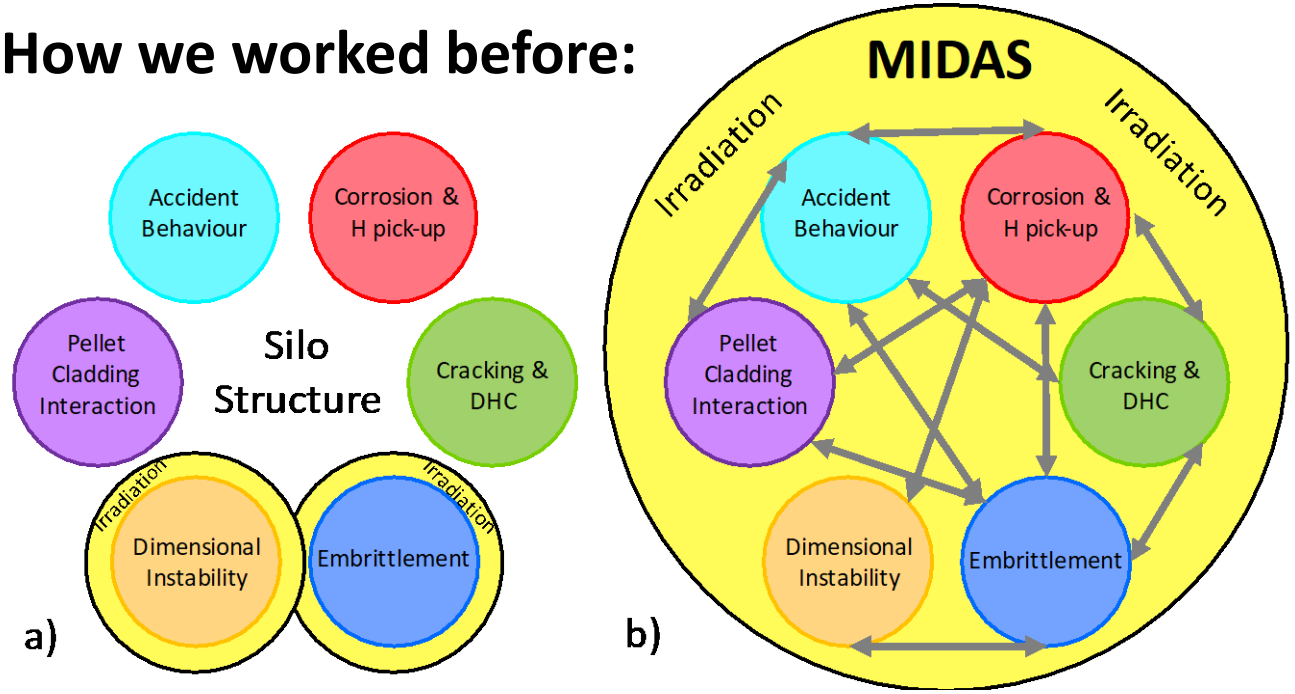
Engineering and Physical Sciences Research Council

MIDAS – Mechanistic understanding of Irradiation Damage in fuel ASsemblies

Philipp Frankel

UK Nuclear Academics Meeting 2023
6-7 September 2023

How we worked before:



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Key Challenges and Expertise

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KC-4 – Failure Mechanisms

KC-3 – Environmental Degradation

KC-1 – Irradiation Damage Evolution

KC-2 – Irradiation Hardening

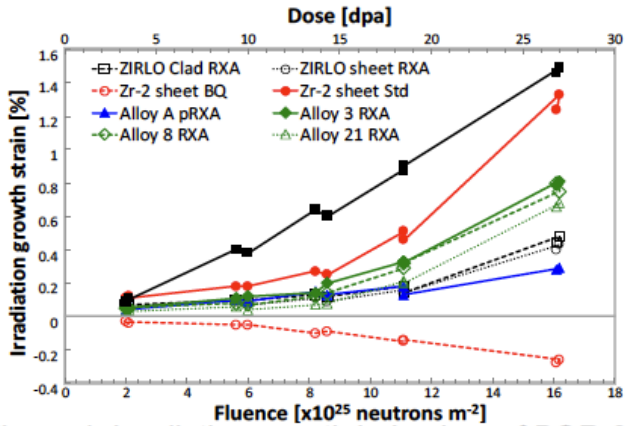


Figure 4: Irradiation growth behaviour of BOR-60 neutron irradiated samples provided to MIDAS

Expertise and People

Length Scale	Characteris. Observation	Modelling Understanding
Atomistic description	Moody/ Frankel	Dudarev/ Race
Elemental/H Segregation	Grovenor/ Moore/ Moody	Dudarev/ Wenman/ Race
Dislocations	Preuss/ Grovenor/ Wilkinson	Race/ Balint
Precip./ Matrix	Moody/ Grovenor/ Preuss	Dudarev/ Robson
Strain/ Stress	Preuss/ Frankel/ Wilkinson	Dunne/ Balint
Env./Mech. Perform	Frankel	Dunne/ Wenman

Management Group

KC-1: Race, Preuss — Irradiation Damage

KC-2: Preuss, Balint — Irradiation Hardening

KC-3: Grovenor, Wenman — Environmental Degradation

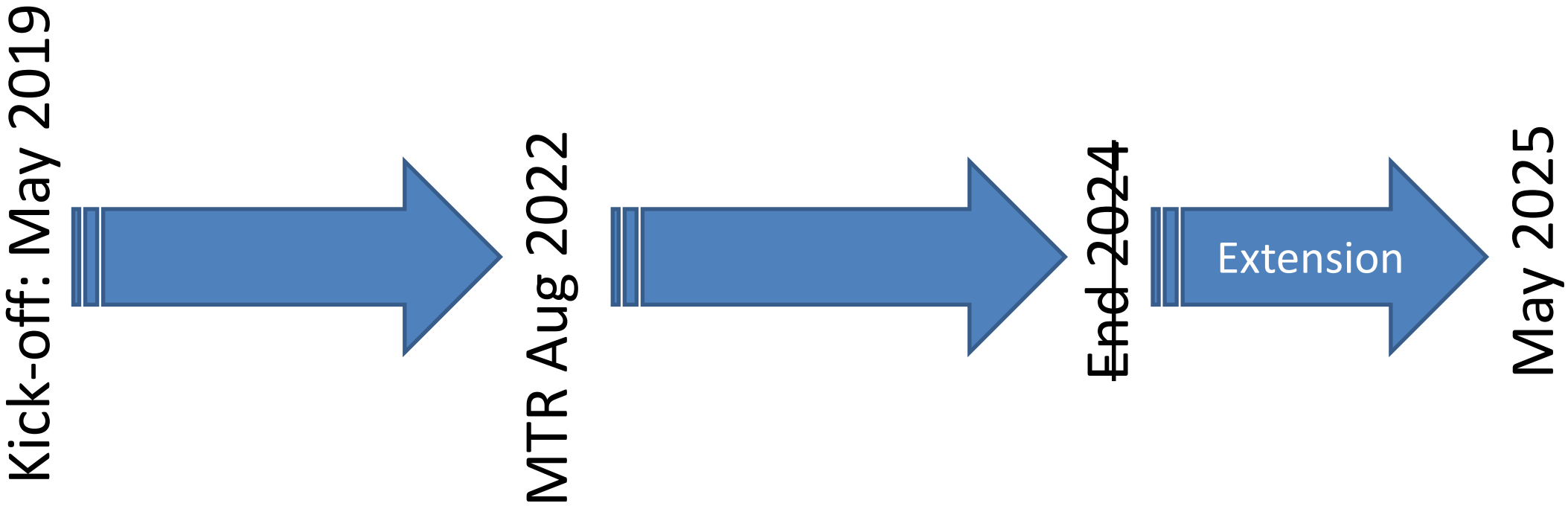
KC-4: Dunne, Frankel — Failure Mechanism

Independent Advisory Board (academia and industry) progress monitoring of KC1-4

Impact Monitoring Working Group

DOI: 10.1520/STP159720160040

MIDAS Timeline



Staff Update

- Doyin Mansell – Programme Manager since June

- Mia Maric – RR/UoM Research Fellow in Nuclear Cladding Materials
  - Started July
  - Microstructural evolution with hydrides and irradiation
  - Characterisation and Simulation

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Public Engagement - Outreach

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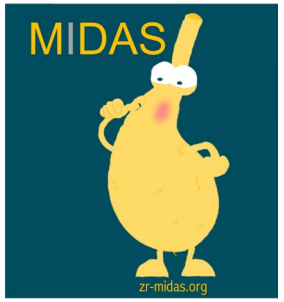
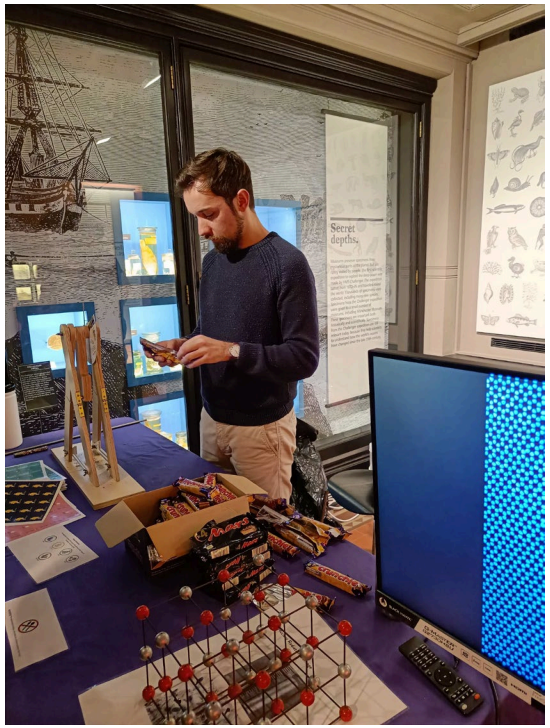
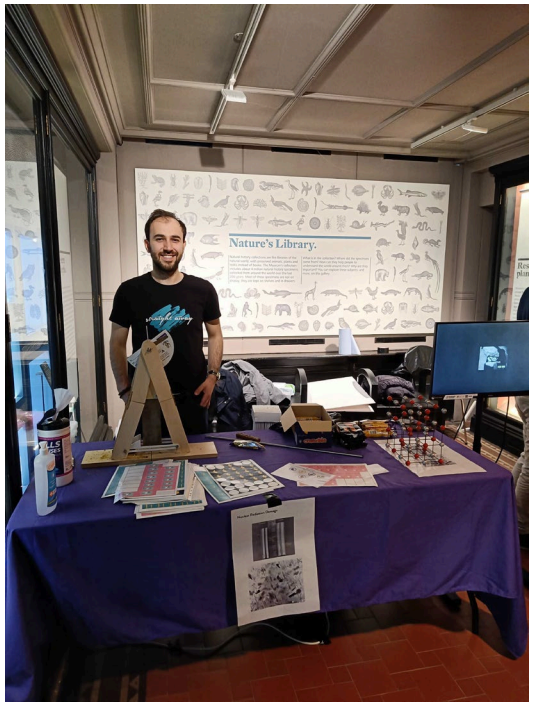
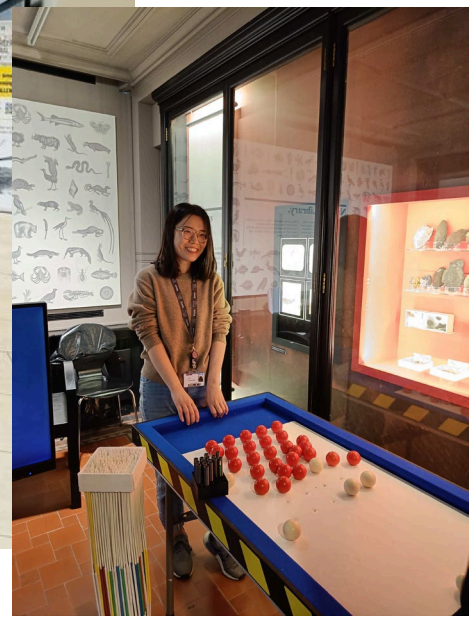
- **Manchester Science Festival – March.**
- **UoM Community festival - June**
- **Bluedot Festival – July**



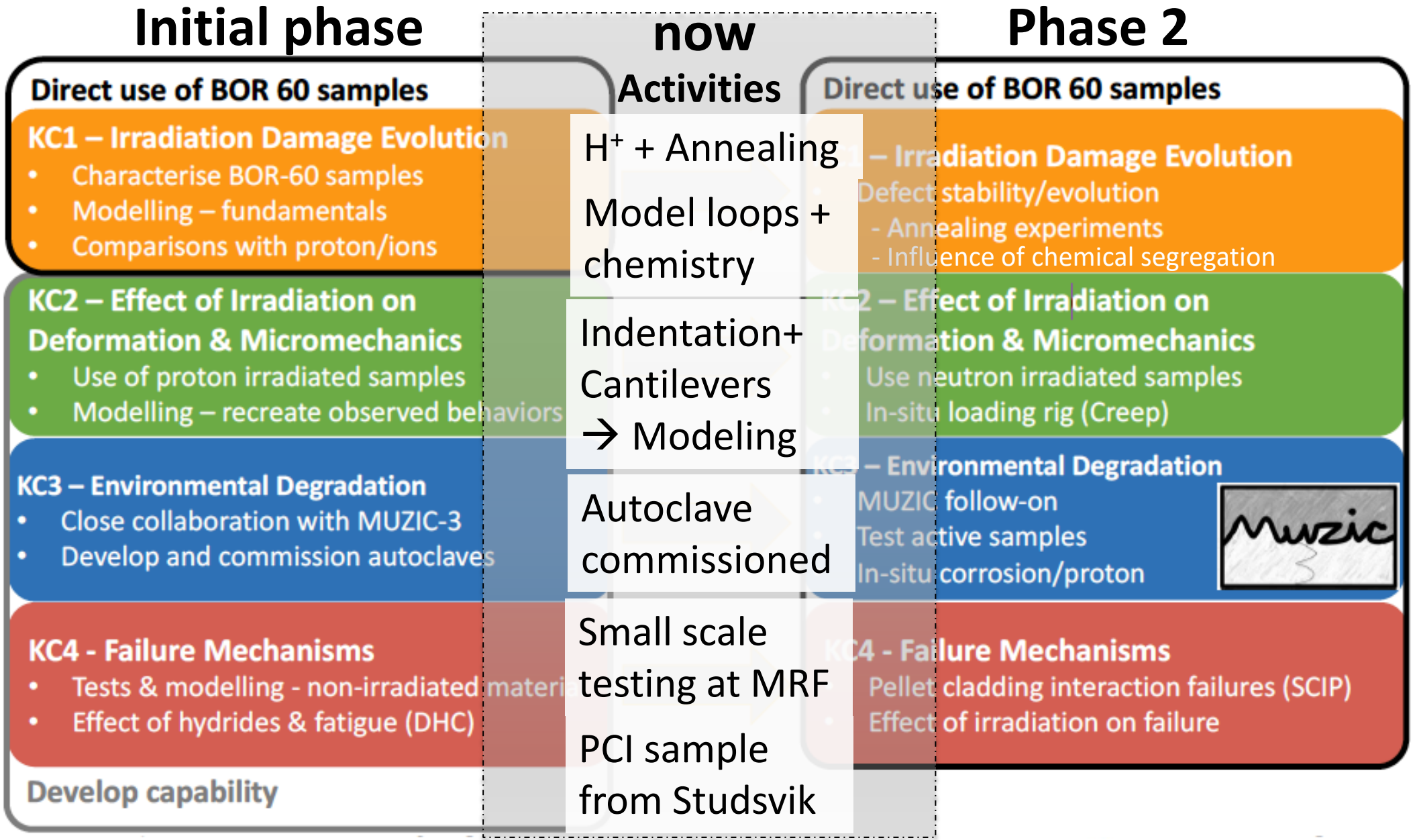






MANCHESTER 1824 The University of Manchester | Imperial College London | UNIVERSITY OF OXFORD | CCFE CULHAM CENTRE FOR FUSION ENERGY | NATIONAL NUCLEAR LABORATORY

Where are we now?



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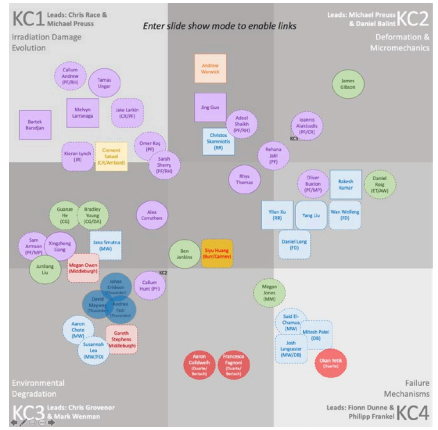
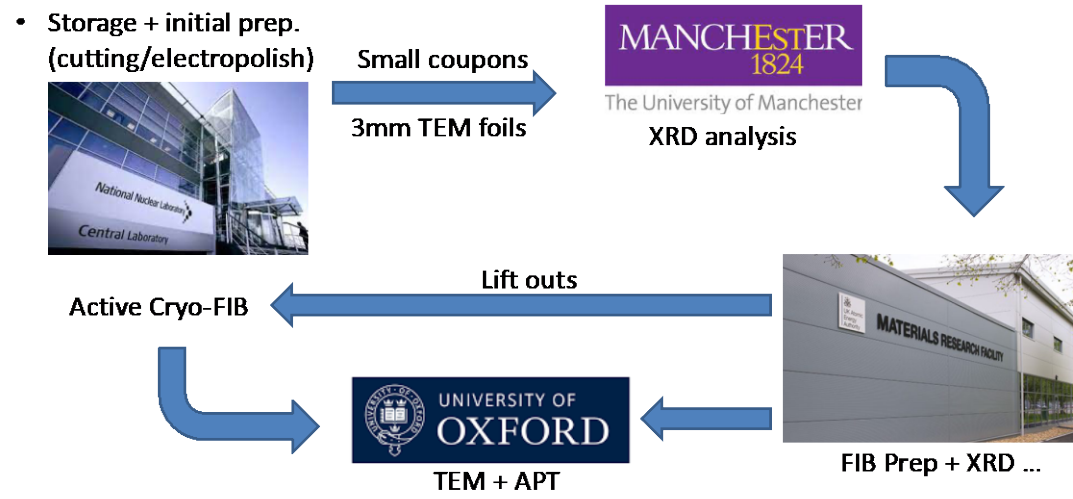
Highlights:

- Extension to 2025
- Cross-institution collaborations
  - Strain localization: HR-DIC vs CPFEM
  - TEM, XRD, APT + multi-scale modelling
- Active facility development/use
  - NNL, MRF, Royce & DCF
- Training & workforce pipeline
  - Fellowship training for PDRAs
  - PDRAs/PhDs to industry
  - Seconded researchers e.g. UKAEA, Jacobs





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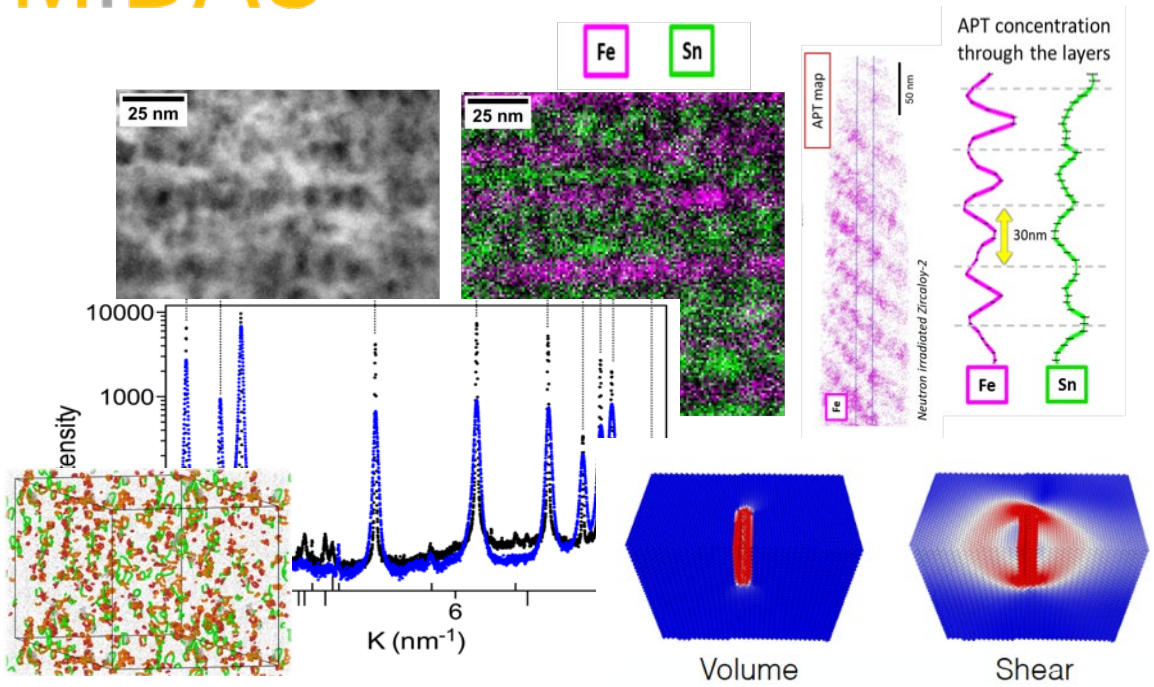
KC1: Irradiation damage evolution



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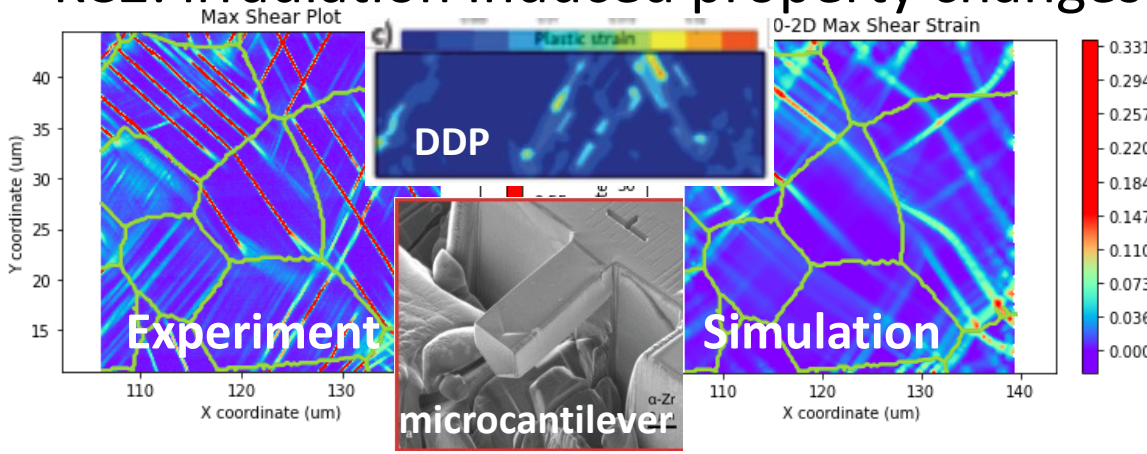
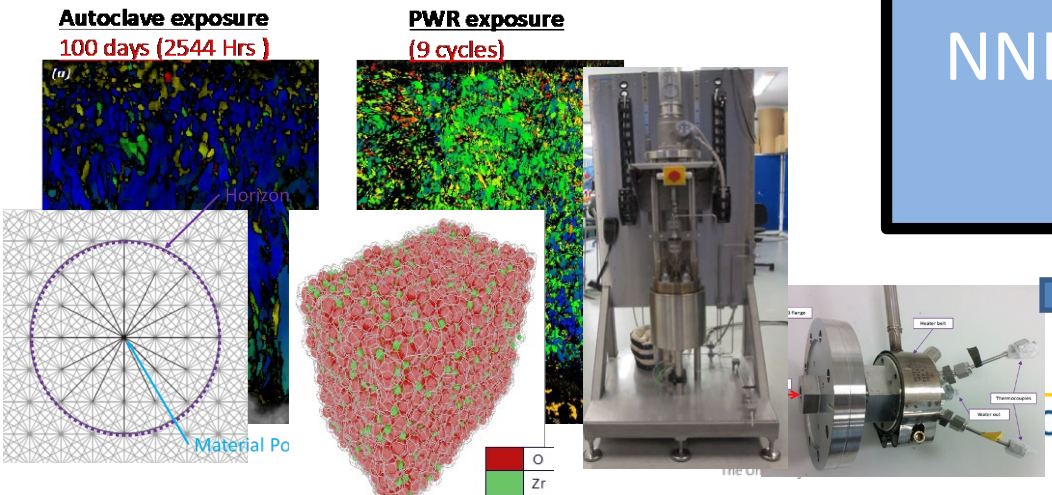
KC2: irradiation Induced property changes

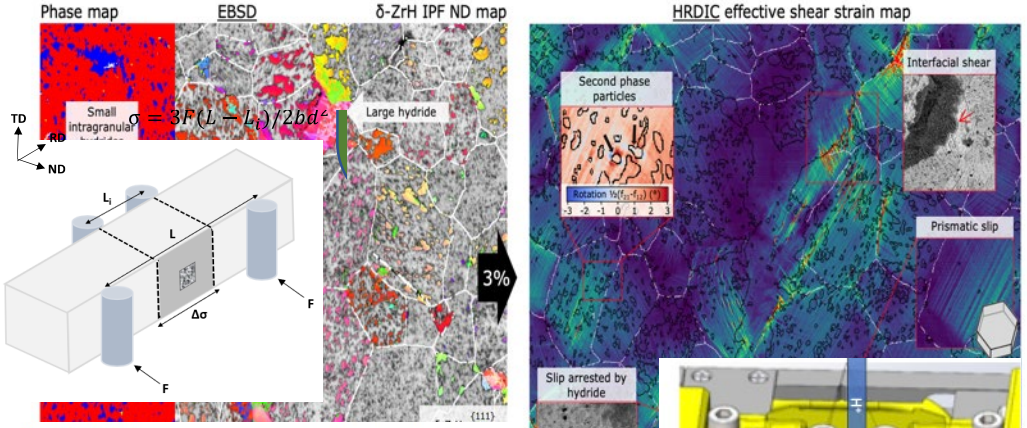


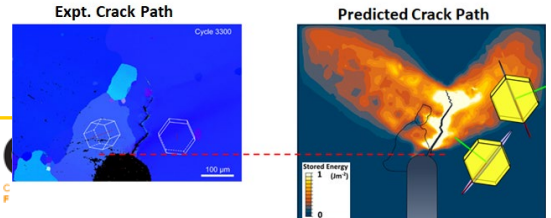
KC3: Environmental degradation



Active facilities : NNL, MRF, DCF, DLS, HRI

KC4: Failure mechanisms





College

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Figure 1: Rig for in-situ load + irradiation at DCF

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Use and movement of samples

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BOR60 samples now in use:

Alloy	XRD	TEM (FIB foil)	TEM (electropolished)	APT	Micro-cantilever	NanoHardness	Corrosion	H-charging	Annealing
ZIRLO	✓	3 fluences*	In-progress	3 fluences*	Ready for test	3 fluences	2023		2023
Zr-2 (W8)	✓	3 fluences*	In-progress	3 fluences*	Ready for test	3 fluences	2023	trials	2023
Zr-2-BQ (W7)	✓	3 fluences*		3 fluences*		3 fluences	2023		2023
Alloy 21 (W13)	✓	In-progress							
Alloy 3 (W10)	✓	In-progress							

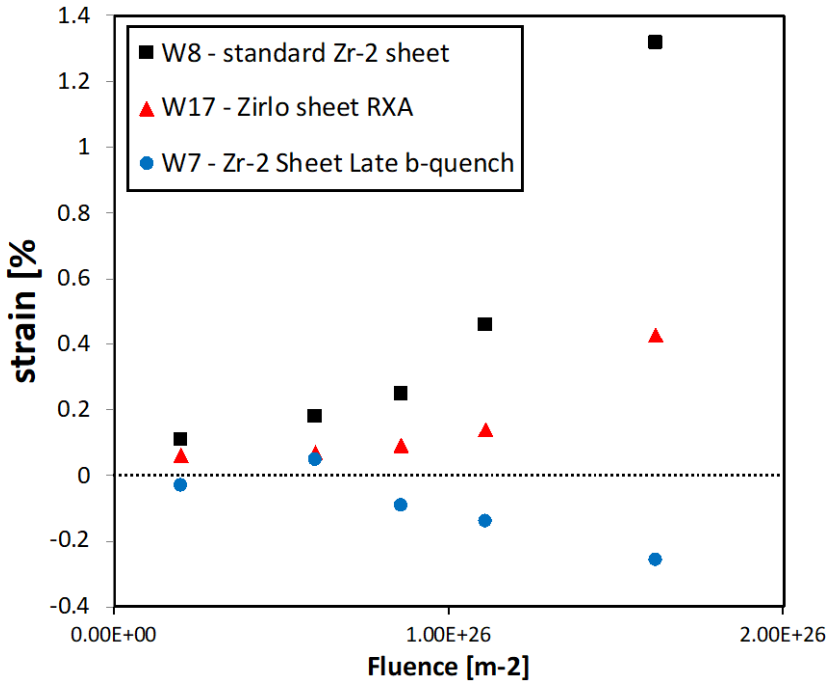
*Including Cryo-prep. trials

Baseline analysis:

Alloy	XRD	EBSD	TEM	APT	Micro-cantilever	Corrosion
ZIRLO	✓	✓	✓	✓	✓	✓
Zr-2 (W8)	✓	✓	✓	✓	✓	In-progress
Zr-2-BQ (W7)	✓	✓	✓	✓	✓	
Alloy 21 (W13)	✓	✓	✓	2023		
Alloy 3 (W10)	✓	✓	✓	2023		

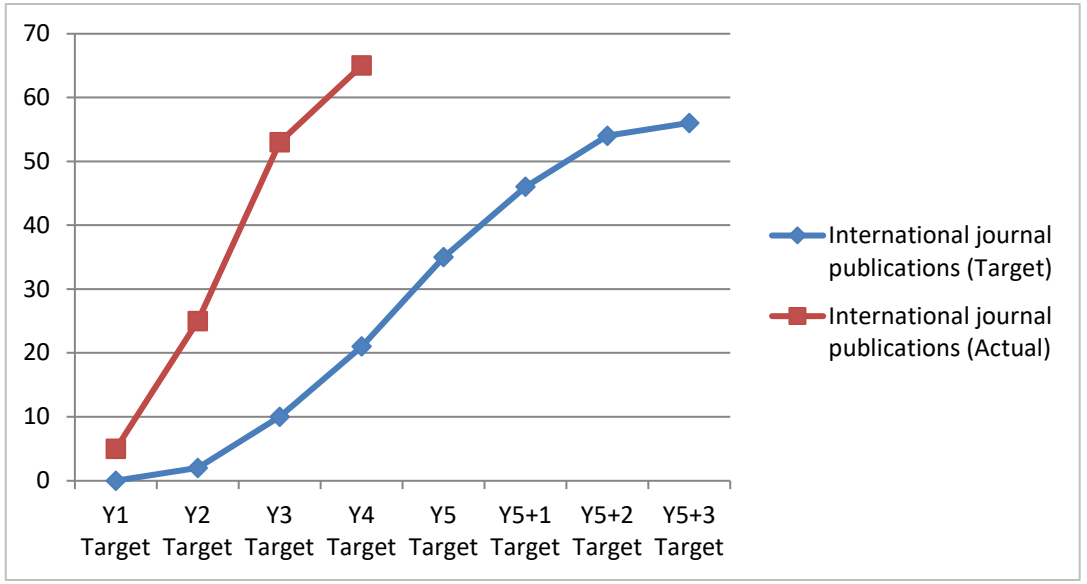
Proton irradiated samples:

Alloy	XRD	S-XRD	Nano-hardness	HR-DIC	Micro-cantilever	Corrosion	APT
ZIRLO	✓	✓	✓	✓	✓	In-Progress	✓
Zr-2 (W8)	✓	✓	✓	✓		2023	✓
Zr-2-BQ (W7)							
Alloy 21 (W13)	In-progress						2023
Alloy 3 (W10)	In-Progress						2023



Output

Our KPI was to have a total of 21 peer-reviewed journal publications by this point in MIDAS. We have achieved over three times this number.



Five Key Recent publications

- ***Untangling competition between epitaxial strain and growth stress through examination of variations in local oxidation***
  M. Yankova, et al. (Manchester) – *Nature Communications*
- ***Zirconium hydride phase mapping in Zircaloy-2 cladding after delayed hydride cracking***
  A.W. Colldeweih, et al. (PSI) – *Materialia*
- ***Simulation of crystal plasticity in irradiated metals: A case study on Zircaloy-4***
  C. Hardie, et al. (Imperial, Manchester, UKAEA) – *Acta Materialia*
- ***Preliminary Atom Probe Tomography Evidence for Hydrogen Trapping at a β-Nb Second Phase Particle in a Neutron-irradiated Zirconium Alloy***
  B.M. Jenkins et al. (Oxford, UKAEA, MPI Eisenforschung, imperial, UNSW) – *Microscopy and Microanalysis*
- ***Microstructural complexity and dimensional changes in heavily irradiated zirconium***
  A.R. Warwick et al. (UKAEA) – *Physical Review Materials*

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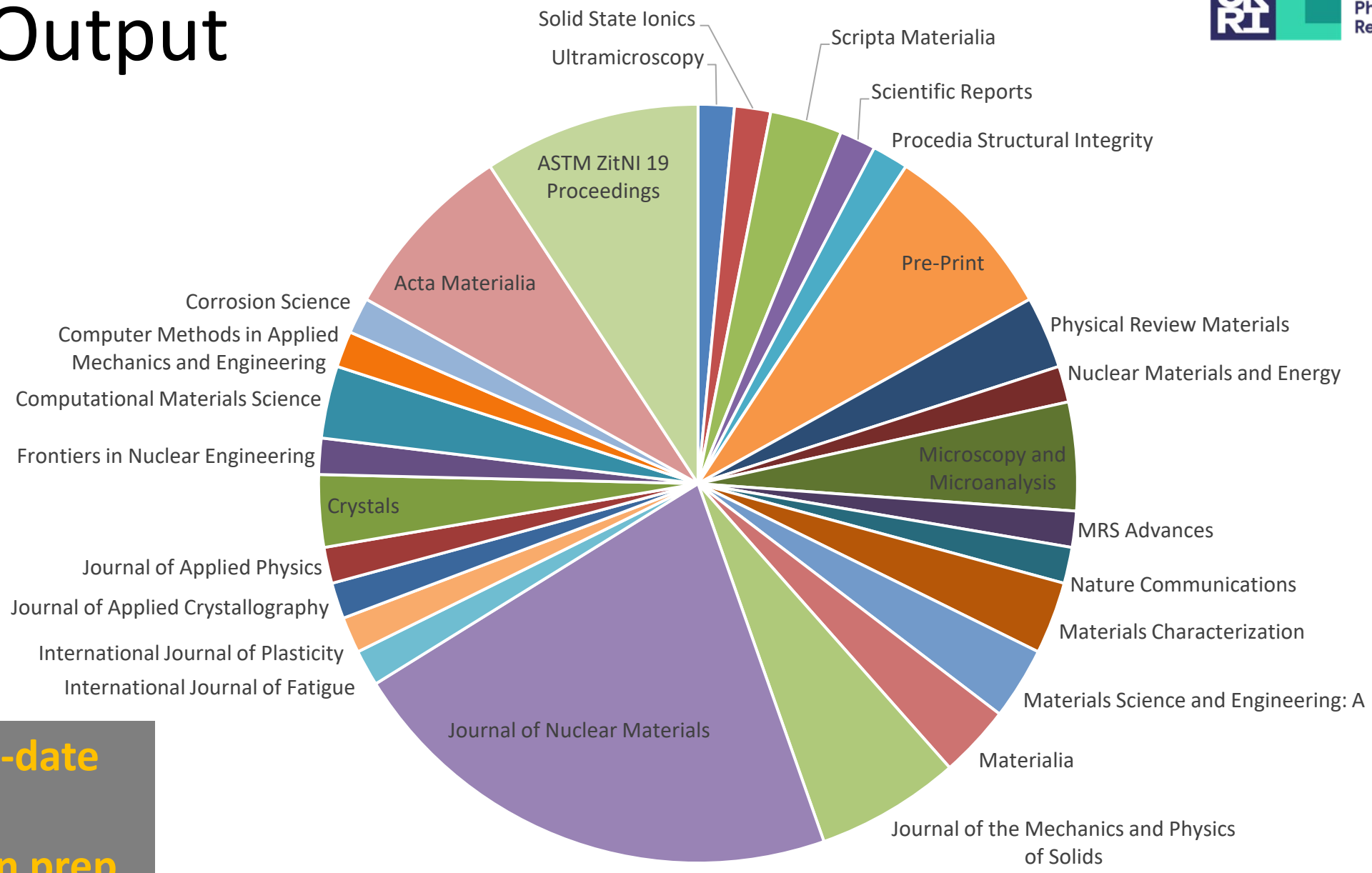
Output



- 66 papers to-date
- 27 journals
- 20+ papers in prep.

Thank you