OV - OVERVIEW OF UKAEA'S INTEGRATED FUSION TECHNOLOGY PROGRAMMES, EMPHASISING A DIGITAL FIRST STRATEGY

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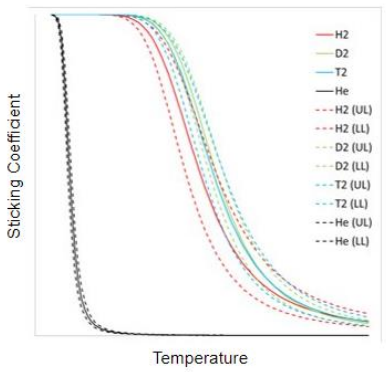
The UK Atomic Energy Authority (UKAEA) has experienced significant growth in its fusion technology programs, marked by the development of cutting-edge facilities and a robust technical expertise foundation. This paper provides an overview of the critical advancements within UKAEA's fusion technology initiatives, including JET Decommissioning, Robotics, Materials, Technology Development, and Tritium. It also highlights the status of world-leading fusion facilities such as H3AT, CHIMERA, and LIBRTI, emphasizing the integrated nature of these programs. We will provide an overview of the breadth of our programmes and highlight influential results, with a specific focus on UKAEA's multidisciplinary, digital-first approach in our paper.

Since building fusion experiments is relatively slow and expensive compared to public and private timelines for fusion delivery, we must be strategic. Rather than focus on empirical data gathering and real-life experience of every system and condition, we use advanced modelling to guide us toward the minimum number of targeted experiments needed to validate our predictions. In addition, we focus on working across various programmes to bring together experts and models from different fields to ensure that implications of any results or design decisions are fully understood. Examples of impactful results, emanating from this strategic digital first approach, are presented below.

Tritium: Developing models that can predict tritium behaviour across the range of conditions and materials encountered in the fusion fuel cycle is essential for estimating tritium inventory requirements and predicting system performance. UKAEA has been utilizing JET's own fuel cycle, the Active Gas Handling System (AGHS) to assist in the development of advanced multiscale tritium modelling. A key milestone in this approach is the first-ever full validation of a continuous cryopump model for tokamak pumping and Direct Internal Recycling (DIR) using the AGHS prototype cryopanel. Absorption and regeneration data was gathered from 71 experimental runs with He, H2, D2, T2 (pure and mixtures) in static, semi-flowing and full-flowing modes. The kinetic parameters were used to derive sticking coefficients and adsorption isotherms as shown in figures 1 and 2. This validated model enables optimization of cryopanel design, redundancy strategies, and DIR loop configurations while providing system-wide performance insights.



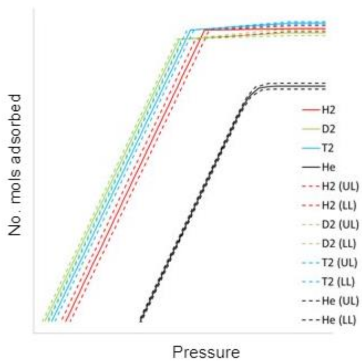


Figure 1: Sticking coefficient vs temperature for hydrogen isotopes and helium. Uncertainties shown with dotted lines.
Figure 2: Absorption vs pressure for hydrogen isotopes and helium, uncertainties shown with dotted lines.

Similar analysis has been undertaken on other fuel cycle subsystems including uranium storage beds and the gas chromatography isotope separation system. These experiments currently provide the only available data for validation of fuel cycle unit operation models, enabling increased understanding of fuel cycle performance, and enabling improved estimates for power plant tritium inventories [1].

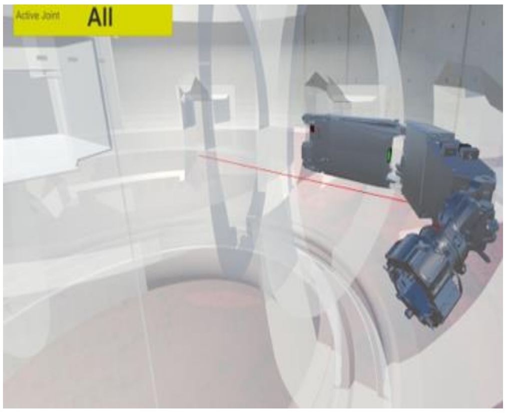


Figure 3: Digital model of TARM, i.e., a slender manipulator with flexible nonlinear dynamics, in JET for decommissioning tasks.

Robotics and decommissioning: The UKAEA has launched the JET Decommissioning and Repurposing (JDR) programme following the completion of JET's final deuterium-tritium campaign. It plans to use multi-purpose deployers (MPDs) to carry out non-repetitive motions for decommissioning tasks. However, MPDs are flexible, slender robots that exhibit nonlinear dynamics. Any manoeuvre performed by/to an MPD could lead to vibrations and potential collisions. UKAEA has developed modelling and control techniques enabling digital simulations of the dynamic challenges, to verify associated risks and accelerate the decommissioning process (see a digital nonlinear model of TARM [2] moving in JET in Fig. 3). Simulation studies show a possibility of operating MPDs at a 3x speed for complex decommissioning movements, thereby reducing risks and enhancing operational efficiency [3]. Future plans to exploit the full potential of the technology include experimental verification in research platforms such as TARM.

Materials: Efforts on materials developments at UKAEA have also emerged at pace, including the NEURONE programme. NEURONE is a UKAEA-led steels consortium of UK academics and industrial partners, with a goal to develop and assess new, advanced, fusion-ready reduced-activation ferritic-martensitic (ARAFM) steels for tonnage-scale production by 2028. One such development is the recent UK-first production of fusion-grade RAFM steel using a seven-tonne Electric Arc Furnace (EAF), shown in Figure 4. This landmark achievement demonstrates new capability for the production of fusion grade steel with sufficiently low impurity levels and only a single production process required, resulting in significantly reduced costs and production timescales. This achievement has also now been replicated with the production of a novel UKAEA designed material. We will also discuss the novel digital first approach that is being applied to the NEURONE steels, to determine irradiation induced deformation and failure modes under fusion conditions.

Figure 4: NEURONE project billet leaving the caster and entering the product straightener. Image Credit: Materials Processing Institute

REFERENCES

[1] Chr. Day et al. “The pre-concept design of the DEMO tritium, matter injection and vacuum systems” Fusion Engineering and Design, vol.179 (June 2022)

[2] Grazioso, S., et al. "Multibody simulations of the telescopic articulated remote manipulator with flexible payload for demo studies on remote handling." Eng. Des (2019).

[3] Zhang K., et al, “Efficient and Safe Fuel Debris Retrieval Utilising Long-Reach Manipulators Through Advanced Control Techniques and Motion Planning.” FDR 2024. Fukushima, Japan. (2024 Oct).

[4] Kodelli et al, “Use of shielding benchmark experiment database (SINBAD) to identify nuclear data status and guide future experimental activities” Proposed for FEC 2025

[5] Lim et al, “Accelerating development of sustainable fusion reactors with tuneable neutron field of compact accelerator-based neutron sources” Proposed for FEC 2025

[6] Skilton et al, “Overview of recent results in research tackling remote maintenance challenges of future fusion energy devices” Proposed for FEC 2025

[7] Barth et al, “STEP Exhaust System – Architecture and Technology Development overview” Proposed for FEC 2025