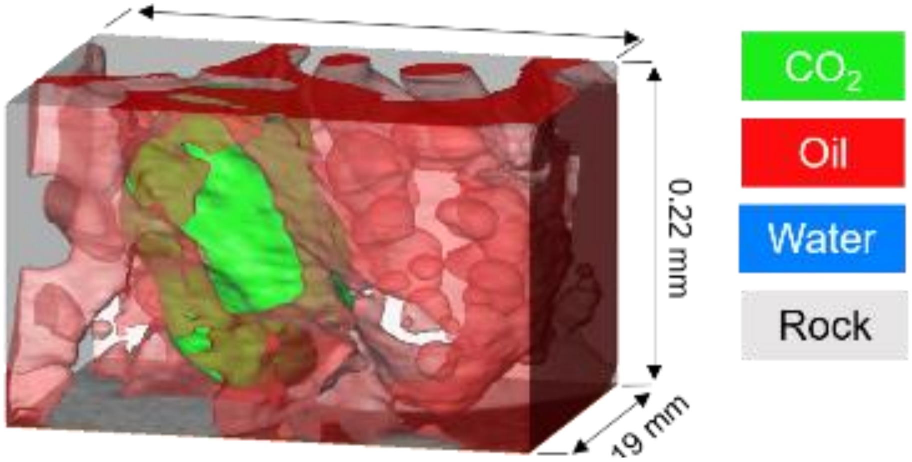
Technical Challenges: Extreme pressures/temps, multi-visit experiments; long-durations (months/years)

Solutions: special environmental rigs to be wheeled into beamline periodically

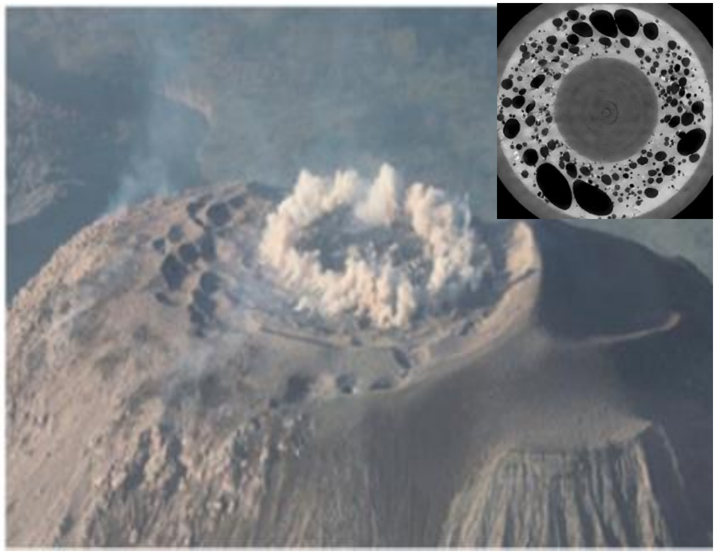
Link to CO_2 Storage Testbed

Strengths: Scotland, North West, South West

Fluid phase occupancies govern chemical interactions with solids



Replicating conditions at 600km depth



Experiments on magma at 1200^{o}C imaging exsolved bubbles at sub-second intervals

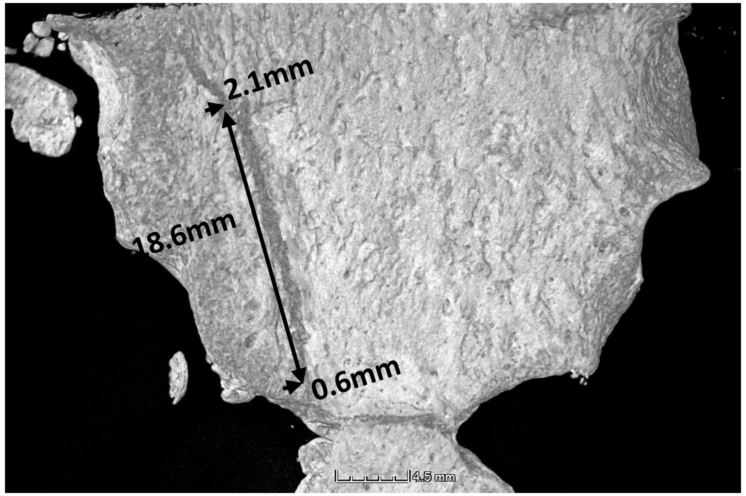
Exemplar: Forensics hub

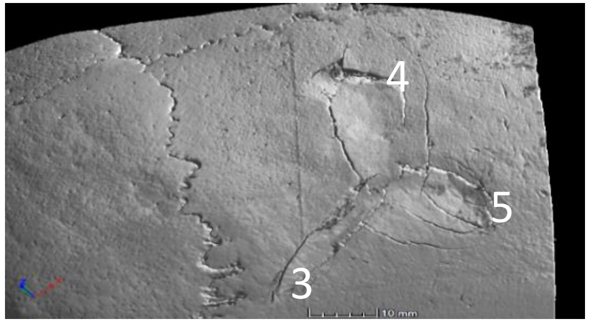
Challenge

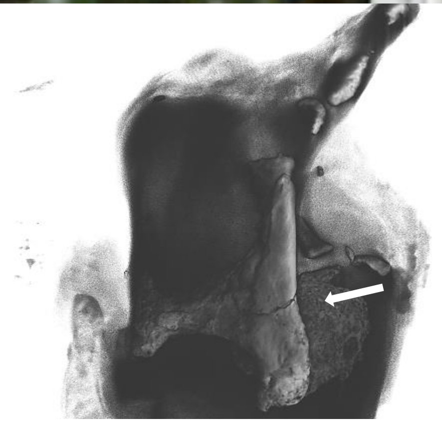
- Certification and Data Management structure
- Advanced 3D Imaging and analysis capabilities to support forensic research
- Align with the 'Forensic Centre for Digital Scanning and 3D Printing': 200+ cases for 22 UK Police forces
- High resolution reference scans for traceability - Gold standard Digital Histology
- Characterisation of soft tissue injuries

Links with national bodies:

- Forensic Science Regulator (FSR)
- Crown Prosecution Service (CPS)
- National Crime Agency (NCA)
- National Injury Database







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