Modelling Materials to withstand the extreme conditions of future Nuclear Fusion Power Reactors

UNIVERSITY OF OXFORD

UK Atomic Energy Authority

WHY I have a dream of clean, cheap and endless energy.

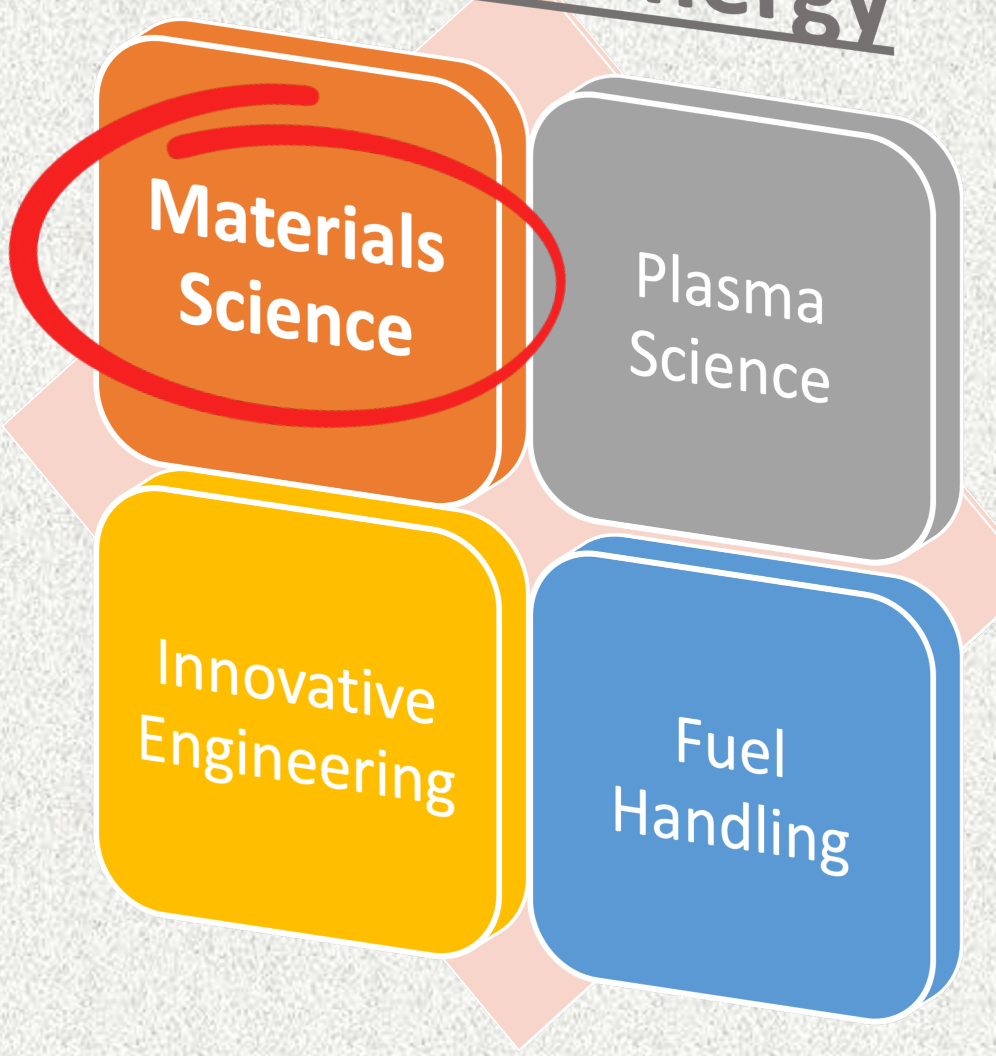
WHAT Creating a mini-Sun on Earth.

HOW Fusion energy is considered the "holy grail" of energy, practically clean (without radioactive waste), endless for next centuries and much cheaper than current energy sources.

WHO It is crucial for nations and businesses to embrace opportunities in the energy transition for success in a post-oil world.

UK Atomic Energy Authority (UKAEA) is leading the ambitious £600 million STEP project.

Challenges in Fusion energy



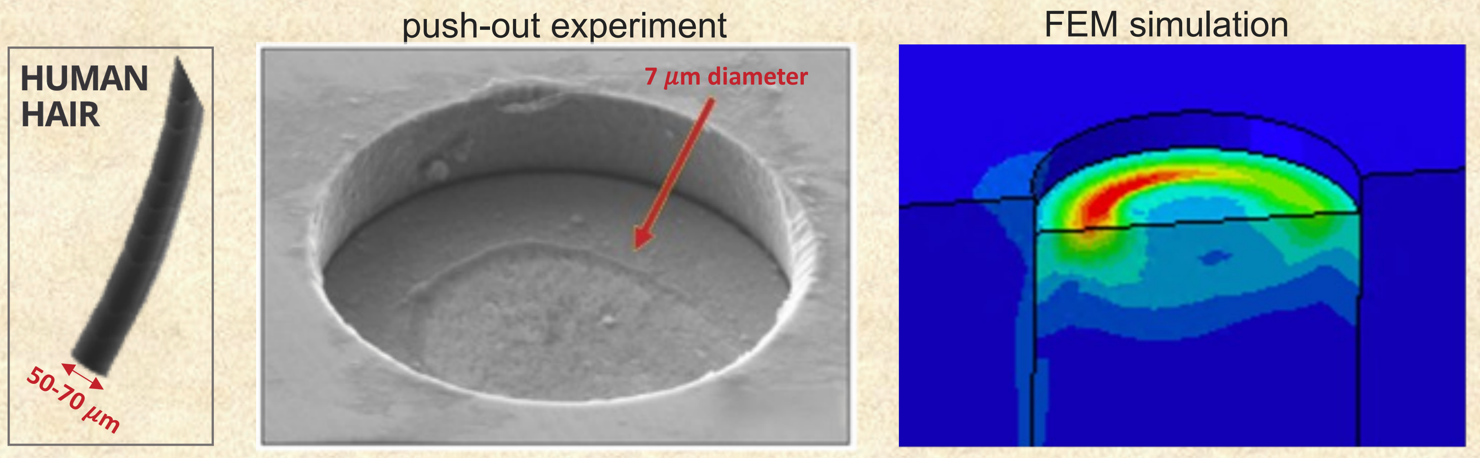
Materials within reactor are exposed to a combination of high temperatures and intense radiation. Developing materials capable of withstanding these **hard conditions** for long periods is a fundamental objective for the nuclear industry.

To accomplish this objective, the **physical laws** that explain the behaviour of reactor materials have to be derived using **mathematical models**.

In addition, the use of **simulation algorithms** based on the finite element method (FEM) makes it possible to analyze different configurations quickly and cost-effectively.

Silicon Carbide (SiC)

Silicon Carbide (SiC) supports the lithium for fusion fuel production, but radiation and temperature can cause dangerous cracks. We **minimized crack** propagation by **inserting SiC fibers** with a carbon barrier, which prevents fiber breakage and slows crack expansion. Our work focused on optimizing the barrier thickness and identifying the supported strength through fiber push-out experiments and **analytical FEM models**.



[1] Martinez-Pechero, A., Zayachuk, Y., Widdowson, A., Armstrong, D. E., Tarleton, E. (2023). Obtaining SiC Fibers–PyC interfacial properties through push-out FEM Models. *Journal of the European Ceramic Society*.

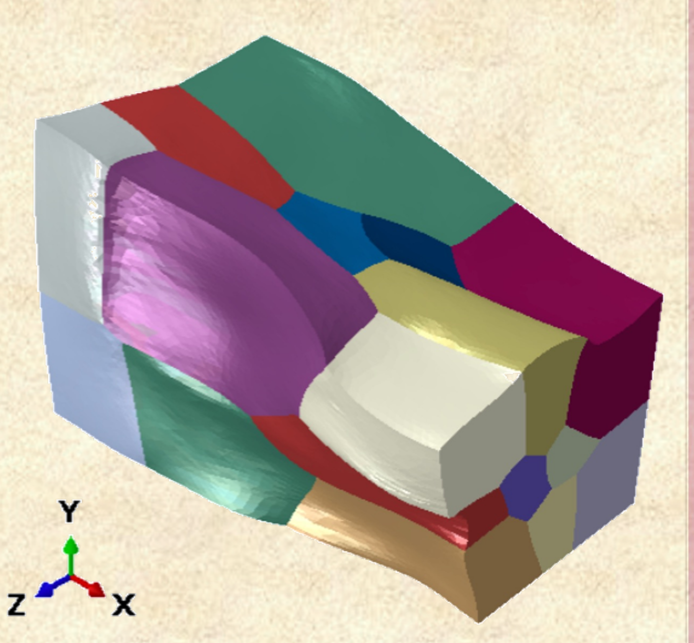
[2] Martnez-Pechero, A. "Cohesive zone modelling of SiC Fiber-PyC crack propagation during fibers push-out". 21st International Conference on Fusion Reactor Materials (2023).

Beryllium and virtual materials

Beryllium is essential for constructing fusion reactor walls, acting as a final barrier during **fuel loss incidents**. Its unique, grainy structure makes it particularly brittle in certain orientations, raising concerns about its use in fusion reactors despite the lack of suitable alternatives.

Crystal plasticity models are being developed in Oxford to simulate these grain structures under different temperature and radiation conditions.

These models provide insight into fracture and deformation in many materials (**copper, beryllium, zirconium** ...). This research is essential to help UKAEA find potential alternatives.



[3] Demir, E., Martinez-Pechero, A., Hardie, C., & Tarleton, E. (forthcoming 2024). Consistent calculation of geometrically-necessary dislocations in the crystal plasticity-based finite element method.

[4] Martinez-Pechero, A. & Kuksenko, S., et al. (forthcoming 2024). Modelling Fracture Properties of monocrystalline Beryllium.

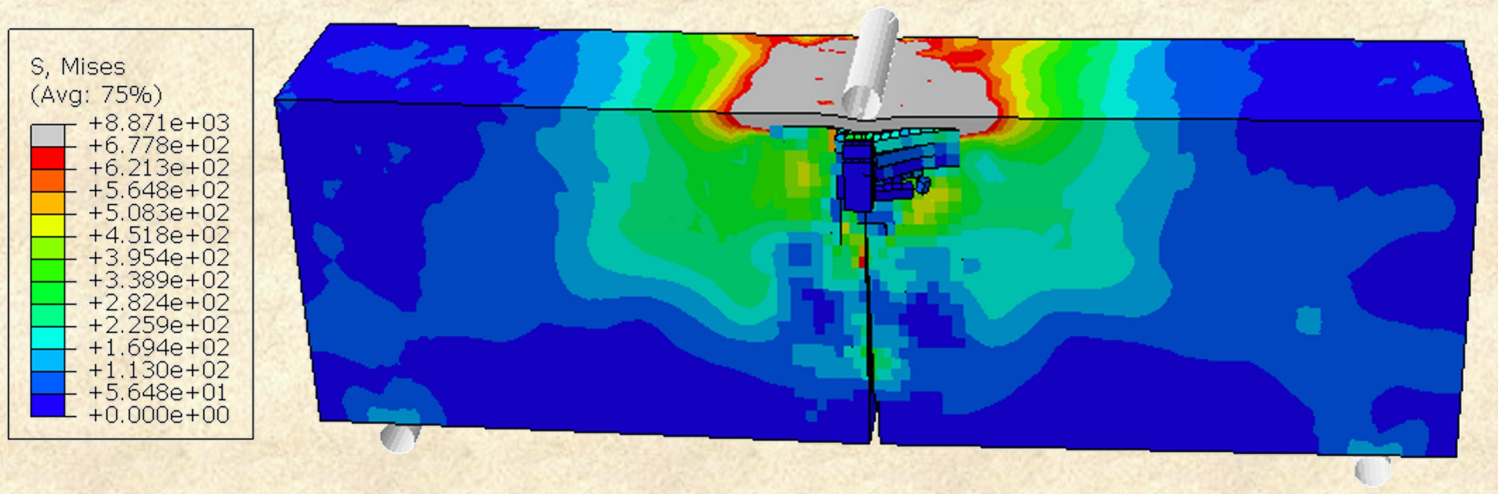
[5] Martinez-Pechero, A., Demir, E., Hardie, C., & Tarleton, E. (forthcoming 2024). Modelling Bauschinger effect in Copper during preliminary load cycles.

Tungsten Fiber reinforced

Finding a material that can withstands up to 3,500ºC and rapid cooling in the **power/heat exhaust systems** of the reactor is a major challenge for Fusion.

Tungsten is one of the main candidate materials. **Forschungszentrum Jülich** (Germany) has developped an innovative technique to enhance its **toughness 10 times** by introducing plastically deformed tungsten fibers into the material.

During my stay, I have studied how the reinforcement provided by the introduction of fibers **scales with size**.



[6] Shu, R. , Mao, Y. , Coenen, W. J., Martinez-Pechero, A., et al. (forthcoming 2024), Study on the fracture behavior and toughening mechanisms of continuous fiber reinforced Wf/Y2O3/W composites fabricated via powder metallurgy.

Acknowledgements

- Department of Engineering Science, University of Oxford.
- UK Atomic Energy Authority (UKAEA), Culham Centre for Fusion Energy.
- Forschungszentrum Jülich GmbH, Institut für Energie-Plasmaphysik, Jülich, Germany.
- EUROfusion Consortium (Grant Agreement 12490 — EUROfusion).
- EPSRC (Grant Number R76251/CN001).

Alvaro Martínez-Pechero alvaro.martinezpechero@eng.ox.ac.uk

- **Enrolled in a doctoral program at Oxford University and UK Atomic Energy Authority**
- **MSc Fusion Energy (York University)**
- **Physics degree (Salamanca University, Spain)**