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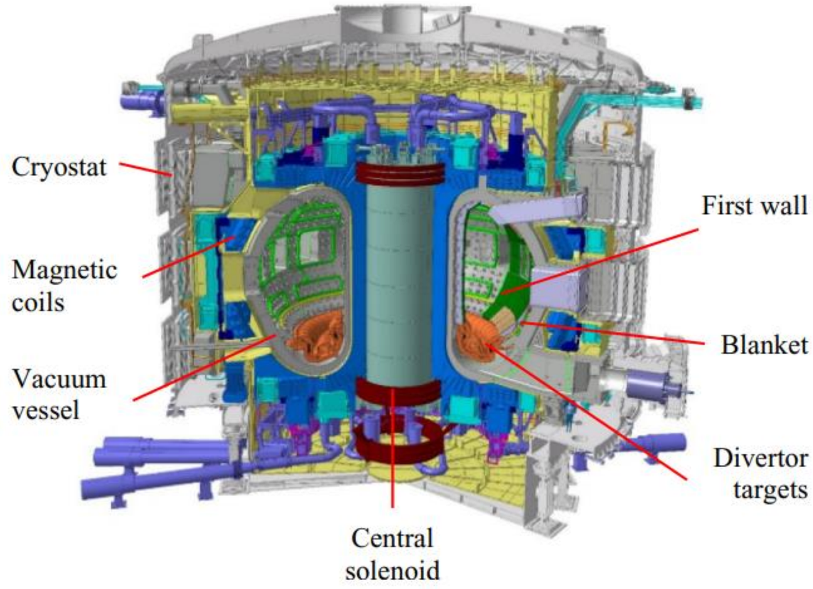
UK Atomic Energy Authority

3D Lattice Strain Quantification in Neutron Irradiated ODS Steel for Fusion Energy

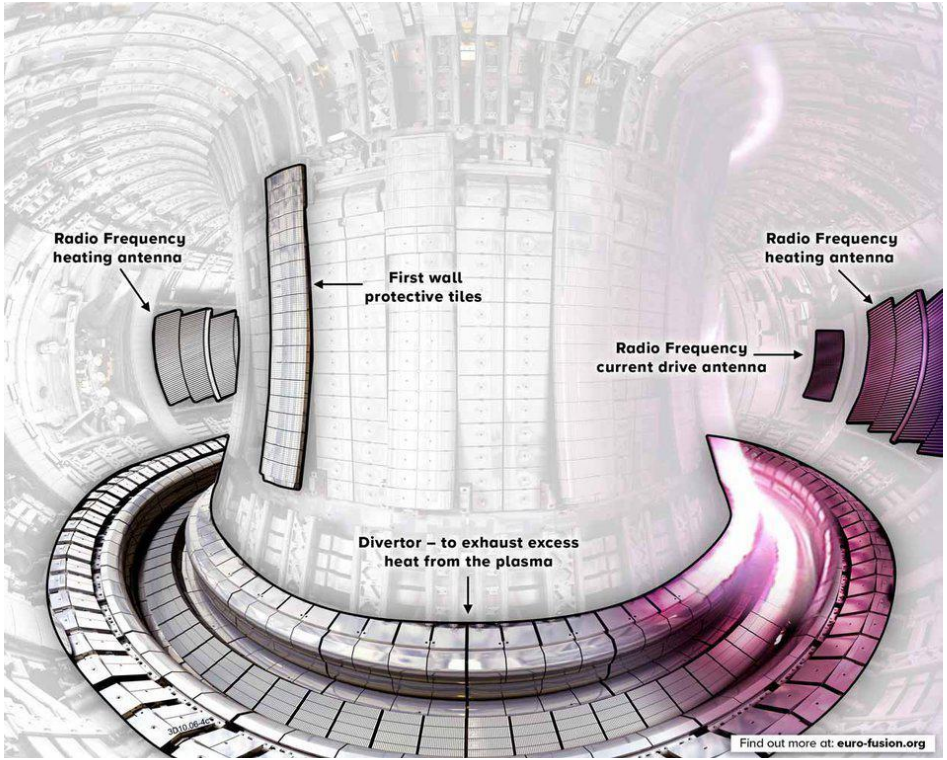
Lucy Fitzgerald (UoB), Slava Kuksenko (UKAEA), Duc Nguyen (UKAEA), Yiqiang Wang (UKAEA), Steven Leake (ESRF), Biao Cai (UoB)

Fusion Reactors

Harsh Environments:
- Extreme temperatures.
- High energy neutrons (~14 MeV).



P. Zach and S. Entler, *NET*, vol. 51, pp. 1251-1260, 2019.



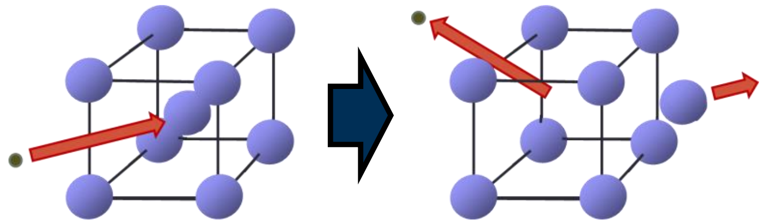
https://ccfe.ukaea.uk/programmes/joint-european-torus/

Lucy Fitzgerald
lxf287@student.bham.ac.uk

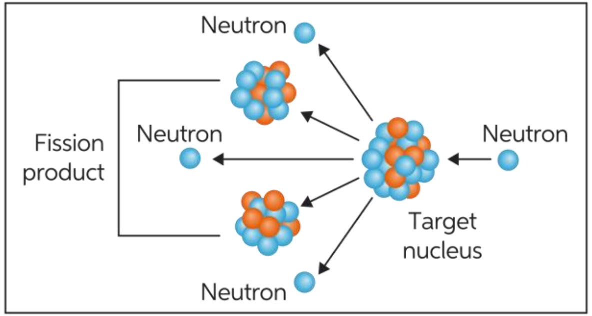
Radiation Damage

Neutron bombardment cause "radiation damage" via two main mechanisms:

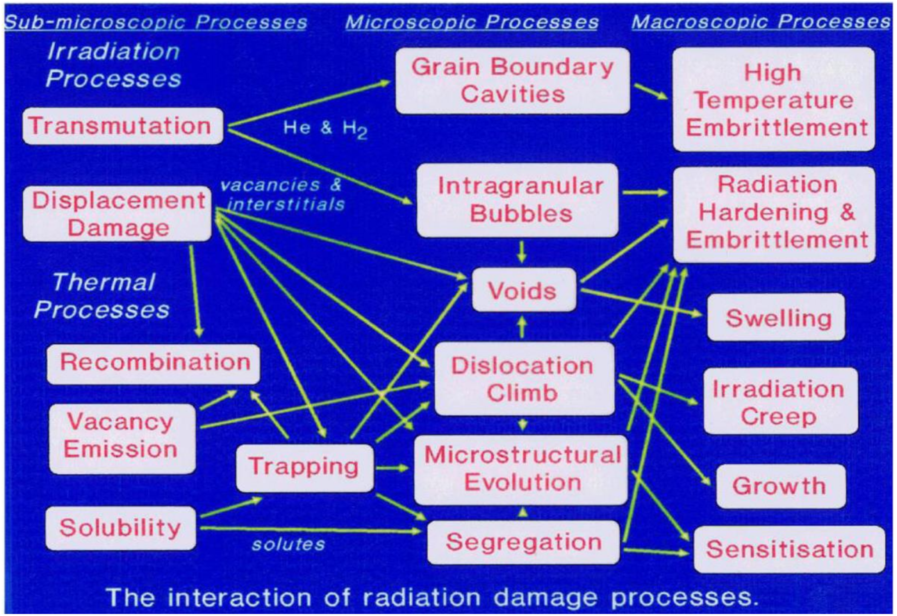
- **Displacement damage** creates disorder in materials



- **Transmutation** creates new isotopes and elements



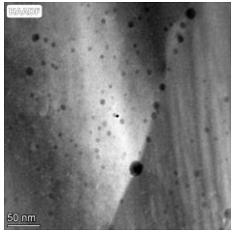
Possible consequences:

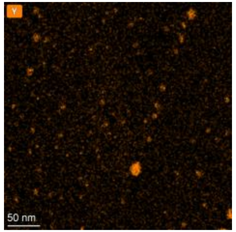


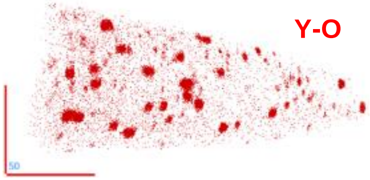
C.A. English (2011)

ODS Steels

The fine distribution of Y_2O_3 particles, is essential to improving the high temperature strength and radiation resistance of ODS steels.



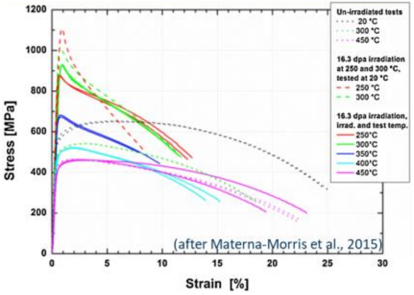


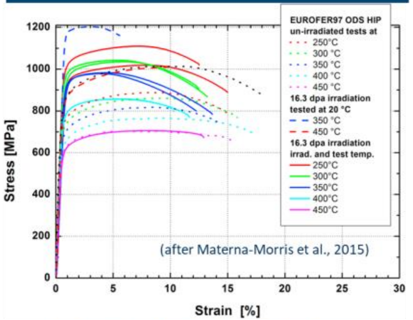


Fe-14Cr-YWTi.
S. Kuksenko et al. to be published

Substantial improvement to radiation damage resistance

EUROFER	ODS-EUROFER

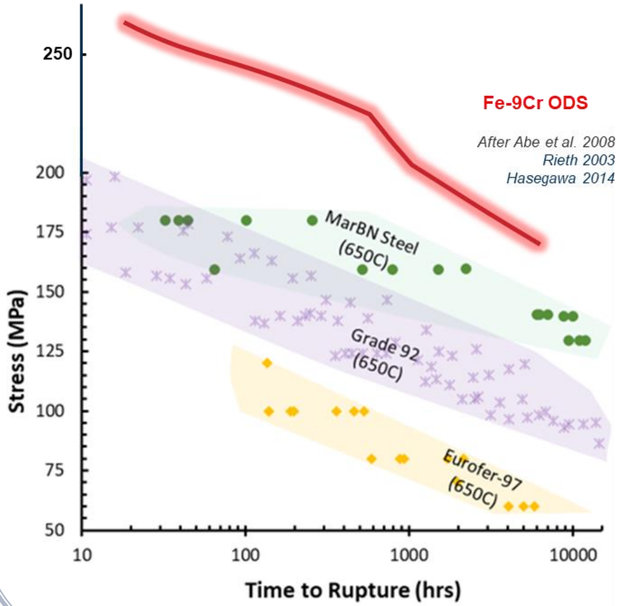




- Substantial irradiation hardening
- Early strain localization due to dislocation channelling

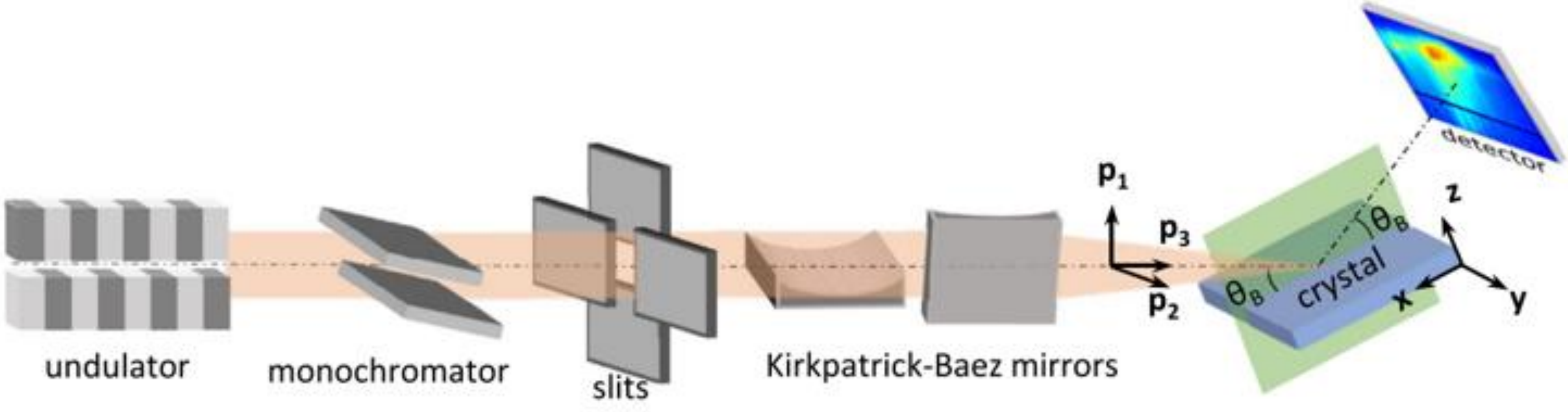
- Somewhat less irradiation hardening
- Still work hardening and almost no
- loss of uniform elongation

Improvement of Creep Rupture Strength of nuclear-relevant Steels



Lucy Fitzgerald
lxf287@student.bham.ac.uk

3D Bragg Ptychography

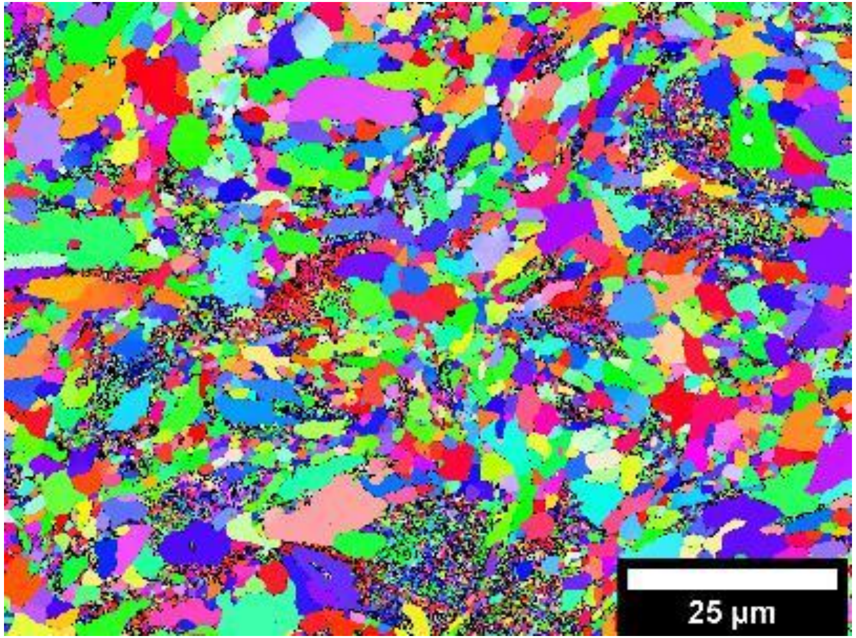


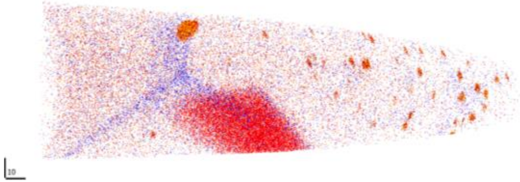
Experimental setup for Bragg ptychography on beamline ID01 at the European Synchrotron.

P. Li, et al., Nat Commun, vol. 12, no. 1, pp. 1–13, 2021.

Sample Material

- Fe-14Cr-2W-0.3Ti-0.3Y_2O_3.
- Neutron irradiation carried out at 600°C to ~2.5dpa.





Y
Ti
W-containing isotopes

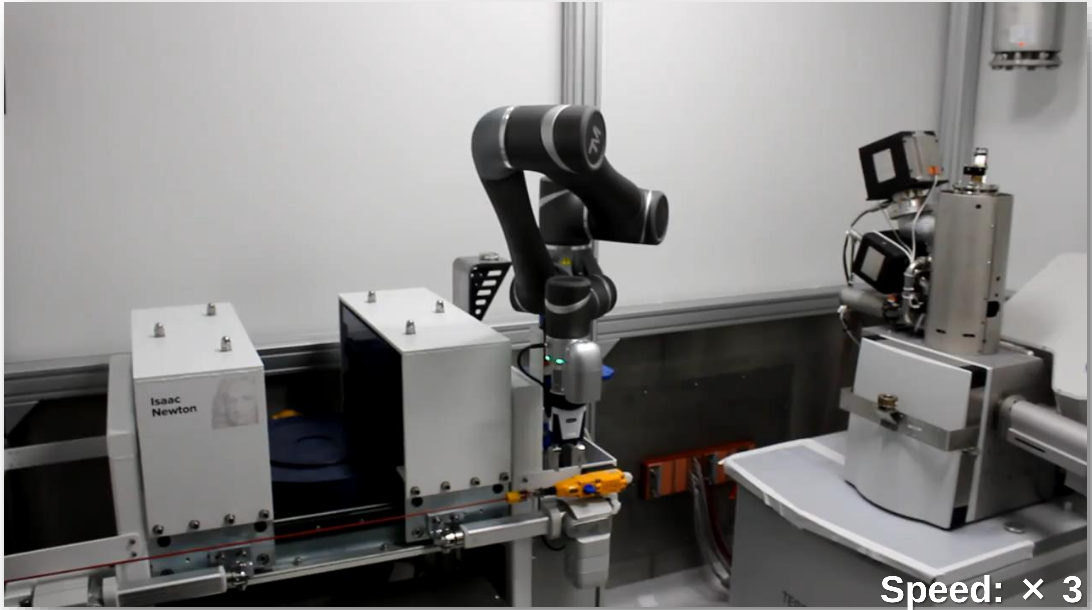
	Fe-14Cr-WTY
	wt%
Cr	13.7
Mn	0.16
Si	0.031
C	0.088
N	0.035
O	0.48
Ti	0.26
Y	0.23
Mo	0.008
W	1.84
Fe	Balance

Material	Consolidation	Irradiation	T median, °C	T max, °C	dose, dpa
14Cr- WTY	HIP-ed	HFR	601	632	2.51

Preparation of Radioactive Samples

Prepared at the Materials Research Facility (MRF) using a FIB-SEM with an EBSD detector.

ALARA → **A**s **L**ow **A**s **R**easonably **A**chievable.

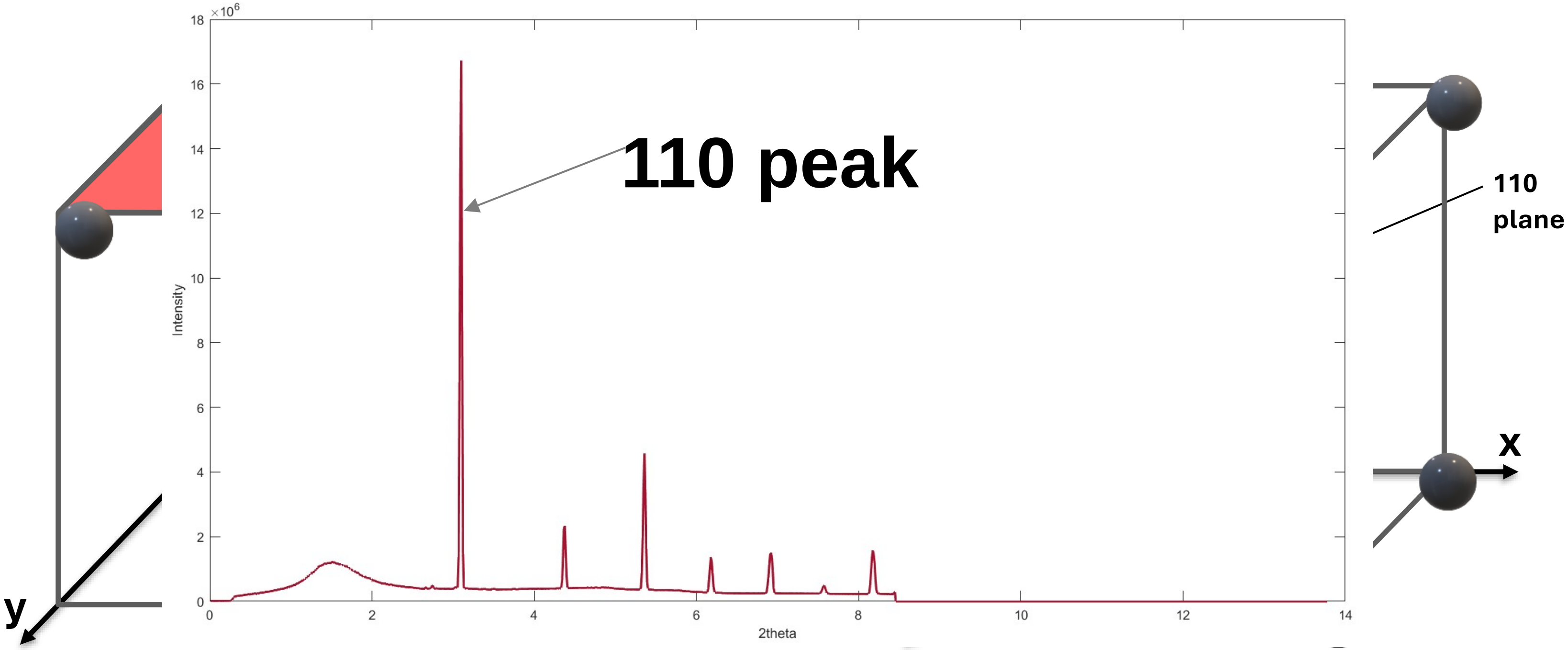


Lucy Fitzgerald
lxf287@student.bham.ac.uk

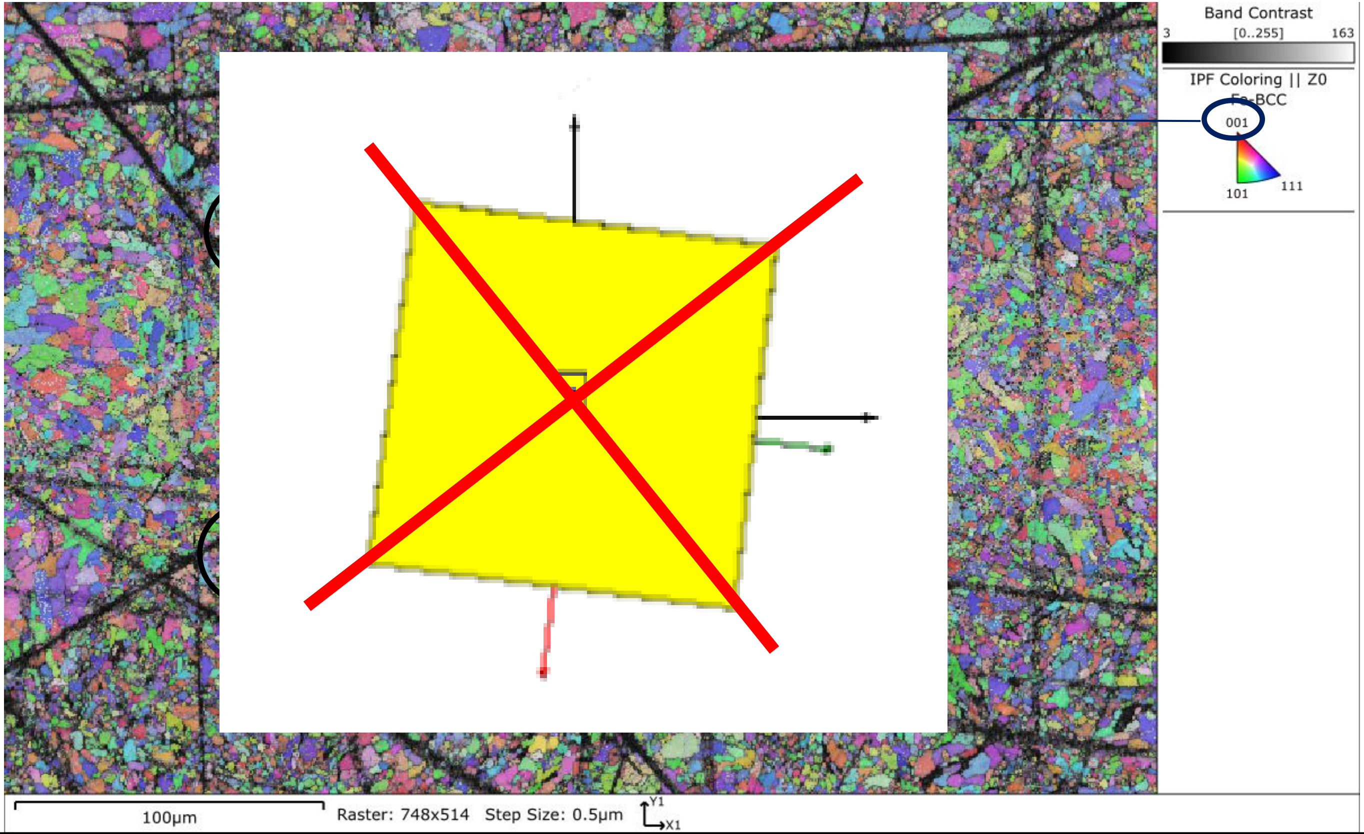
Sample Preparation – Theoretical

A known crystal orientation perpendicular to the surface of at least one grain is essential.

The 110 plane was chosen as it has the smallest bragg angle.

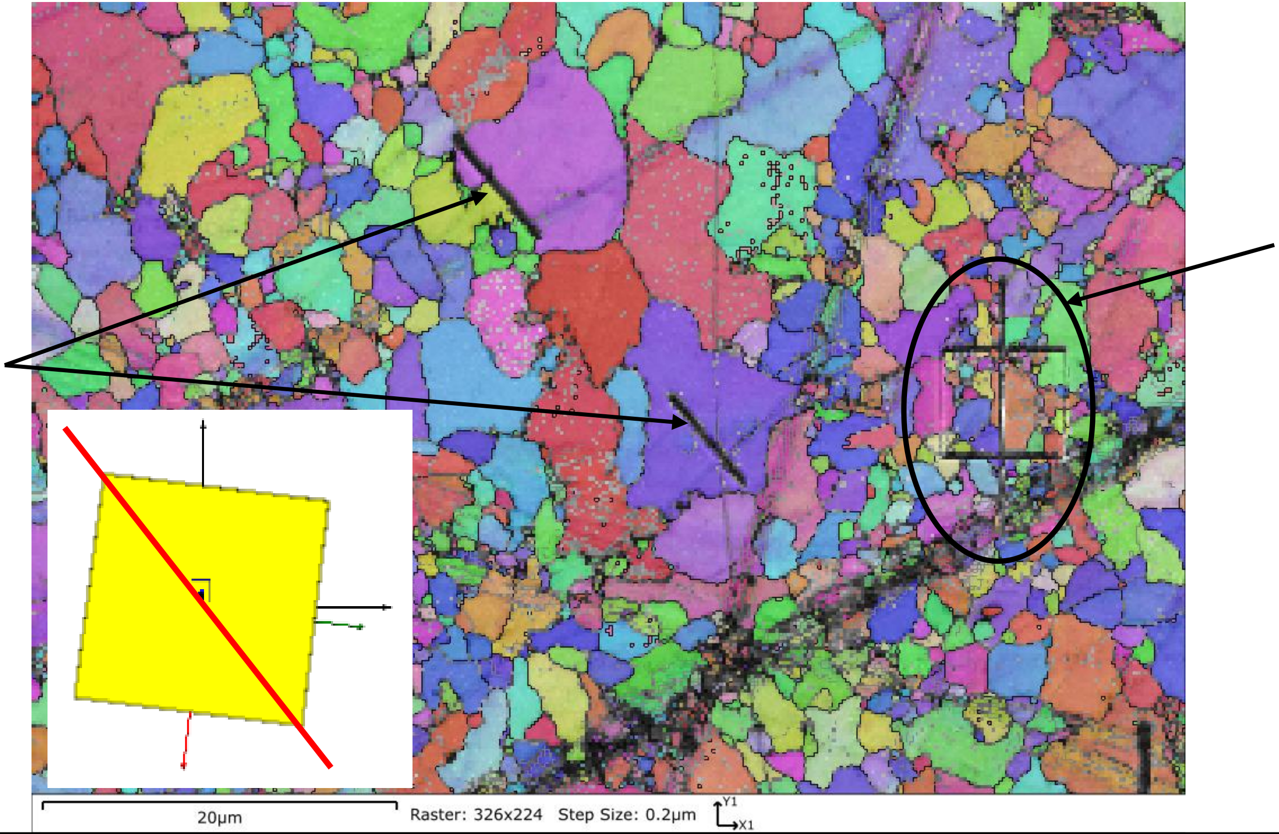


Sample Preparation - Experimental



Sample Preparation - Experimental

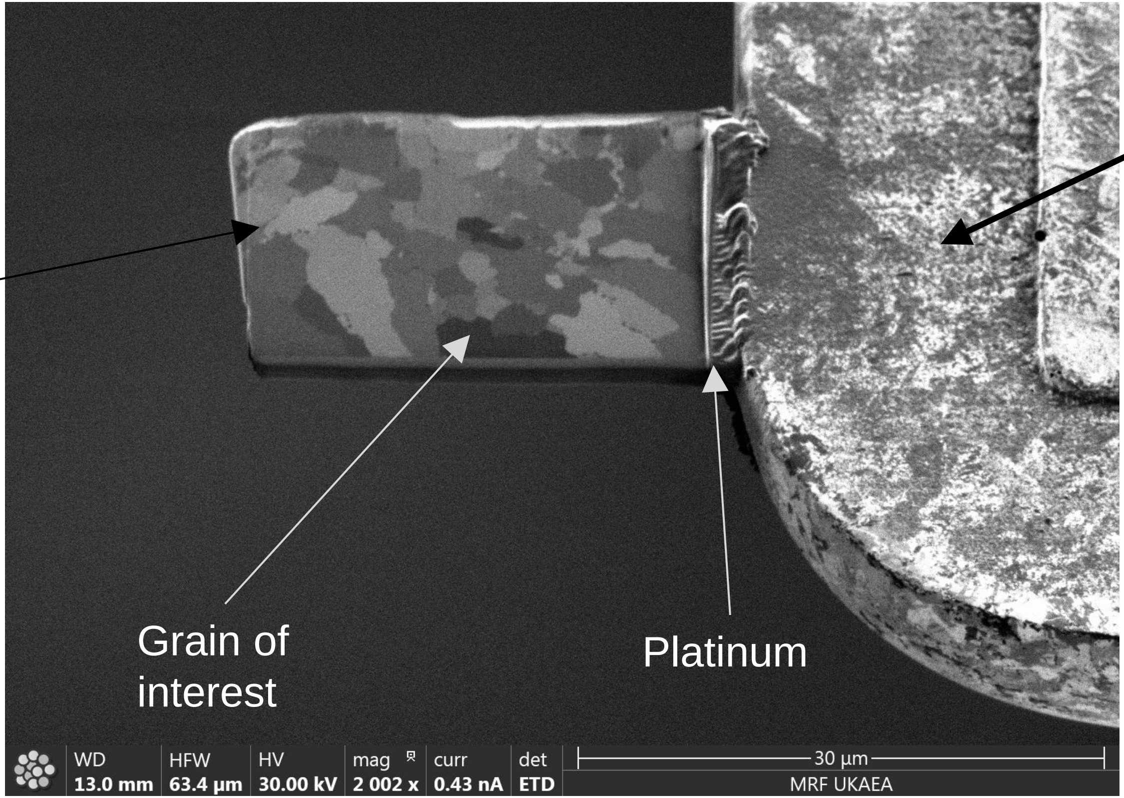
Surface of the material marked in the direction the sample will be cut out and then checked with EBSD



Fiducial to differentiate each sample.

Completed Sample

Sample lamela



Copper TEM grid

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Synchrotron Experiment

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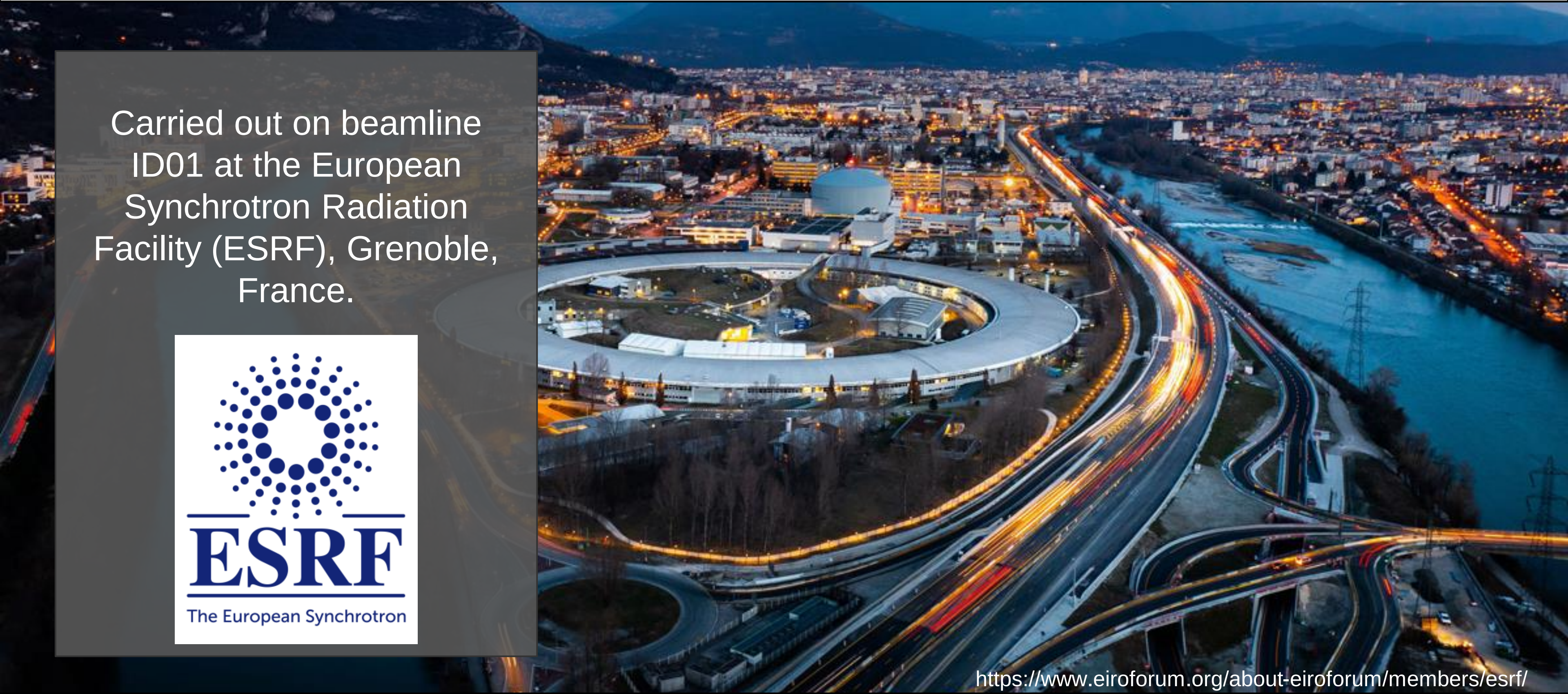


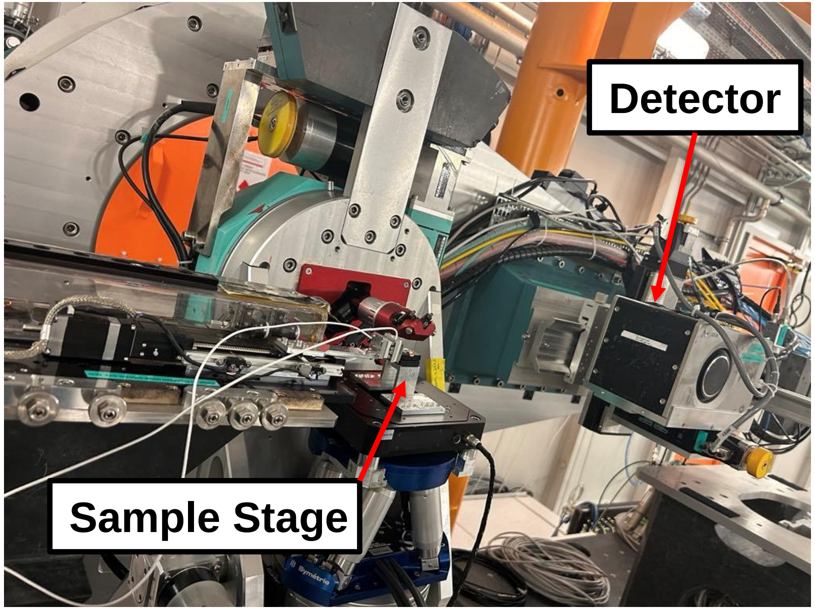
Carried out on beamline ID01 at the European Synchrotron Radiation Facility (ESRF), Grenoble, France.

ESRF
The European Synchrotron

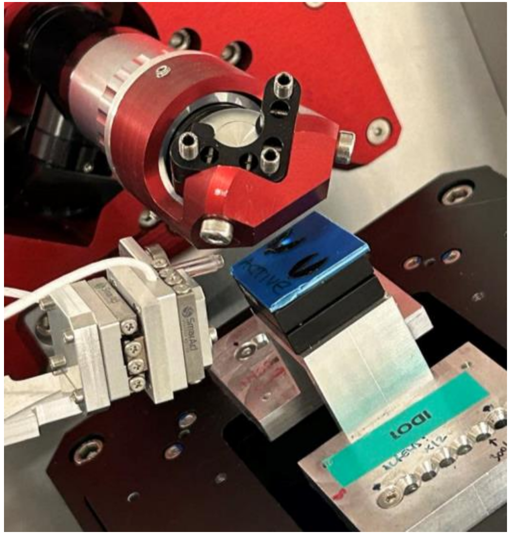
https://www.eiroforum.org/about-eiroforum/members/esrf/

Lucy Fitzgerald
lxf287@student.bham.ac.uk

ID01 Beamline



Beamline ID01



ID01 beamline sample stage

Lucy Fitzgerald
lxf287@student.bham.ac.uk

Bragg Angle Calculations

$$d_{hkl} = \frac{a}{\sqrt{h^2 + k^2 + l^2}}$$

Where a is the lattice constant/parameter (2.865 Å for iron).

$$sin\theta = \frac{n\lambda}{2d}$$

Where the wavelength (λ) of the x-ray beam is 1.3776 Å and n is 1.

θ = 19.88° and 2θ = 39.75°

Where the sample is set to θ and the detector is set to 2θ.

Lucy Fitzgerald
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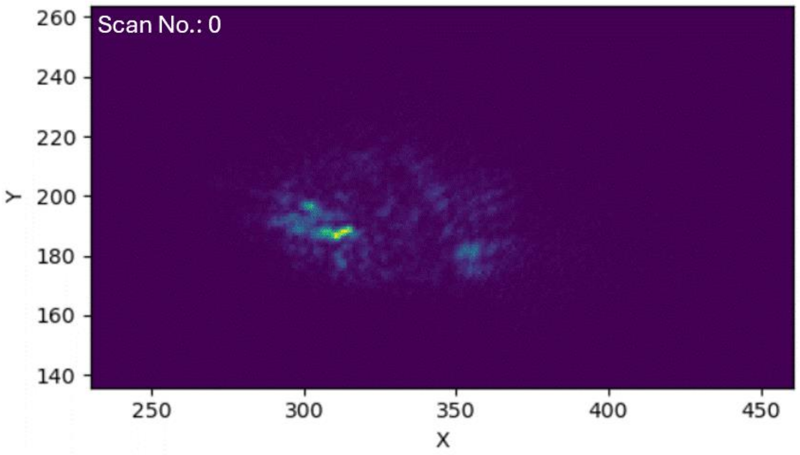
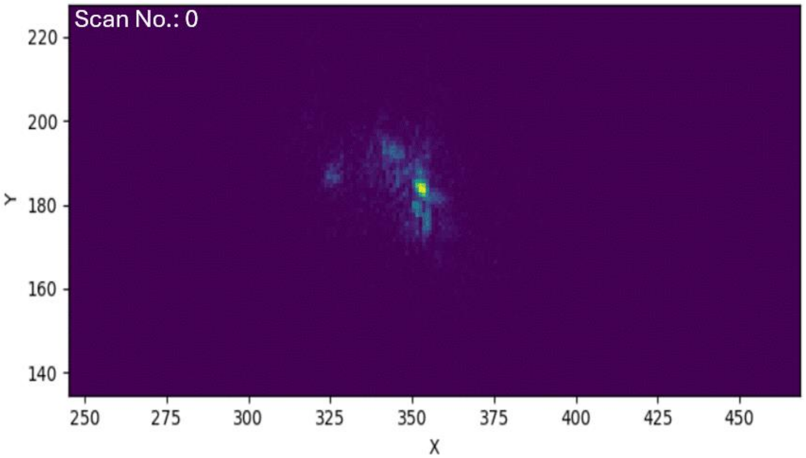
Preliminary Results

These videos show the bragg spots as seen on the detector and how they change with changing scan angle.



Non-irradiated sample

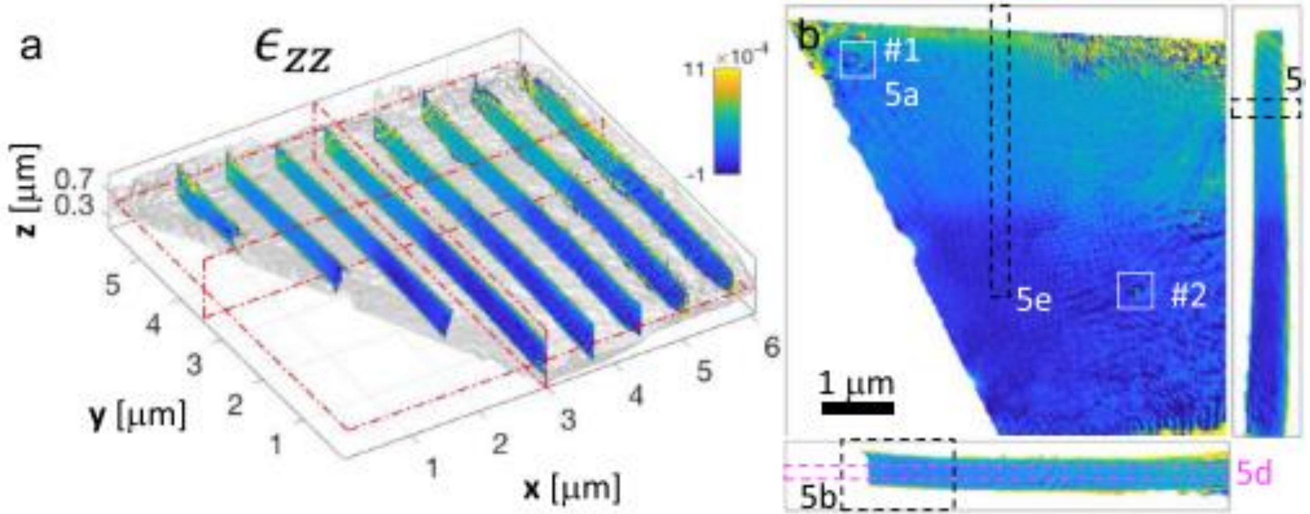


Irradiated sample

The grain scanned in the non-active sample was much larger than the grain in the active sample.

Next Steps

- 3D reconstructions of data collected.
- Code for reconstruction being developed between various facilities.



3D iso-surface plot along with full strain map and cross-sectional strain maps.

P. Li, et al., Nat Commun, vol. 12, no. 1, pp. 1–13, 2021.

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Conclusions

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1. EPFL in Switzerland – Manufactured
2. NRG in Netherlands – Irradiation in HFR
3. UK Atomic Energy Authority in England – Preparation and characterisation
4. ESRF in France – Synchrotron Experiment

Lucy Fitzgerald
lxf287@student.bham.ac.uk

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Appreciation must be shown to Sam Waters, Andy London, and Kate Breach at the MRF for training and shipment of samples to France.

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Thank you to my colleagues Phoebe, Jatinder and John for joining me and helping to run my experiment at the ESRF.

Lucy Fitzgerald
lxf287@student.bham.ac.uk

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My LinkedIn

Research Group Website

Thank you!

Any Questions?