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Graphite – Molten Salt Interactions Workshop 20th/ 21st July 2022

Nuclear Graphite Research to Support MSR development

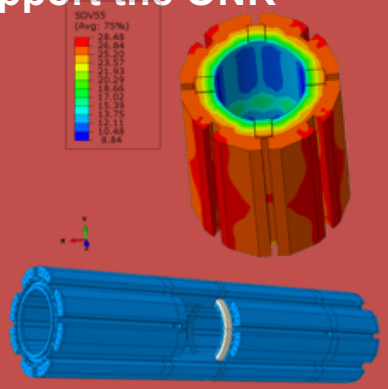
Prof. Abbie Jones

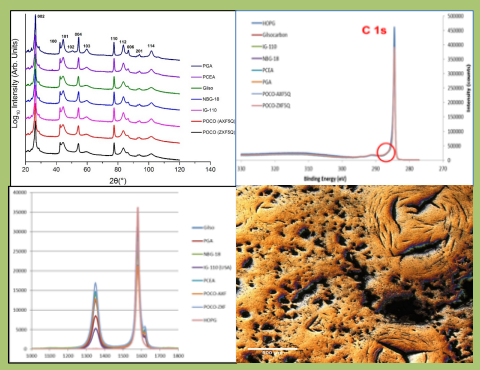
Nuclear Graphite Research Group
The University of Manchester, UK

Nuclear Graphite Research Group

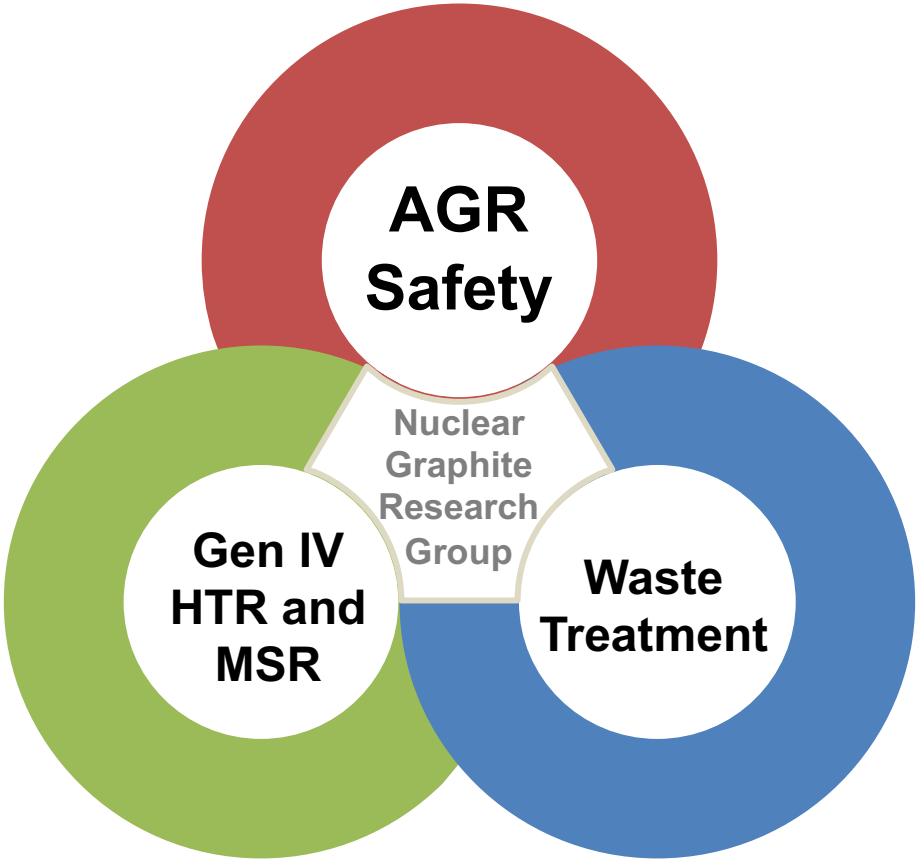
- Founded in September 2001, we are an internationally recognised nuclear research group based at the University of Manchester
- Within the UoM, NGRG are members of:
  - Dalton Nuclear Institute
  - Henry Royce Institute for Advanced Materials
- Major Partnerships - NGRG > £24M in funding and collaborations including:
  - Research Councils & Innovate UK
  - National and International Facility Access
  - UK Nuclear Industry
  - European and International Commission
  - Worldwide collaborations
- Publications and IMPACT
  - over 150 open literature publications
  - Two UK REF impact cases – 2014 and 2021
  - Over 280 substantial industrial reports

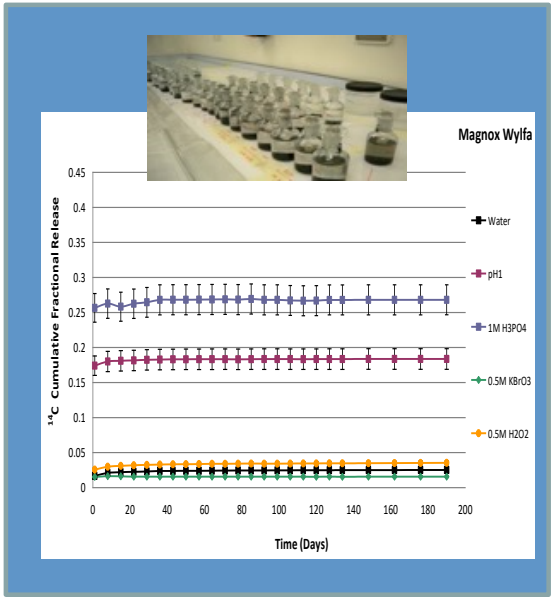
Independent Stress analysis of AGR bricks to support the ONR





Mechanisms of Retention and Transport of Fission Products in Virgin and Irradiated Nuclear Graphite





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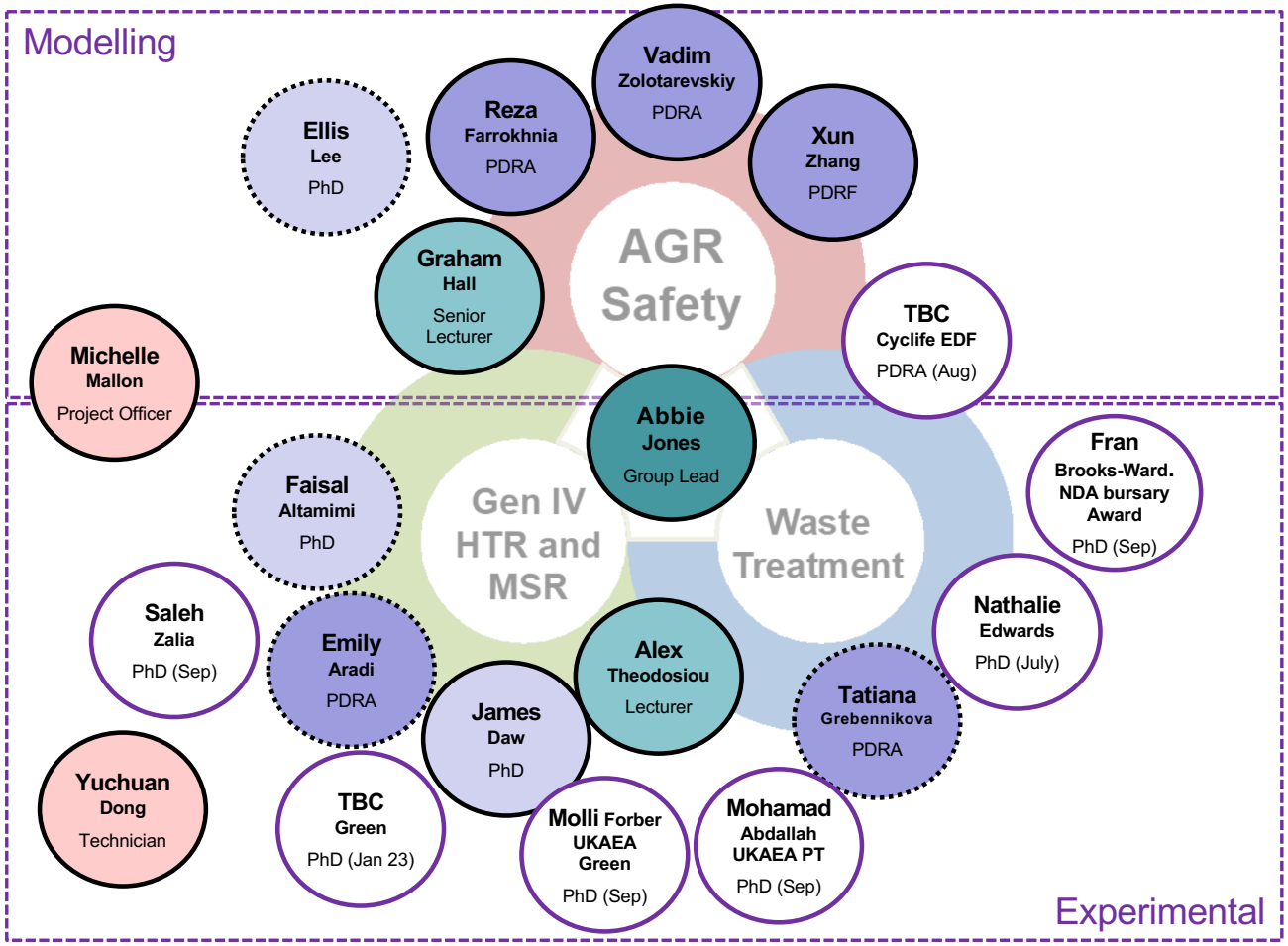
Nuclear Graphite Research Group (NGRG)



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FACILITIES

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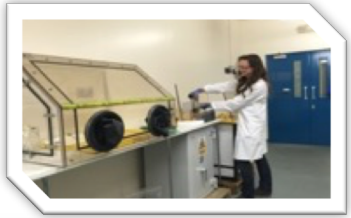
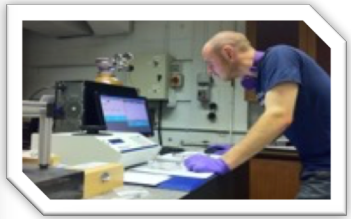
Irradiated Materials Facility

- **Reactor graphite samples**
- Sample machining, preparation, radiometric and radiological fingerprint characterisation (α, β & γ)
- Microstructural characterisation (2 & 3D) including spectroscopic & crystallographic
- In situ testing mechanical and environmental
- Chemical and physical treatments with on line spectroscopic evaluation
- Moved into Royce Hub irradiated materials facility → June 2022 with £1M equipment expansion



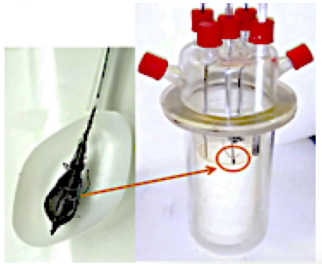



Molten Salts in Nuclear Technology Laboratory

National Nuclear User Facility

- £2.3 M new research facility – several hubs
- The MSNTL aims to provide a molten salt R&D capability for studying ***fluoride salts in nuclear systems*** **within the UK for the first time.**
- Enabling the UK's expertise in chloride salts from pyroprocessing research to alternative salt systems in order to explore expanding research areas such as ***Molten Salt Reactor*** technologies
- Providing an ***interdisciplinary hub*** for molten salts research with radioactive materials.
- Utilising bespoke experimental rig designs
  - Molten salts irradiation test rigs
  - High temperature column for dynamic ion exchange studies with molten salts



The high-temperature molten salt graphite treatment

Dalton Cumbrian Facility

(image courtesy of Dalton Nuclear Institute)

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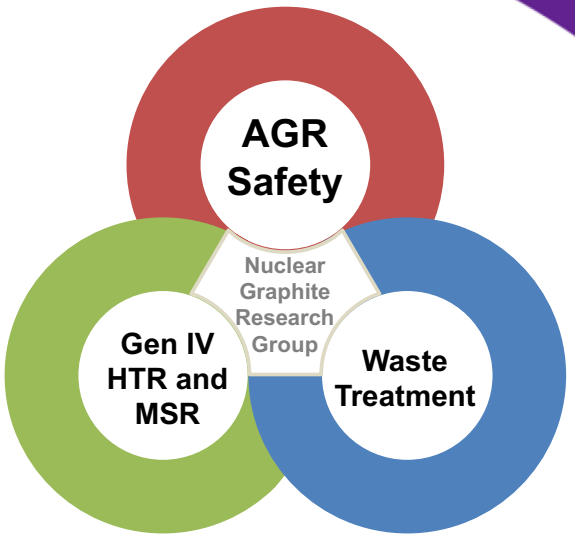

R&D PROJECT AREAS – AGR SAFETY

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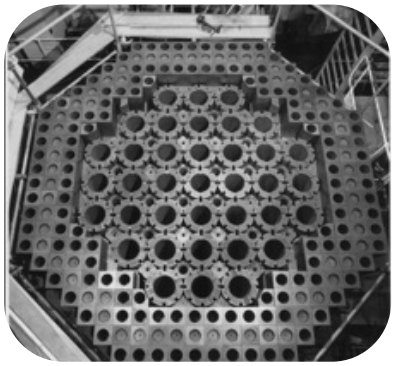
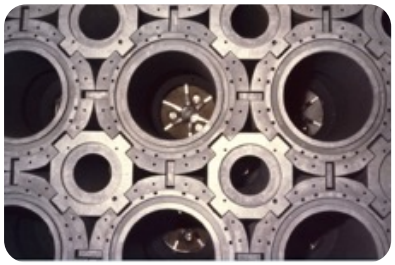
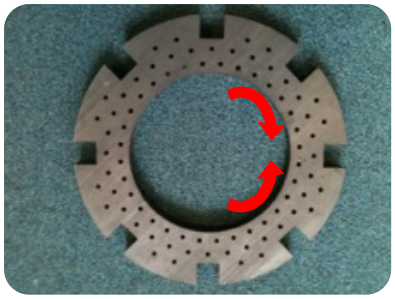
AGR lifetime evolution







- **Brick –Brick interactions**
- **AGR single Brick**
  - Irradiated Induced Dimensional Change / Thermal Stresses → Cracks / Shrinkage
  - Δ F/ T and Oxidation
- **Radiolytic Oxidation**
  - Pore structure evolution with irradiation
  - Permeable flow and chemistry

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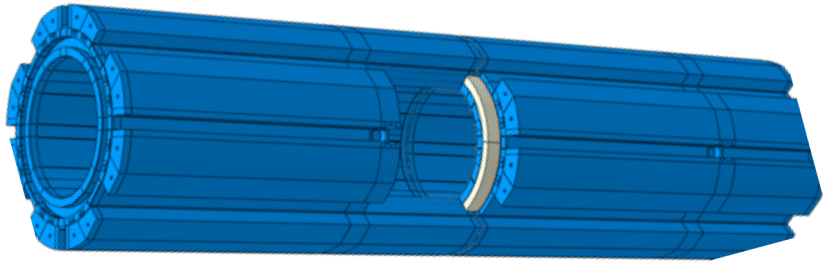
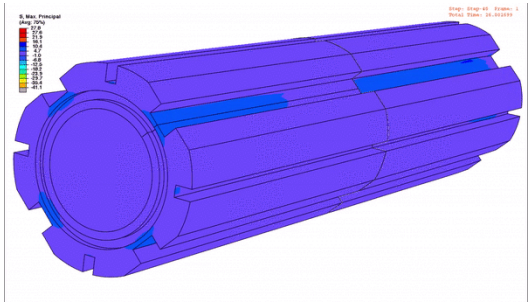
Finite element modelling & analysis to provide independent support the ONR

Heysham 2 & Torness sealing ring analysis to support the ONR

Detailed finite element model assembly



Stresses due to crack opening



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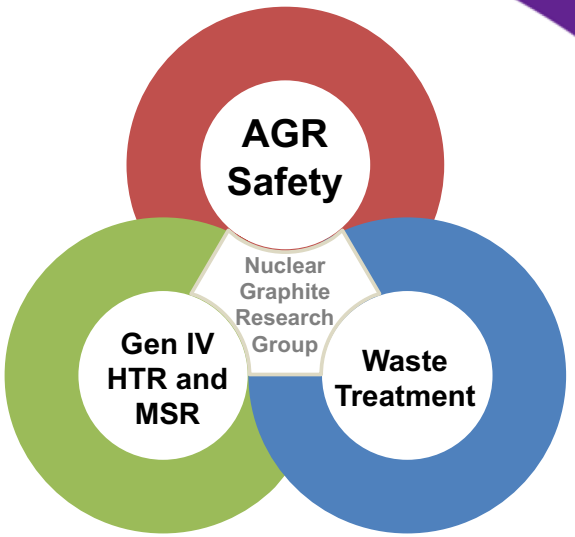


R&D PROJECT AREAS – NEW TECHNOLOGY: HTR AND MSR

MSR challenges

Research Areas

- Understanding new graphite
  - microstructures and porosity distributions
- Materials properties behaviour → evolution with irradiation and high temperatures
- Fission product behaviour → intrusion, retention, migration and location
- Electrochemistry interactions
- Waste behaviour and treatment options - reduce impurity content, management of ^{3}H and others

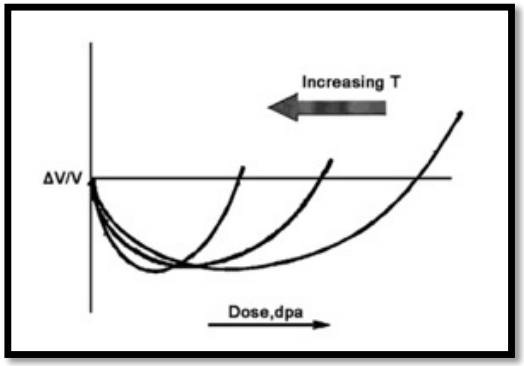
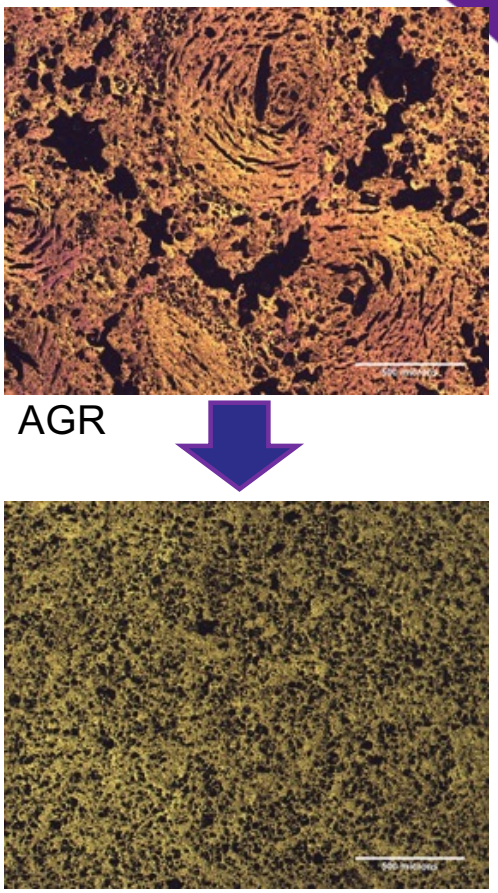


Fig. 1 Schematic of the effects of temperature on the irradiation damage behaviour of graphite.



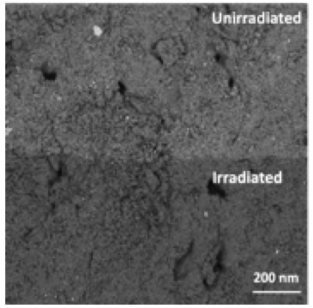
AGR

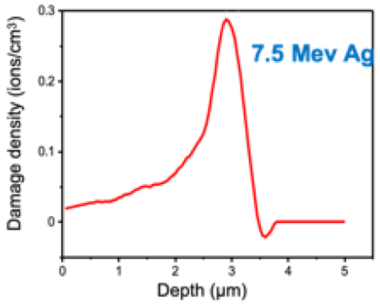
MSR / HTR

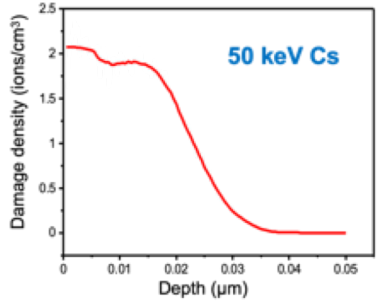
Mechanisms of Retention and Transport of Fission Products in Virgin and Irradiated Nuclear Graphite

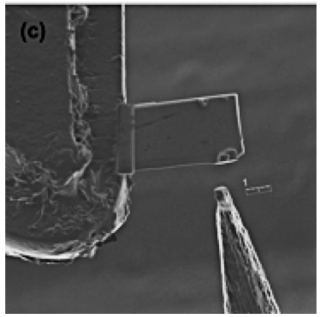
UoM, Loughborough, UCF, ORNL, NCSU

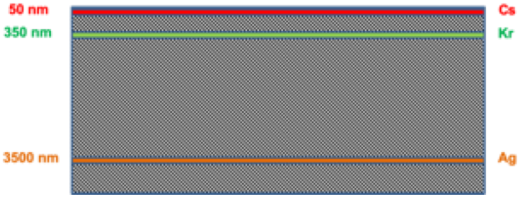
- NBG-18, PCEA and POCO (ZXF-5Q and AXF-5Q), IG-110 and HOPG;
- Infusion/ infiltration
- Implantation using ion beam irradiation (Cs and Ag);
- Crystallite recovery via annealing;
- Techniques: TEM, HAXPS, Raman spectroscopy.

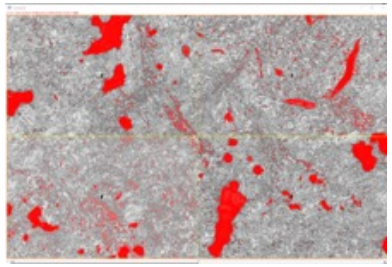


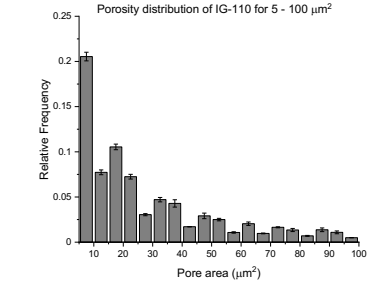


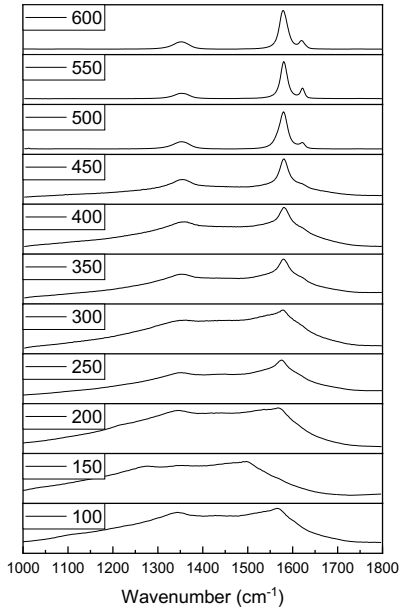












https://doi.org/10.1016/j.jnucmat.2021.153262

https://doi.org/10.1016/j.apsusc.2019.144764

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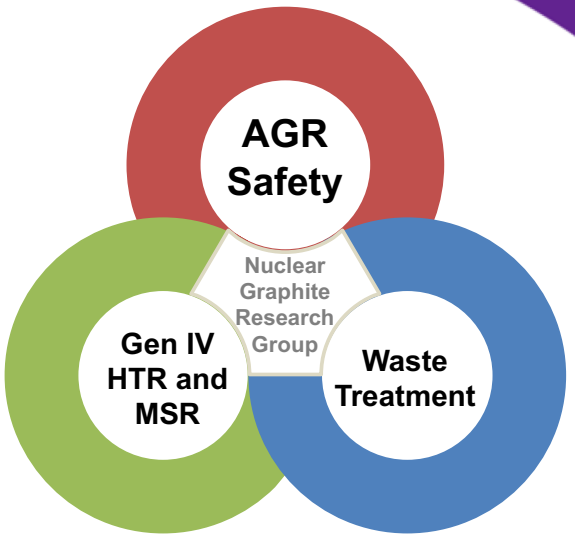

R&D PROJECT AREAS – WASTE TREATMENT

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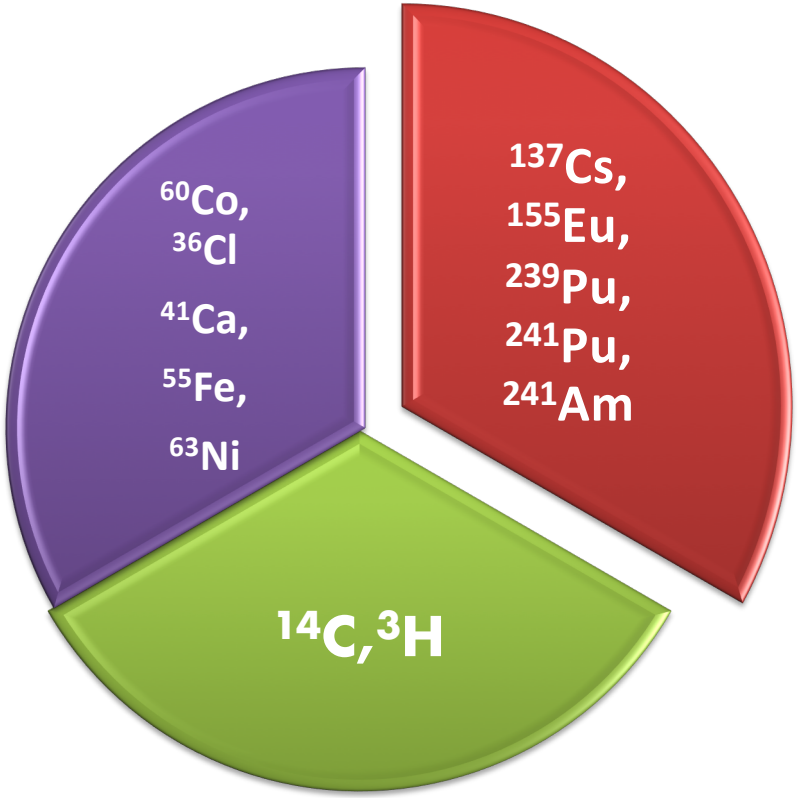
Graphite Waste and Treatment

Research challenges

- Complexities due to graphite grades, varied operational environment, oxidation and irradiation damage
- Challenges around removal, treatment and long term behaviour in a GDF

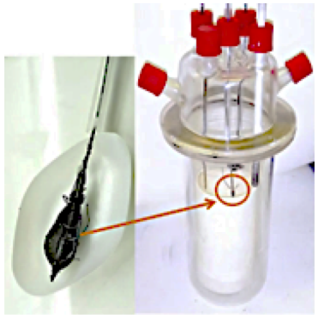
Research needs

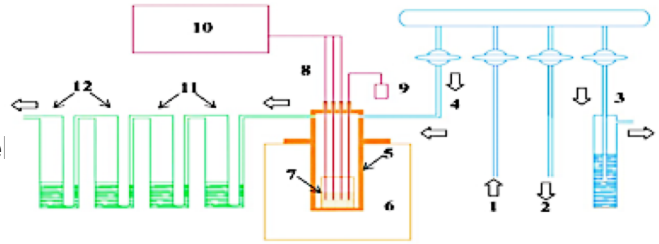
- Scale up: ⇡ TRL with industrial partnerships
- Provide joined up solutions for graphite waste from retrieval to GDF
- Decontamination of ^{14}C & further long lived nuclides
- Volume / isotope reduction (ILW →LLW)
- **Potential reuse and recycle graphite material for Gen IV**



Graphite Waste R&D: decontamination project

1. Investigate the application of electrolysis to irradiated graphite
2. Assess the release of corrosion and fission products in molten salt media
3. Examine graphite behaviour and structural changes under molten salt conditions
4. Understand the behaviour and associated release into the gas phase





Working electrode with graphite basket and the ce used

The high-temperature molten salt apparatus

[1] Grebennikova T, Jones AN, Sharrad CA Energy Environ Sci 2021. doi:10.1039/d1ee00332a.

[2] Worth RN, Theodosiou, Wickhamd AJ, Jones AN, J Nucl Mater 2021; doi:10.1016/j.jnucmat.2021.153167.

[3] Theodosiou A, Jones AN, J Nucl Mater 2018. doi:10.1016/j.jnucmat.2018.05.002.

[4] Theodosiou A, Jones PLoS One 2017;12:1–19. doi:10.1371/journal.pone.0182860.

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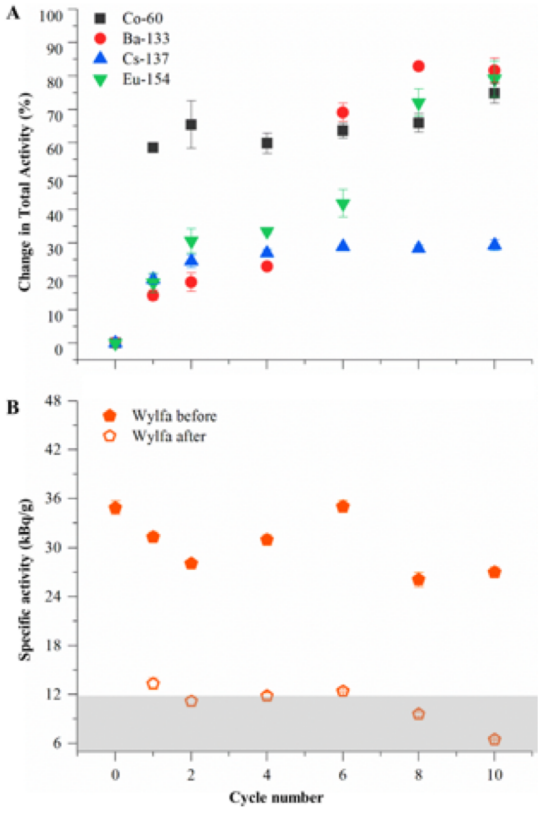
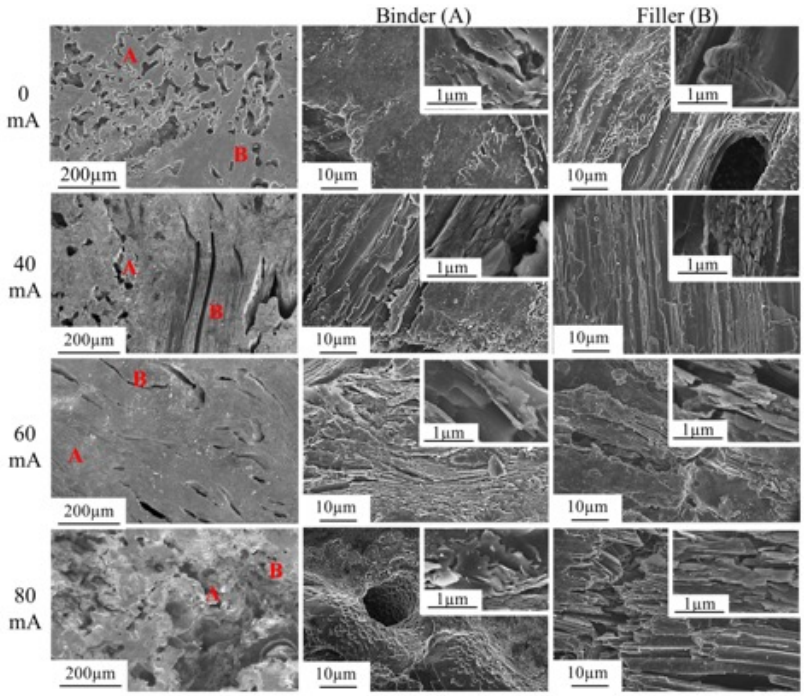
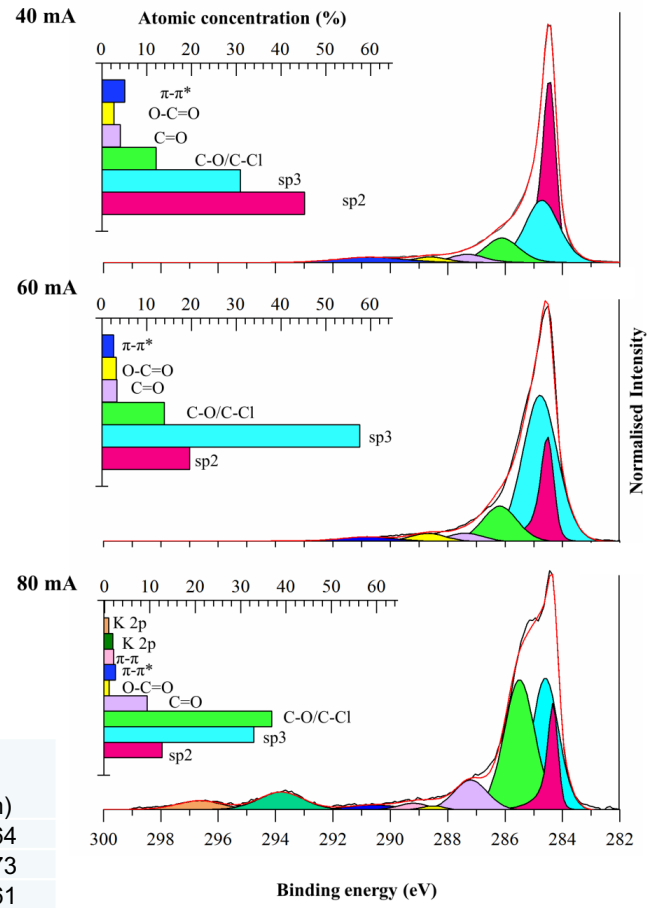
Graphite Waste R&D: decontamination project





Current, mA	2 θ (°)	$d_{(002)}$ (nm)	c (nm)	Bθ (radian)	L_c (nm)
0	26.37	0.3380	0.6760	0.0095	15.64
40	26.35	0.3383	0.6766	0.0101	14.73
60	26.21	0.3400	0.6800	0.0102	14.61
80	26.60	0.3352	0.6704	0.0116	12.79



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Ongoing and forwards research

- Retention and Transport of Fission Products in Nuclear Graphite for Next Generation Nuclear Reactors – James Daw, Alex Theodosiou and Abbie Jones
- The Electrochemical Treatment of Nuclear Graphite in Molten Salt media - Faisal Altamimi, Abbie Jones and Clint Sharrad
- Decontamination of carbonaceous nuclear waste streams for segregation and re-use: Graphite recycling - Fran Brooks-Ward, Abbie Jones and Clint Sharrad
- Tritium removal from molten salt media in nuclear fission / fission processes – Molli Forber Abbie Jones and Clint Sharrad

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