UK Atomic Energy Authority

RACE

2025 ANNUAL

Contents

Introduction

I have been in post as RACE Director for over a year and I am delighted to introduce the RACE Annual. This is an opportunity to reflect upon and celebrate what our collaborations have achieved. Robotics and embodied AI are core to a successful, sustainable new energy economy. They give us a unique opportunity for learning from the past and to develop cost-effective systems that manage the whole lifecycle, from initiation, through operation and maintenance, to final decommissioning. There is no sector of that economy where that is more important than fusion, so I am really pleased in reading this document to see what our teams – teams involving industry, research centres, academia, and education providers – have achieved.

These contribute to UKAEA's goals: to solve the challenges of fusion energy, to enable partners to build commercial fusion power plants, to support the success of industry, to create the places where this can happen, and to support the development of people in the fusion community. I hope that you, while reading this document, can see the value of these contributions and if you would like to get further involved with RACE, to join these teams, we would love to hear from you.

Nick Sykes
Director of RACE
UK Atomic Energy Authority

Robotics and fusion energy

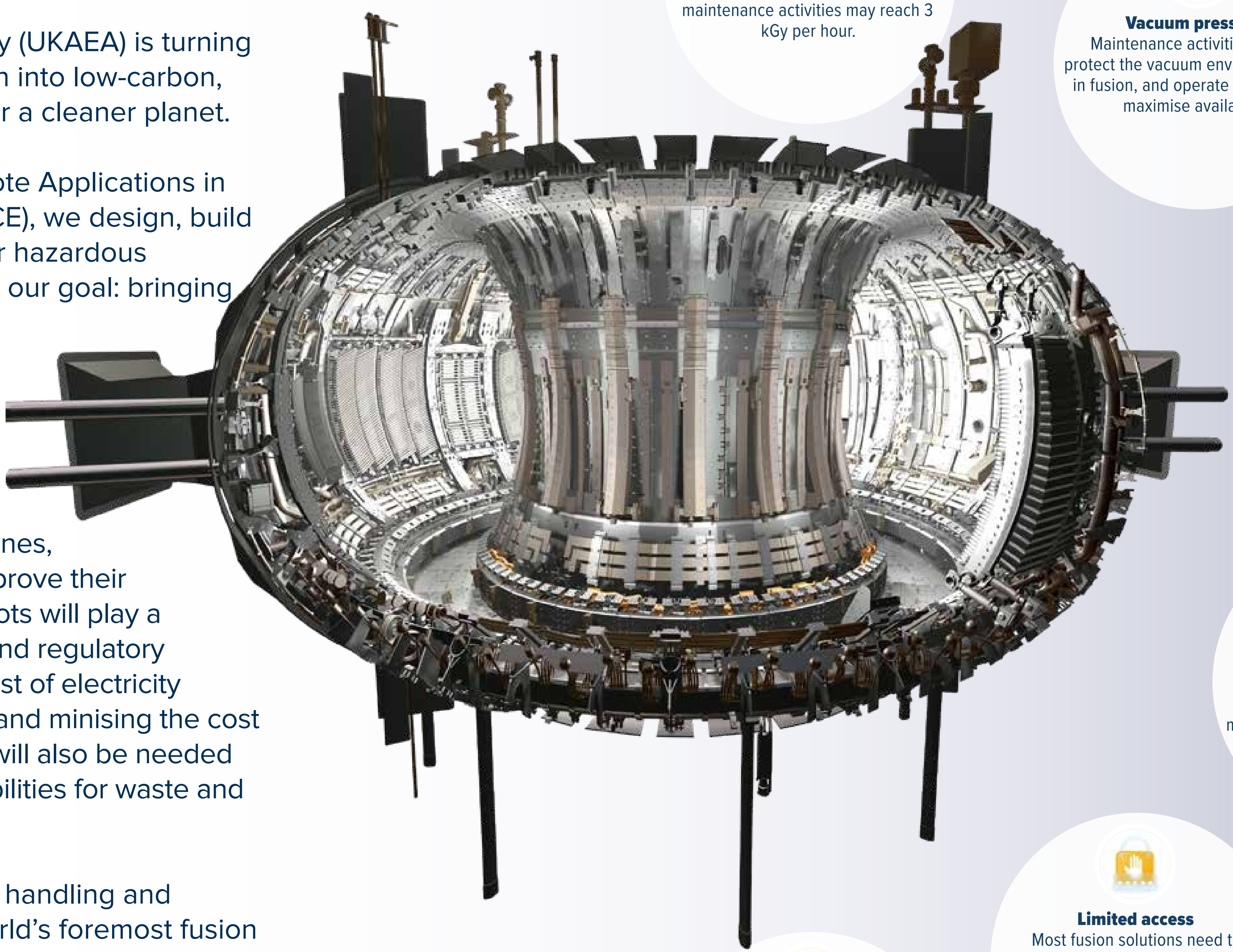
The UK Atomic Energy Authority (UKAEA) is turning the process that powers the sun into low-carbon, safe and abundant electricity for a cleaner planet.

At the UKAEA's centre for Remote Applications in Challenging Environments (RACE), we design, build and operate robotic systems for hazardous environments, working towards our goal: bringing fusion energy to the grid.

A CRITICAL ENABLER

Fusion power plants will use robots for inspection, to replace critical components, to repair the heart of their machines, to continuously develop and improve their power generation systems. Robots will play a vital role in meeting our safety and regulatory commitments, minimising the cost of electricity through maximising availability, and minising the cost of construction. Robot systems will also be needed to minimise the downstream liabilities for waste and decommissioning.

We develop remote inspection, handling and processing solutions for the world's foremost fusion energy projects and collaborate on some of the most prominent engineering challenges of our generation. These challenges need innovative solutions and so we collaborate with industry, academia and like-minded institutions in the UK and around the world.



High radiation
The neutron flux of a fusion machine creates short-lived activation products, and so radiation dose rates during maintenance activities may reach 3 kGy per hour.

Vacuum pressures
Maintenance activities need to protect the vacuum environment used in fusion, and operate in vacuum to maximise availability.

Extreme temperatures
Components in a fusion power plants will become extremely hot. Remote equipment will need to be deployed shortly after fusion conditions, and so may need to tolerate temperatures in the 100s of degrees Celsius.

Magnetic fields
Most fusion solutions use large magnetic fields to confine plasma, maintenance solutions need to manage residual magnetic fields and operate at high field to minimise down time.

Limited access
Most fusion solutions need to maximise the area used for energy capture and fuelling, necessitating maintenance ports being long and narrow access ports with large and complex payloads.

Hazardous materials
Many fusion machines need to use challenging materials that can be corrosive, toxic and/or explosive.

RACE Capabilities

To bring fusion energy closer to reality, we closely collaborate with our partners by offering world-leading robotics capabilities. Enabling industry is one of our top priorities, and our team provides essential skills, knowledge and support when it comes to remote handling in extreme environments.

RACE's core capabilities are:

ADVANCING RESEARCH AND DEVELOPMENT

RACE contributes to world-leading applied research in remote handling for nuclear decommissioning through several collaborative programmes. The £12M LongOps project advanced remote handling technologies for decommissioning at JET, Sellafield and Fukushima Daiichi. As part of the Robotics and Artificial Intelligence Collaboration (RAICo), we are deploying robotic and AI technologies for faster, safer and more cost-effective decommissioning.

PROVIDING FACILITIES AND INFRASTRUCTURE

Situated on the UKAEA's campus in Oxfordshire, our facilities are amongst the best in the world for developing remote handling robotics. The RACE work hall includes reconfigurable robotic cells hosting a variety of equipment, multi-functional control rooms for remote operations trials and the National Institute of Standards and Technology (NIST) test lanes for unmanned vehicles. RACE also acts as the primary hub of the National Nuclear User Facility for Hot Robotics (NNUF-HR), supporting UK academia and industry.

DESIGNING, INTEGRATING AND DELIVERING SOLUTIONS

Beyond fusion, RACE supports international science projects such as the European Spallation Source (ESS), a neutron source being constructed in Sweden. RACE leads the delivery of the site's Active Cells Facility – the world's largest windowless hot cell – designing, specifying and commissioning the facility that will process irradiated waste.

DESIGNING FOR REMOTE MAINTENANCE

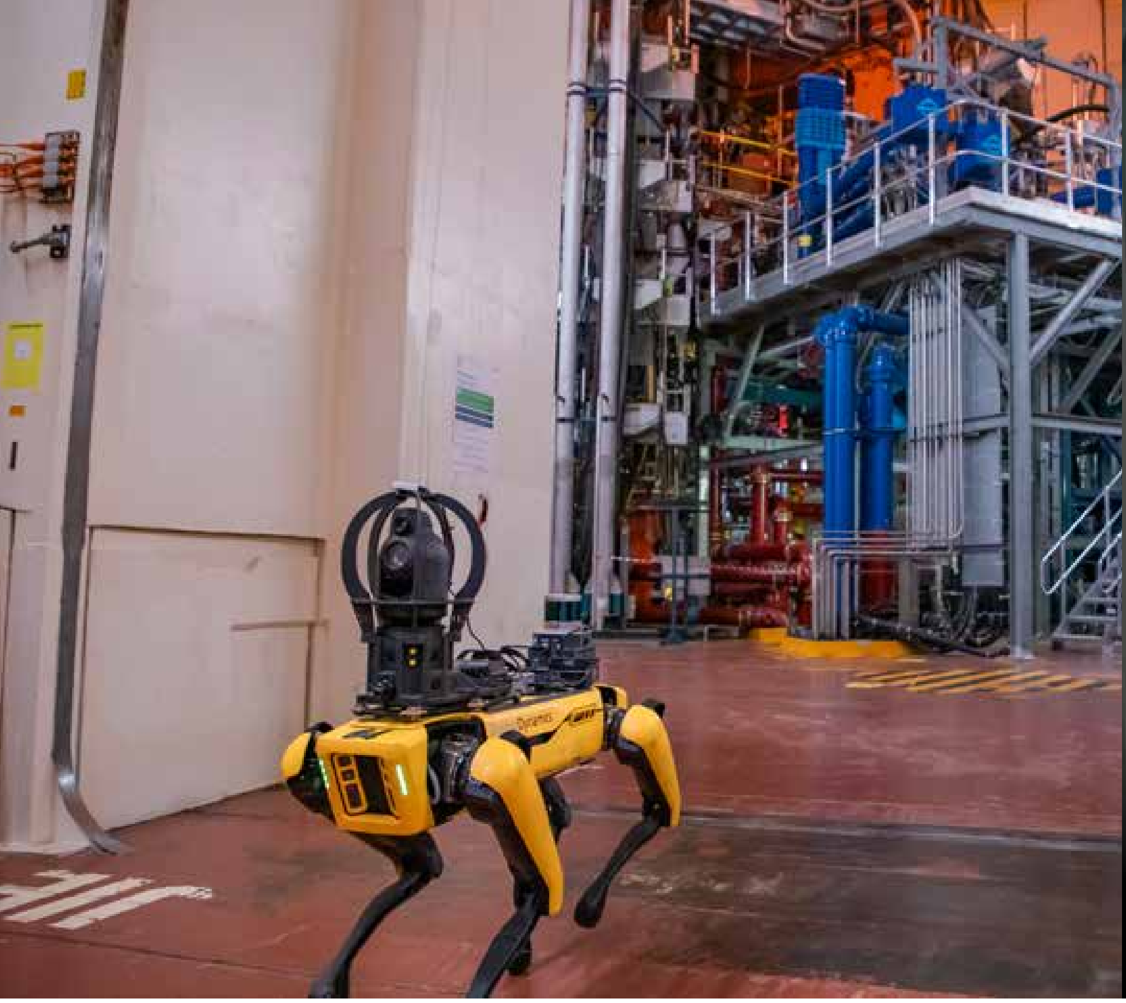
RACE plays a key role in international efforts to create a commercially viable fusion power plant, including the UK's STEP and Europe's DEMO fusion machines. In these projects, our engineers help define the remote handling requirements and incorporate them in the design of the plants themselves to ensure the plants can be operated and maintained.

CONDUCTING REMOTE OPERATION TRIALS

Our team has demonstrated and evaluated remote handling techniques and equipment using physical mock-ups for remote operations at JET, ITER, STEP and Europe's DEMO. By hosting the ITER Robotics Test Facility, we have reduced risk in ITER's planned interventions to ensure that this prominent international fusion research machine can be maintained over its operational lifetime.

EXECUTING REMOTE OPERATIONS

RACE's remote handling expertise stemmed from the need to design and operate remote handling equipment for the maintenance of the Joint European Torus (JET). Now, with over 30,000 hours of in-vessel operational experience, the RACE team provides training for remote handling teams in the UK, Sweden and Japan.



10 stories – supporting UKAEA goals

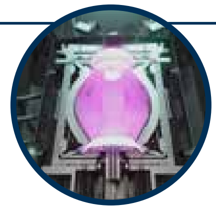
The UKAEA mission is to lead the delivery of sustainable fusion energy and maximise the scientific and economic benefit. RACE plays a pivotal role in advancing robotic capabilities central to UKAEA's mission.

The following section highlights ten stories that showcase some of the achievements of our robotics work, aligned to the UKAEA strategic goals.

PROBLEM-SOLVING

Solve challenges of sustainable fusion energy - from design through to decommissioning - with world-leading science and engineering.

1. Supporting ITER for non-destructive pipe weld testing using Eddy Current Array Technology
2. Developing control algorithms for breeding blanket handling with EUROfusion



PRODUCT

Enable partners to design, deliver, and operate commercial fusion power plants.

3. Delivering the world's largest windowless hot cell for ESS in Sweden
4. Collaborating with ITER to demonstrate maintenance of a critical safety system

PROSPERITY

Drive UK economic growth and a thriving industry that exports fusion technology around the world.

5. Delivering the ESS safety system with Frazer Nash
6. Providing NavLive, a spinout from the University of Oxford, with their first project

PLACE

Create clusters that accelerate innovation in fusion and related technologies.

7. Supporting early career engineers
8. Partnering with universities to accelerate innovation

PEOPLE

Develop the talented, diverse people needed to deliver fusion energy.

9. Inspiring the next generation of robotic engineers through RAICo
10. Helping STEM professionals to re-start their career

1. Supporting ITER for non-destructive pipe weld testing using Eddy Current Array technology

Diego Suarez
Electrical System Design Engineer

RACE has a long-standing relationship with ITER, including hosting the ITER Robotics Test Facility. One of our recent projects in this partnership has been to develop a concept design architecture for an Eddy Current Array (ECA) non-destructive testing system tailored to one of ITER's use cases.

The project's primary objective was to recommend a standard approach for remote pipe weld inspection within ITER, particularly focusing on the task of inspecting the welds of the Blanket First Wall (FW) to Shield Block (SB) cooling pipes.

EDDY CURRENT ARRAY TESTING

The project began by assessing the requirements and constraints associated with the ITER environment, particularly the vacuum vessel where high radiation levels and difficult access conditions necessitate highly reliable and radiation-resistant Non-Destructive Testing technology. After reviewing 11 different technologies, and physically testing the top three technologies, the ECA technology was chosen due to its potential for detecting both surface and sub-surface defects in welds, which are critical for ensuring the structural integrity of the pipes within the ITER facility.

Two types of probes were created: one with high-frequency coils for detecting surface defects and another with low-frequency coils for identifying both surface and sub-surface defects. These probes were tested under various conditions, including pipe misalignment and radiation exposure, to evaluate their performance.

The project also involved bench testing to assess the impact of cable length and signal transmission over long distances, which is crucial for remote handling applications. The results indicated that, the ECA system could maintain signal quality over 60 meters and across 11 in-line electrical connectors, ensuring reliable performance even when the sensor and signal processing units are separated by considerable distances due to the radiation environment. Figure 3 shows the bench testing setup.

RESULTS

The ECA probes were tested using representative pipe weld samples. The ECA probe inspection results used X-ray tomography to validate the accuracy and reliability of the ECA technology. The findings demonstrated that the ECA probes could effectively detect defects, with results closely aligning with those obtained from X-ray tomography. However, it was noted that further calibration and testing would be necessary to refine the system's ability to provide accurate measurement of defect sizes accurately, particularly in misaligned pipes.

In summary, this project made progress in adapting ECA technology for use in the ITER Vacuum Vessel and potentially for any other remote application. It successfully delivered the design and initial testing of a rad hard ECA probe, providing a foundation for further development.

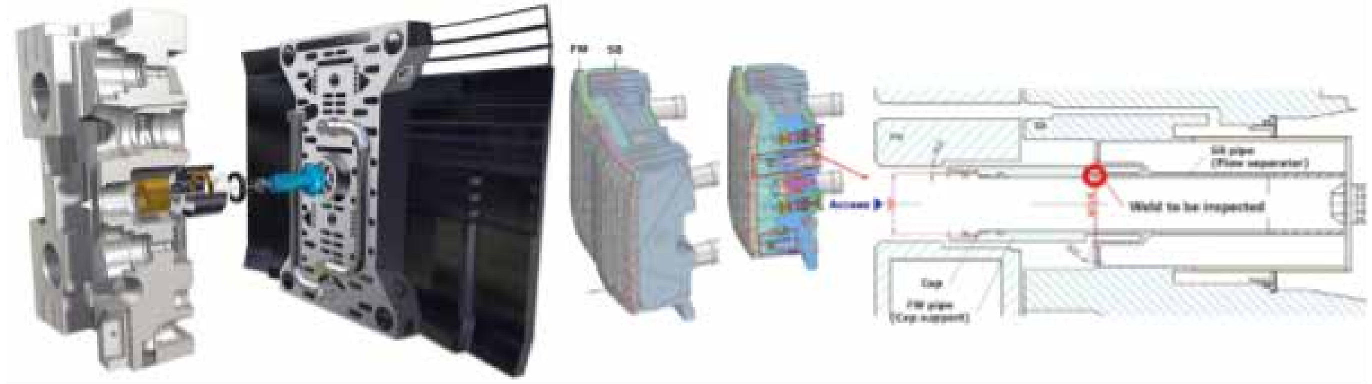


Figure 1
ITER blanket cooling water pipe use case

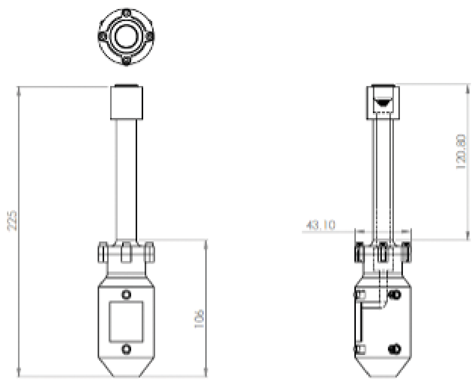


Figure 2
Mechanical drawing of ECA probes

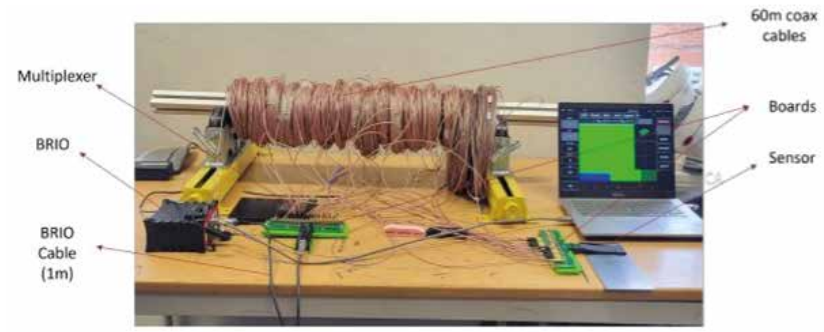


Figure 3
Signal integrity bench test setup

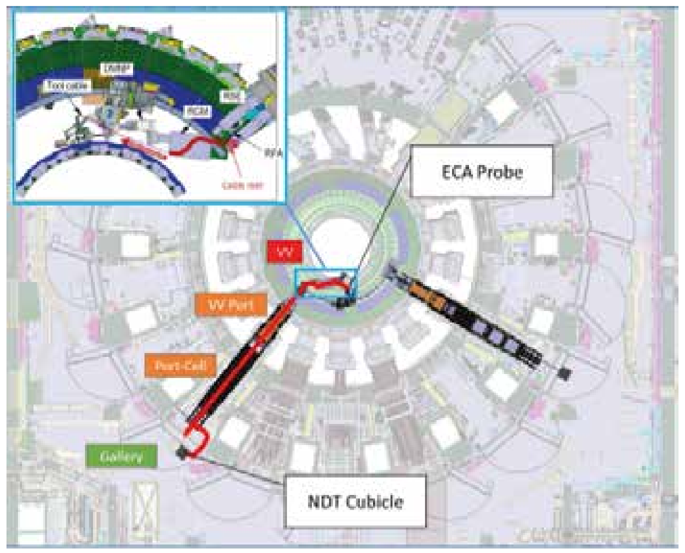


Figure 4
Layout of the cable routing between the control cubicle to the ECA probe

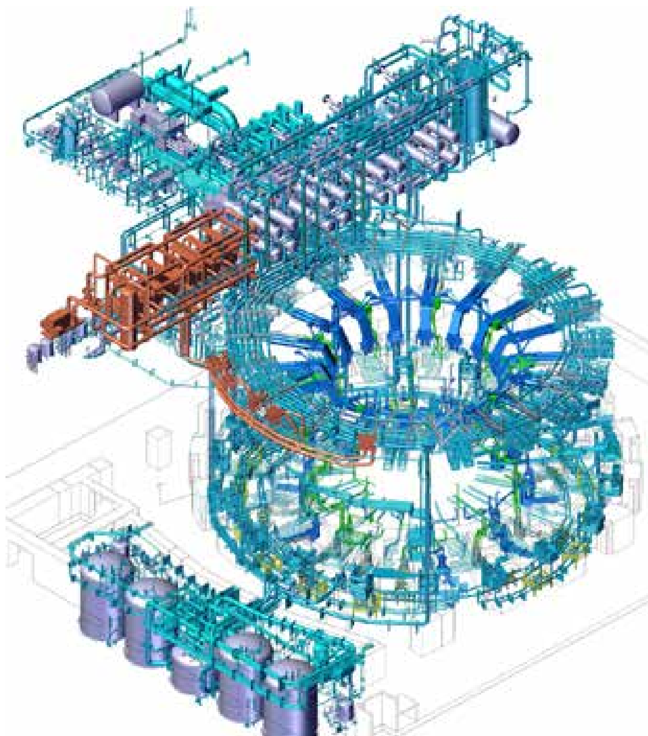


Figure 5
The ITER Tokamak Cooling Water System containing 33 kilometres of pipework

PROBLEM-SOLVING
PRODUCT
PROSPERITY
PLACE
PEOPLE

2. Developing control algorithms for breeding blanket handling with EUROfusion

Sam Herschmann
Senior Control Systems Engineer

RACE's team for EU-DEMO has been developing control algorithms to manoeuvre the large blanket segments in and out of the vessel.

Blanket segments are extremely large and will be a major component of any commercial tokamak that generates tritium. Handling these components is considered to be one of the most challenging remote handling operations for commercial-scale fusion machines.

Magnetic confinement fusion, an approach used in experiments like JET and ITER, holds the plasma in place using large magnets. Neutrons from the fusion reaction can be used to produce tritium inside the layer of banana-shaped 'breeding blanket segments'.

BREEDING BLANKET MAINTENANCE CHALLENGES

These breeding blanket segments will need to be removed from the machine via ports near the top of the torus as part of the regular maintenance cycle. The EU-DEMO design has been studied in detail at RACE, and there are several constraints which make blanket segment handling extremely challenging:

- the blankets are likely to be very large and heavy – around 12 meters and 80 tonnes
- positional tolerances are extremely small, possibly requiring millimetre-scale precision
- the conditions inside and near the machine mean the lift can only be performed using remote equipment and cameras, with no human intervention
- the lift involves rotating the payload in mid-air using a manipulator that is much smaller in size than the blanket itself
- radiation may limit the type and placement of motion sensors

Blankets must be manoeuvred safely without colliding with or scraping other components in the machine. Control techniques are required that can account for the structural flexibility of the components to minimise oscillations and account for static deflections induced by gravity. In other words, we must prevent vibrations, and factor in that the blanket segments can bend under their own weight.

MODEL-BASED CONTROL APPROACH

In our recent work we have developed and applied a model-based, optimal path planning algorithm to a miniaturised and simplified version of the EU-DEMO blanket handling problem.

The first step was to create a model of the system, which is a mathematical description of how the robot and its payload can move and bend. We used a finite element approach to create a model which can be used in a computer simulation to assess how the system will react to forces.

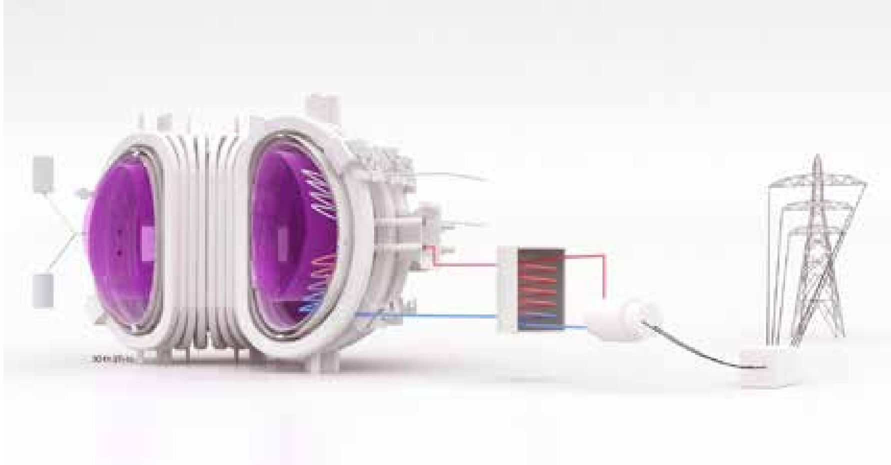
The second step was to calculate a suitable robot trajectory. We used a numerical optimisation approach to calculate a best-case robot trajectory, accounting for obstacles, actuator limitations and the modelled payload dynamics. This was optimised based on our chosen objective, to minimise the tracking error of the position payload's tip.

We then improved our trajectory using a technique called input shaping. This smooths the trajectory in a way which avoids creating vibrations, based on knowledge of the natural frequency of the robot-payload system.

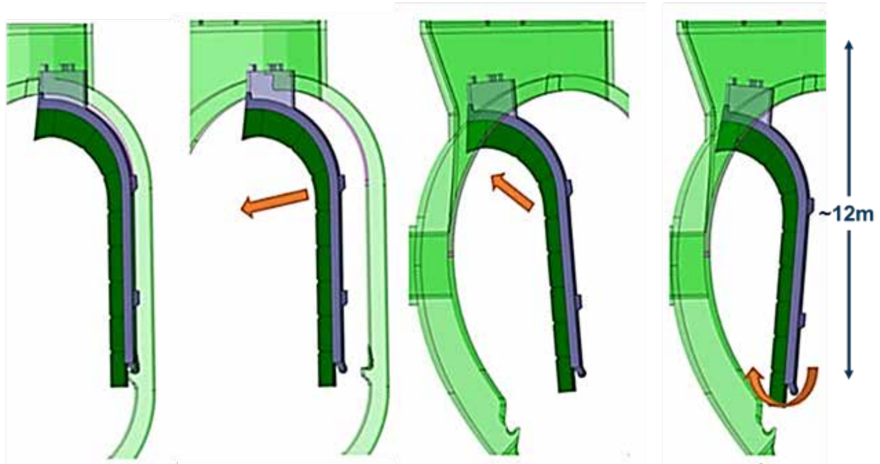
RESULTS

This approach anticipates oscillatory behaviour and takes corrective action to reduce structural vibrations in the system. Specifically, this approach allowed us to control the robot payload whilst accounting for the influence of gravity, and simultaneously reducing post-manoeuvre oscillations. This demonstrates the benefits of using model-based optimisation for automated path planning of challenging remote handling systems.

In future we will extend our investigation to larger and more complex payloads, and include various other aspects which make the problem more realistic including out-of-plane and torsional motions, viscoelastic damping and actuator dynamics.



Artists impression of a grid-connected fusion device



A proposed manipulation sequence during blanket handling in the current EU-DEMO design

Experimental UR10e robot and aluminium payload setup

3. Delivering the world's largest windowless hot cell for ESS in Sweden

Harry Robinson
Principal Mechanical Engineer

The European Spallation Source (ESS) is a multi-disciplinary research facility currently under construction in Lund, Sweden and will be the world's most powerful accelerator-based neutron source, enabling research in materials, energy, health and the environment.

It will include a particle accelerator, target station, experimental halls, laboratories and office facilities. Crucially, it will also include a waste processing plant known as the Active Cells.

RACE has been engaged by the UK's Science and Technology Facilities Council (STFC) to design and supply significant parts of the ESS Active Cells as part of the UK's "in-kind" contribution to the ESS.

CHALLENGES OF THE ESS ACTIVE CELLS FACILITY

The Active Cells will size reduce – predominantly by cutting – then store and enable shipping of radioactive material produced as a byproduct of ESS operations. Due to the radiation levels, human access to the Active Cells will be highly restricted; almost all operations and maintenance will need to be undertaken remotely, using robotic handling and size reduction equipment.

CONTRACTING TO THE SUPPLY CHAIN

RACE carried out a competitive tender process in 2018 to select a contractor to design, build, install and test the primary piece of size reduction equipment for the Active Cells. This machine must receive a range of radioactive components and orientates, fixes and cuts them into pre-defined sections ready for disposal or other subsequent operations. The machine must also enable maintenance, decontamination and recovery activities.

The requirements did not specify the technology to use, but did specify the space allocation, environmental constraints, inability to use cutting coolant, test sample to be cut, and the allowable dust production. This allowed industry experts to propose appropriate cutting methods based on their experience. The contract was won by Aquila Nuclear Engineering supported by cutting experts BD Nuclear, and their supplier SMO Machine Builders.

PROGRESS

The initial design process ended with a detailed design review towards the end of 2019 with the final design accepted in 2020. Manufacture then began and factory acceptance tests for the saw and pivot assembly succeeding despite COVID restrictions, which required significant trust and compromise from all parties. These tests showed that the cutting of the challenging 'Super Duplex' material sample complied with the required limits on cell dust levels and the overall cutting schedule.

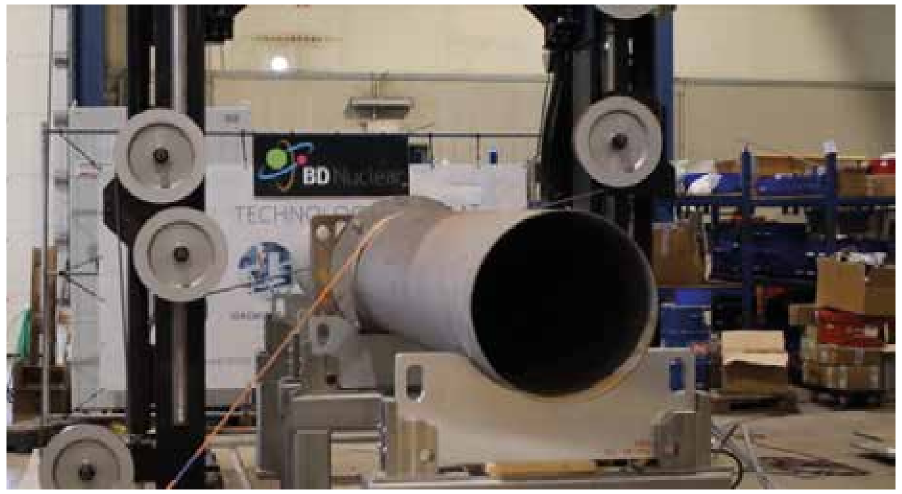
DELIVERY OF THE DIAMOND WIRE SAW

The diamond wire saw itself was shipped to site in the first half of 2022, with testing starting in the second half the year following commissioning. Testing was paused until a temporary ventilation system was installed as the primary HVAC system was not yet commissioned.

RESULTS

Two follow-on visits were carried out, and the entire team – ESS, Aquila Nuclear Engineering, BD Nuclear, and SMO Machine Builders – saw the fruits of their labour: the first test sample was cut in March 2023. This was rapidly followed up with the cutting of a second sample whilst integrated into the Active Cells Control System, supported by the RACE controls team.

Remote operation saw via camera from outside the hot cell, fully integrated with the Active Cells Control System



FAT test witnessed remotely from Belgium, during COVID

Checking cut progress during SAT

Testing geometric mock-ups of real components during SAT

Checking cable wear during SAT

4. Collaborating with ITER to demonstrate maintenance of a critical safety system

Garin Schoonhoven
Principal Engineer

In a collaboration between ITER and RACE, a demonstration of the remote maintenance tasks for the replacement of burst discs in ITER's Vacuum Vessel Pressure Suppression System (VVPSS) was successfully completed.

VACUUM VESSEL PRESSURE SUPPRESSION SYSTEM

The VVPSS in ITER's Neutral Beam cell is a safety critical over-pressure relief feature that uses burst disks and bleed valves. These components will require replacement for lifecycle milestones or after accidental overpressure of the vacuum vessel if there was a cooling water leak within the ITER vessel whilst the vessel is under vacuum.

The VVPSS remote handling project demonstrated feasibility of maintaining the Bleed Line Valve Assembly by developing concept designs, manufacturing and validating mock-up remote handling tooling, and performing an evaluation trial.

The full sequence of the operation was demonstrated using a full-scale mock-up that was designed and manufactured in the UK. Following these initial trials, the hardware was developed to further improve efficiency, and additional features were added and trialled.

Throughout the design and trials, RACE provided feedback to ITER that has informed the final design to be deployed in the Neutral Beam cell at ITER. This equipment will be used during operations on the 300 mm Bleed Line Valve Assembly and 500 mm Rupture Disc Assembly flanges.

The operational environment near these flanges is highly constrained, necessitating compact tooling which can be deployed from and operated reliably fully remotely. As the VVPSS duct is part of the primary vacuum vessel, containment of any contaminants is required to prevent their spread into the Neutral Beam Cell.

TOOLING

During the equipment trials, the manipulator operator was reliant on camera views, through a bank of screens, to position tools that were lifted using a crane and ensure correct operation of the following tools:

The Flange Bolting Tool (FBT) contains two Atlas Copco electric torque wrenches that automatically traverse radially around the flange to either bolt or unbolt the 18 pop-up screws that hold the flanges together and retain a double metallic seal. Torque (up to 190 Nm) is reacted locally using reaction features and is incrementally applied to ensure flange distortion is avoided.

The Flange Closure Tool (FCT) is a complex tool that ensures containment when flanges are separated, inserts Closure Plates in the pipe ends and cleans the sealing surfaces of the flanges. It contains an XYZ (and W rotation) manipulator as well as a vacuum cleaner and parking for the Closure Plates.

During bolting sequences, the Bellows Compression Tool (BCT) provides a preload to the flange join to ensure containment of contaminants during bolting sequences. When the bolts have been undone, the bellows are compressed to permit access for Closure Plate deployment.

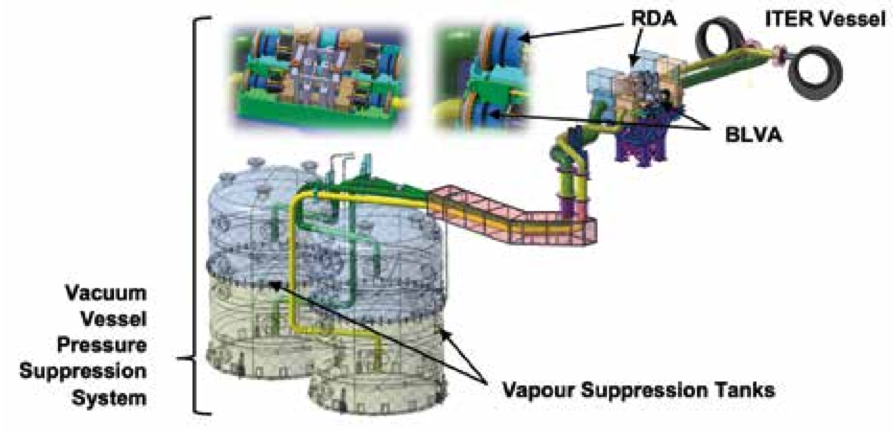
RESULTS

The operational trials and demonstration of the IA17 BLVA RH tooling was extremely successful and demonstrated the feasibility of RH tooling design and operational principles, as well as providing insights for optimisation of the RDA RH tooling. This work has further developed and demonstrated RACE expertise and capabilities in the full lifecycle design through to delivery of bespoke remote handling technologies.

"The collaboration with UKAEA's RACE has allowed us to demonstrate, or even "qualify", the majority of the VVPSS maintenance processes foreseen in ITER and formed the centrepiece for our recent VVPSS RH preliminary design review. Not only did it allow us to identify and solve small but important teething issues associated with our earlier concept designs, it also allowed us to better understand the mechanical characteristics of the VVPSS components at each step of the maintenance process.

It is rare that we are able to so clearly demonstrate the validity of our designs in such a comprehensive way at this stage of the design lifecycle and it is thanks to our strong and energetic collaborations with the UKAEA's RACE team that together we could make this happen".

Jim Palmer, Remote Handling Project Leader, ITER



ITER Vacuum Vessel Pressure Suppression System

Remote maintenance trials of the VVPSS Remote Handling System at RACE

5. Delivering the ESS safety system with Frazer Nash

Christopher Hume
Functional Safety Group Leader

CHALLENGES OF EUROPEAN SPALLATION SOURCE

ESS will become the world's largest and brightest spallation neutron source to be used for scientific research. This sort of research is not possible without producing high levels of short-lived radiation. The most contaminated components will be remotely handled within the Active Cells, delivered by the UKAEA, which will be the largest nuclear hot cell ever built.

Although this radiation does not present a risk to the public, robust safety systems are required to minimise risks to operators and scientists within the facility.

WORKING WITH FRASER NASH

To deliver the Active Cells Radiological Safety Systems, UKAEA collaborated with Fraser Nash Consultancy. Fraser Nash possessed both experience in supporting conventional nuclear and fusion energy projects, and the competency to deliver Safety Systems to stringent requirements set out in Functional Safety Standards.

Despite this experience, this project presented substantial novelty in:

- the size of the Active Cells
- the sensor technology to detect this kind of radiation and automate action from those readings
- the radiation levels, with a total target lifetime dose of 498 kGy
- the requirement to run the systems for 20 years with minimal human intervention
- gaining approval that these safety systems support and deliver the facility's safety case from the Swedish Nuclear Regulator

RADIOLOGICAL SAFETY SYSTEMS

The Radiological Safety Systems are the hardware that automates critical Safety Functions. This includes:

- detecting the radiation levels inside and outside the active cells
- detecting that radiation shielding and doors are in place to prevent radiation shine paths during operations, and isolating equipment to prevent these shielding elements from moving while the operators are in the line of fire
- managing access to the cells for the rare scenarios that human access is required
- pressure monitoring to ensure that active ventilation is keeping air pressure in the cells lower than air pressure outside the cells
- raising alarms to alert operators and initiate the evacuation of personnel, in the case of any unexpected radiological event

HOW THE ENGINEERING PARTNERSHIP WORKED

In this project, RACE provided:

- requirements and basis of design for the safety systems based on ESS Hazard Analysis
- electrical construction and wiring of logic system cubicles, including hardwired relay systems
- procurement of sensors and programmable logic controllers
- mechanical construction, including mechanisms to interface with large shielding components and pressure containing systems
- remote handleable junction boxes and ducting
- facilities for equipment construction and testing prior to site delivery
- installation at the ESS Active Cells

Fraser Nash provided specialist safety input, particularly for:

- safety system detailed design
- standards compliant programmable logic controller application software
- graphical interface and operator guidance to aid the operators in running the facility
- probabilistic Safety Integrity Level performance calculations
- independent Functional Safety Assessment of the project

Gamma detector for the Component Transfer Hatch

RESULTS

The project would not have been possible without technical input from both sides. Together, we successfully delivered the ESS Radiological Safety System Site Acceptance Test in June 2024.

This represents eight years of work, where we had to overcome challenges that we could have never comprehended at the initiating Hazard and Operability workshop in 2016. This has included:

- 30,000 hrs of resource time
- £1m hardware procured, manufactured, installed and commissioned at the ESS site
- 30 substantiation documents 2000+ pages
- 1000 pages of drawings
- 20 cubicles
- 12 km cabling
- 2 km of cable managements systems
- 4000 components
- 10000 electrical connections
- 200 test configurations

Differential pressure testing

Radiological Safety System team

6. Enabling NavLive, a spinout from the University of Oxford, to grow through a collaborative project

Matthew Goodliffe
Lead Technologist (Digital)

RACE's work under the LongOps project has developed digital tools to enable faster, safer and more cost-effective decommissioning.

LongOps spanned remote handling for both the fusion energy and nuclear decommissioning sectors. These two sectors present some of the most challenging environments to perform remote handling tasks. To carry out decommissioning activities safely, it is important to have an up-to-date, informed model of the site enhanced with capabilities that support the decision-making process.

WORKING WITH NAVLIVE

One of the goals of LongOps was to stimulate innovation through the award of contracts to perform collaborative R&D. One of these contracts was awarded to NavLive, with support from Jacobs, to develop novel methodologies for monitoring changes in hazardous environments.

A spinout of the University of Oxford, NavLive extended their 3D mapping technology to develop new capabilities in change detection, thermal mapping, and augmented reality.

SLAM

Based on input from stakeholders at UKAEA, Sellafield Ltd and the Tokyo Electric Power Company (TEPCO), NavLive developed an automated technique to detect changes by comparing point clouds – data representations of 3D scans of an environment. This technique can be performed during inspections using a scanning device deployed on a robotics platform. Simultaneous Localisation and Mapping (SLaM) techniques were used to create a 3D model of a site.

The resulting data highlights geometric changes – changes in positions of items or the structure of an environment. In addition, the software platform developed by NavLive can map other properties onto the 3D map, like changes in temperature.

RESULTS

The resulting visualisations provide an efficient way for operators to identify changes in an environment and make informed decisions about maintenance and decommissioning in nuclear facilities.

Experiments and demonstrations took place in a location representative of a decommissioning site. The scanning device captured data using a hand-held configuration as well as when mounted on a remotely operated vehicle (ROV).

To further test the reliability of the methodology in vibrating or shaking scenarios, the sensing equipment was mounted on a long boom manipulator. The sensor fusion approach utilised proprioceptive and exteroceptive sensor data, allowing the system to behave robustly even in the challenging conditions commonly encountered in remote operations.

TESTIMONIAL FROM NAVLIVE

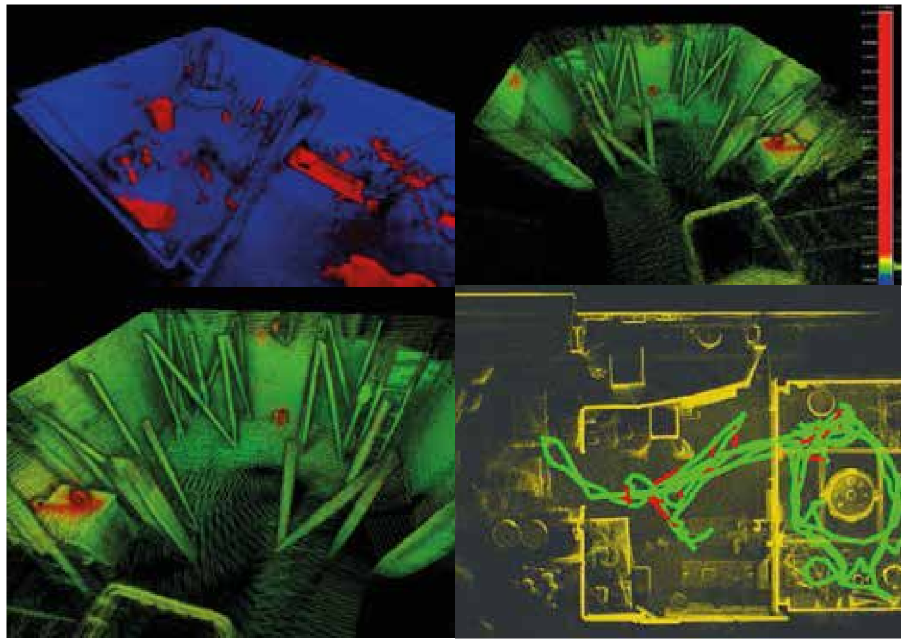
"The LongOps project has made a big impact on NavLive. This was our first project as a spinout from the University of Oxford and provided the funds and opportunities for us to grow and demonstrate our technology in a realistic environment. From a technology point of view, the LongOps project allowed us to improve our 3D mapping technology, and develop new capabilities in change detection, thermal mapping, and BIM visualisation (augmented reality) which are crucial to our future business opportunities.

With UKAEA, TEPCO, and Jacobs, we have shown how this type of technology could help to solve some of the key challenges in nuclear inspection and decommissioning. This includes remote inspection, detecting changes in the environment, and bridging the divide between the digital twin and reality.

More broadly, this LongOps project was an enabler for us to raise our seed round of venture capital investment in mid-2023 and is hopefully the beginning of future projects within the nuclear industry and beyond. The networks, technology, and skills we gained will be very valuable for us in the future."

David Wisth, NavLive

LongOps was funded by UK Research and Innovation (UKRI), TEPCO and the Nuclear Decommissioning Authority (NDA).



For thermal change detection, a thermal camera was integrated into the sensing system and mapped to the point cloud. During the tests in the cell, some surfaces were heated, and hot elements were introduced to simulate changes.

To carry out change detection, multi-session mapping was performed. This process established a baseline of the site's condition, enabling the identification of any changes. The blue points represent parts of the scene that have remained unchanged, while red points denote areas where changes have occurred (within a 5 cm margin).

The team of engineers and researchers from NavLive, Jacobs and UKAEA's RACE.

Inspections were also performed using the same sensors deployed on an ROV, in a mock-up environment representative of a nuclear decommissioning task.

7. Supporting early career engineers

Katy Seymour
Engineering Degree Apprentice

At RACE, we recruit a cohort of early career engineers as well as offering apprenticeship opportunities across different engineering disciplines each year. Katy Seymour is an Engineering Degree Apprentice who joined RACE in September 2022 and shares her experience in her interview below.

WHY I APPLIED

Being enthusiastic about sustainable energy solutions and curious about the engineering challenges behind them, I found that the apprenticeship scheme at RACE aligned perfectly with my career interests and ambitions. The idea of working on something that will make a difference was inspiring, so I decided to apply.

HOW THE APPRENTICESHIP SCHEME WORKS

The electrical and electronic engineering degree apprenticeship is a five-year course during which I study at Bristol University of West England once a week. The programme structure ensures that I change placements every six months, moving to a new project or department. I enjoy this change as it provides fresh perspectives and experiences, allowing me to grow the technical, practical, and professional skills needed to become an engineer.

WHAT I'VE WORKED ON SO FAR

So far, I've had the opportunity to work on several exciting projects within RACE. My first project involved working on the physical build and updating of SolidWorks electrical schematics for one of RACE's projects with ITER. During my time at RACE, I have developed my practical and communication skills while gaining an understanding of the procedures involved during the build stage of a project.

Another placement was with the RACE Networking Team, where the entire remote handling plant network between the J1 Remote Handling Control Room to the Octant 1 and 5 booms was upgraded. Here, I learnt the fundamentals of the communications aspect of electrical engineering, and the integration process between electrical and cybernetics work.

WHO I'VE WORKED WITH AND WHAT I'VE LEARNT

From the beginning of my apprenticeship I have worked with a range of technicians, engineers, project managers and apprentices across all disciplines. This experience has broadened my knowledge and skills in areas I hadn't expected to explore. It has also allowed me to build a solid support network across site.

WHAT I'VE ENJOYED

I've enjoyed many aspects of my apprenticeship so far, but one instance stands out most: seeing the new J1 Remote Handling Control Room with all the camera feeds working for the first time. It was incredibly rewarding to see all the team's work come to fruition.

WHAT I'M DOING NOW

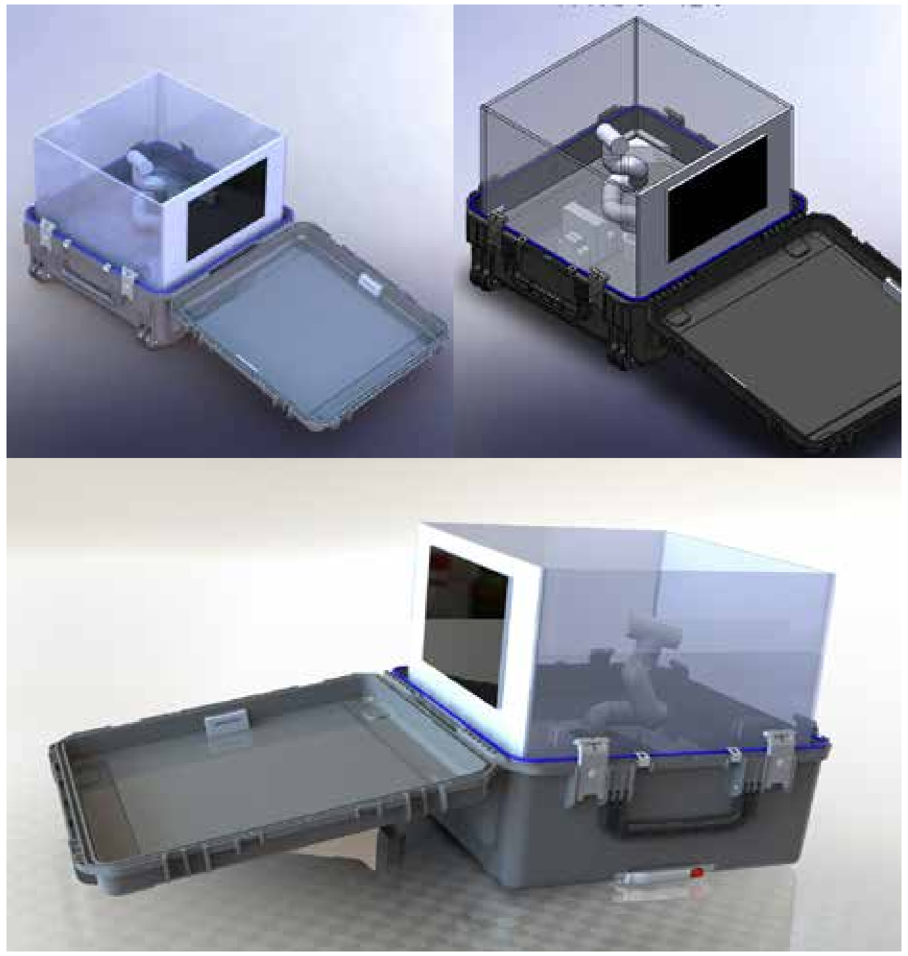
I'm currently working on an outreach project aimed at attracting more people to the RACE stand at events.

I have been researching and completing the detailed design documents, improving my technical report writing skills in the process.

As part of the preparation work for JET Decommissioning and Repurposing, I am also working on the JET In Vessel Viewing System, where we are designing a system to provide wireless lighting when using remote handling equipment in-vessel. This project has developed my knowledge of electronic circuits and components, including battery optioneering as well. I have also received training on how to use Proteus for better PCB design.

WHAT I HOPE TO DO AFTER THE SCHEME

After completing my studies, I hope to become a qualified Electrical Engineer and continue to develop my skills as rapidly as I am now. My goal is to be able to contribute to various future projects within RACE as effectively as I can.



CAD models for a project called DORA, a piece of outreach equipment containing a collaborative robot (cobot)

Electrical cabinet for one of the ITER Robotics Test Facility projects

Inside the electrical cabinet for the ITER Vacuum Vessel Pressure Suppression Remote Handling System trials

8. Partnering with universities to accelerate innovation

Dr Calum Henderson
EPSRC Research Fellow

Calum Henderson is a PhD researcher at University College London. RACE has supported his research, as an industry partner, advancing robotics engineering in challenging environments. Calum reflects on this valuable partnership in his interview below.

PIONEERING RADIATION-TOLERANT ELECTRONICS

My PhD project was focused on robust, radiation-tolerant electronic components – a challenge which must be overcome to achieve and maintain sustainable fusion energy.

Conventional silicon-based electronics are ideal for almost every consumer application, but quickly fail when exposed to extreme environments. Ionising radiation has an extremely detrimental effect on electronic components, where it can produce problematic signal errors and even render entire systems inoperable.

Remote handling systems for future fusion power plants will require electronic components with radiation tolerances up to one million times higher than those of consumer electronics, which is not possible without a radical new approach to electronic system design. But, by carefully selecting the materials used in an electronic component, a component's performance and lifetime in high-radiation environments can be drastically improved.

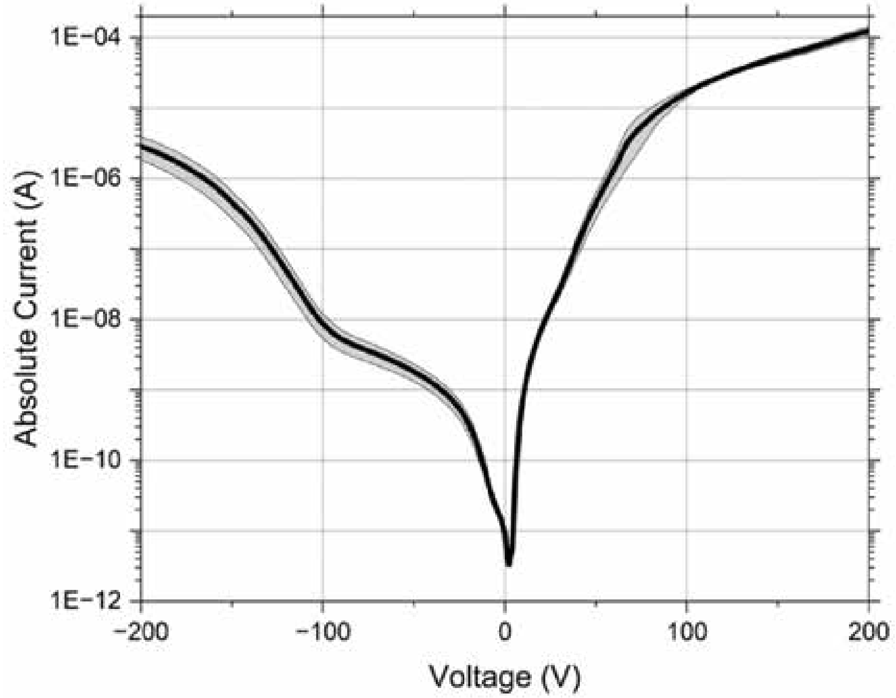
For this project, the use of semiconducting diamond was explored as an alternative to silicon for these applications due to its inherent resilience to ionising radiation. In addition to being a valuable gemstone, diamond is an intrinsic semiconductor with several material qualities which make it a very attractive electronic engineering material for extreme environments – such as those encountered inside a fusion machine during maintenance.

By employing a novel optical technique which involves ultra-high-power lasers, we were able to form complex, three-dimensional architectures of conductive and semiconductive regions within the protective diamond crystal. In my PhD, I used this technology to develop several all-carbon electronic devices, including diodes and transistors, paving the way towards truly robust electronics for fusion remote handling systems.

EMPOWERED BY COLLABORATION

Throughout my PhD project, I was based at my host institution, University College London (UCL), and RACE acted as my industrial sponsor, providing both funding to enable the research and support for me as a student. I had regular meetings with my RACE supervisor, allowing me to discuss my progress and my issues with a specialist outside my immediate field. The RACE sponsorship also provided me with a multidisciplinary forum to present my work, which ensured that I could reach a wide audience and make a positive impact in our endeavour for sustainable fusion. The support was invaluable, as it helped to add much-needed perspective to my research and prevented me from becoming too restricted by my own niche field.

Since completing my degree, I have been fortunate to continue my research with a fellowship at the London Centre for Nanotechnology at UCL. This work focuses on further exploring the applications of laser fabrication with diamond, particularly for the development of electronics capable of withstanding extreme environments. As this research progresses, I hope to maintain my collaboration with RACE so that I can continue contributing to advancements in the field and exploring new opportunities for real-world implementation.



Operation of the all-carbon diode, fabricated by laser-writing in diamond. No breakdown was observed up to ±200 V, with the maximum rectification ratio reaching over 2500.

Electrical testing equipment in the Diamond Electronics Laboratory, showing variable temperature impedance spectroscopy (left) and a semiconductor characterisation system (right). In addition to measuring device parameters, these setups allow for the identification of novel carbon domains formed by the laser processing.

9. Inspiring the next generation of robotic engineers through RAICo

Sophie Finlinson
Project Manager

RAICo

The Robotics and Artificial Intelligence Collaboration (RAICo) is a collaboration between the UK Atomic Energy Authority, the Nuclear Decommissioning Authority (NDA), Sellafield Ltd and the University of Manchester. The collaboration was formed to accelerate the deployment of robotics and AI in nuclear decommissioning and fusion engineering.

RAICo1, RAICo's main facility in Whitehaven, Cumbria, is the first in a series of robotics and AI collaboration facilities across the UK.

THE DECOMMISSIONING WASTE CHALLENGE

A key aim of RAICo is to deliver socioeconomic benefit within West Cumbria, such as providing long-term sustainable career opportunities for local people and delivering outreach activities to provide exposure to students to careers in the nuclear industry, particularly within robotics and AI.

At the start of this year, RAICo developed an outreach initiative 'The Decommissioning Waste Challenge' with the Industrial Solutions Hub (iSH), a like-minded partner. iSH is based in West Cumbria and delivers programmes that bring together industry, SMEs, academia, national bodies, research facilities and the community to deliver growth and regeneration opportunities in West Cumbria.

The challenge was based on real-world decommissioning activities: the students had to design and build a robot which could move a mock nuclear waste barrel from one location to another.

THE OUTREACH CHALLENGE

Students aged 16 to 18 from West Lakes Academy and the Energy Coast University Technical College took part in the challenge, with two teams per school developing their own unique robot. The sprint challenge took place over four weeks, and was designed to encourage creativity, innovation, and enthusiasm for Robotics and AI.

The decommissioning waste challenge incorporated coding, engineering and problem-solving skills, creating a stand-out point for university or apprenticeship applications. As part of the challenge, representatives from RAICo and iSH visited the schools every week for the four weeks, providing support to the students and insight into different careers within the industry.

SHOWCASING THEIR RESULTS

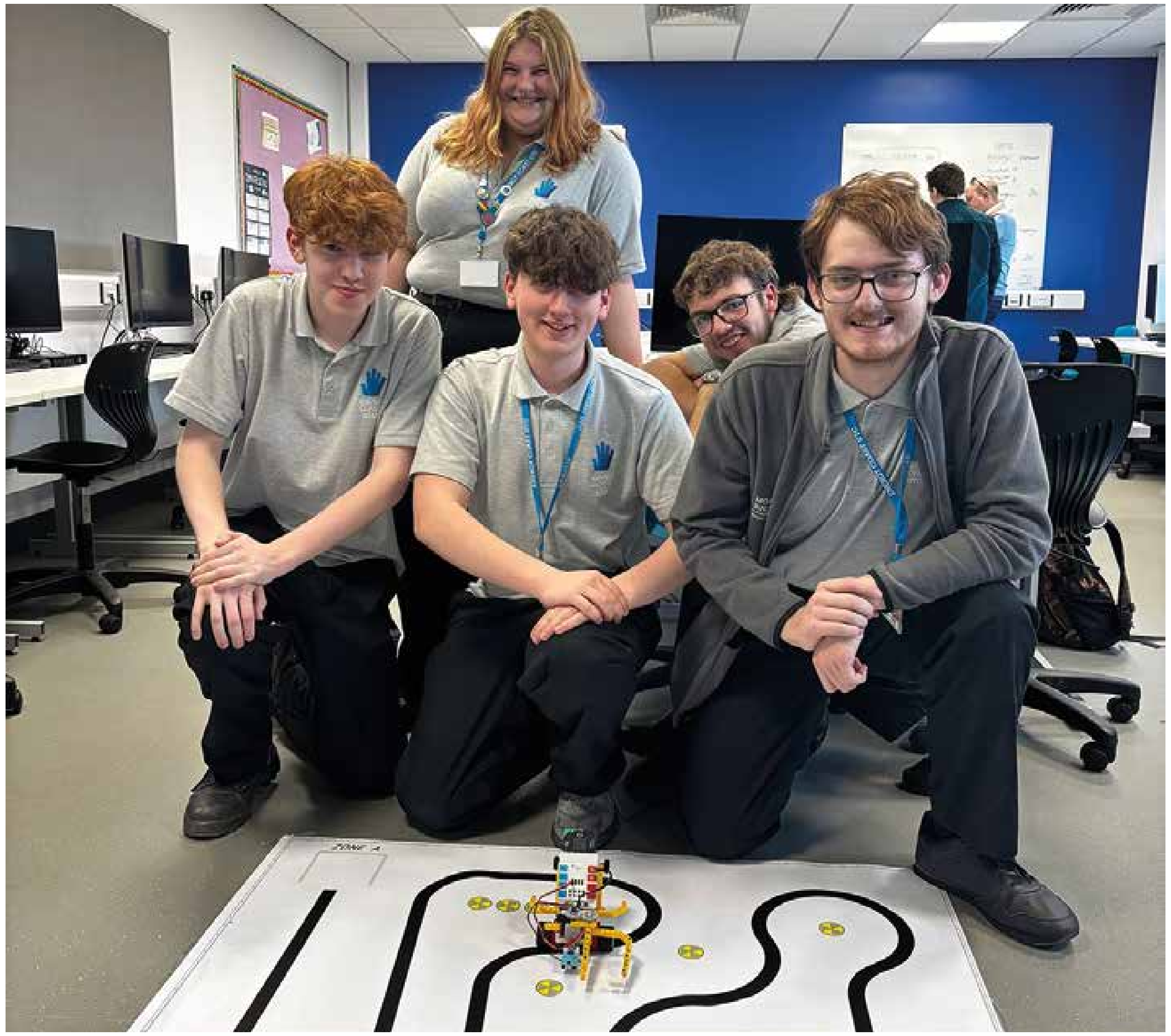
Upon completion of the sprint challenge, the students showcased their robots at the 'Harnessing Robotics and AI for Challenging Environments' event held at Energus, Cumbria on the 21st May, 2024, presenting the outcome of their project and robot to 250 attendees from across the nuclear industry.

The event, supported by RAICo, showcased the region's RAI capability and provided the students with the opportunity to network with industry professionals, listen to keynote speeches and find out about career opportunities in the sector before they embark on their careers.

The students really enjoyed taking part in the challenge, gaining confidence with coding and building the robots over the weeks. At the showcase event they provided impressive presentations and expertly fielded questions from senior leaders within the nuclear industry.

Finlay Forrester, student at West Lakes Academy, speaks of his experience during the sprint programme, and how the Harnessing Robotics and AI for Challenging Environments event bolstered his interest in coding: *"I wanted to widen my horizons and see what was out there. I've always loved coding, so I thought it would be a great opportunity. I found out what I can do, what I love and how to do it as well. It's been a massive help."*

RAICo's next steps are to further develop the challenge for a new cohort next year.



Students from Energy Coast University Technical College with their robot

10. Helping STEM professionals to re-start their career

Christa Davies
Mechanical Design Engineer

UKAEA runs a STEM Returners Scheme to encourage and support STEM professionals back into work after a career break, or for candidates who want to change career and have re-trained to get a STEM qualification but all of their previous work experience is in a non-STEM field. The scheme usually involves a 12-week work placement for the candidate to gain up-to-date work experience in a STEM job. RACE welcomed Christa Davies back in September 2023 as a 'STEM Returner' who recalls her experience in her interview below.

MY ENGINEERING BACKGROUND

I originally studied Aeronautical and Astronautical Engineering at Southampton University whilst working as student apprentice at the Communications Satellite Division of BAe in Stevenage. Working while studying helped to give the academic, theoretical studies a real-life application, made them relevant.

From there I moved on to work as a design engineer in the automotive industry. This was a big change from working on individual, precision-built satellites, to the fast-paced volume production of automotive components.

I then moved back into the aeronautical industry working for Air New Zealand at their maintenance base in Auckland. Again, experiencing another change of engineering culture joining the highly regulated aircraft industry.

TIME OFF FROM ENGINEERING

I took a career break to have children and on returning to work I took up an admin and reception job which was part-time and fitted around family life.

Although always intending to return to engineering work, I began to feel 'out of touch' as the years out of the industry went by. In an effort to refresh my skills, I decided to study part-time for an MSc. After qualifying, I started my search for engineering work at the end of 2022. But having 10 years of my most recent work experience in a non-engineering role, and a significant career break on my CV, I did not fit the profile of a typical engineering candidate. I applied for many engineering jobs and got endless rejections.

MY LUCKY BREAK

One of the many jobs that I applied for was a Mechanical Design Engineer with UKAEA at RACE. Again, I did not fit the profile of the type of candidate that they were looking for, but their 'People Department' got in touch with me to see if I would be interested in joining their STEM returners scheme. I had not heard of the STEM returners scheme but was glad of any opportunity.

I started in September 2023 and it has been great. RACE have taken on a lot of new staff in the past few years and have developed a really comprehensive 'on-boarding' process with lots of information and support to help staff settle in.

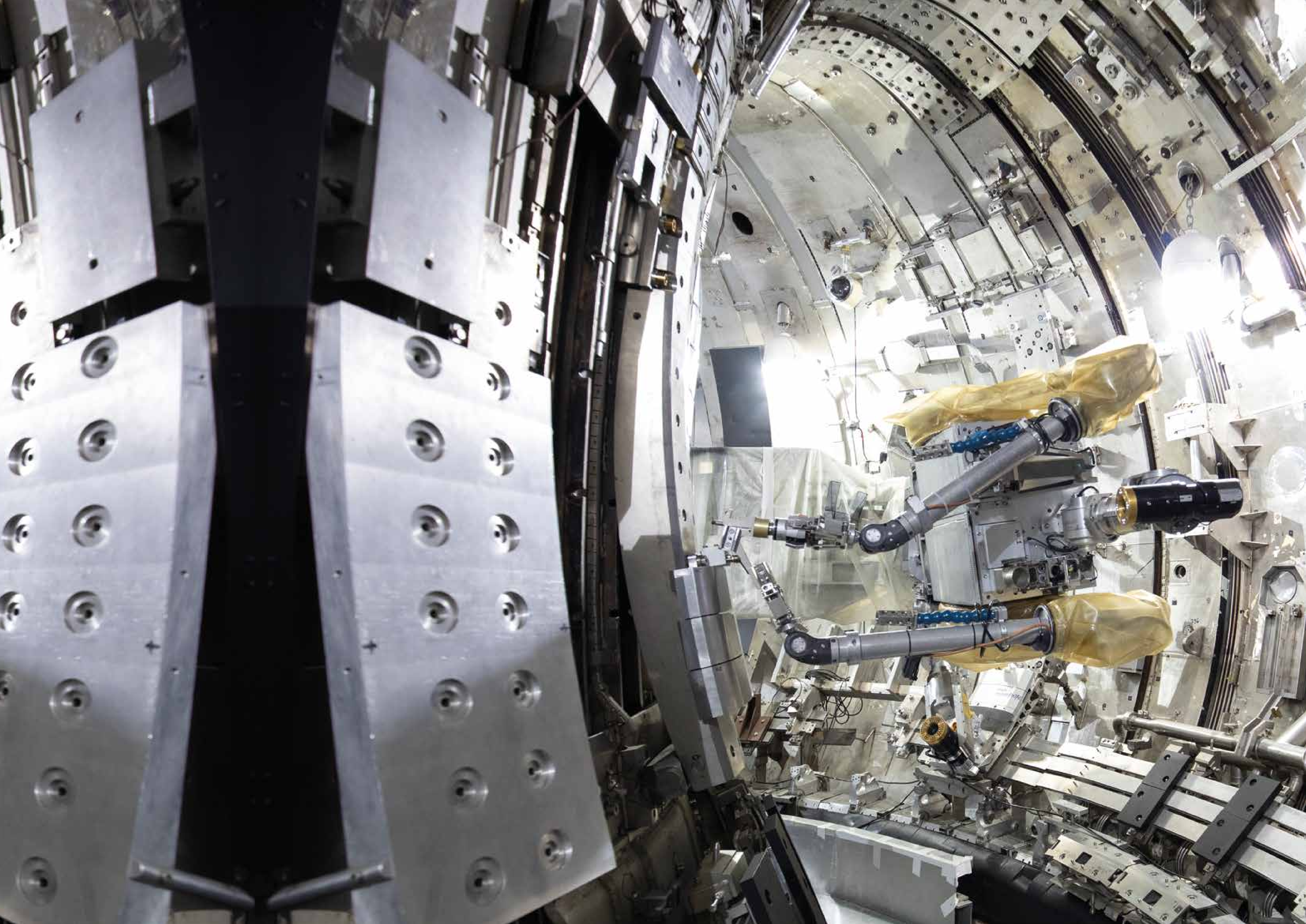
WORKING AS PART OF THE TEAM AT RACE

The team at RACE are genuinely 'a team': they go out of their way to help and have been so supportive. There is a wealth of knowledge and skills amongst the staff at RACE and everyone seems ready to share their expertise and insights from previous experience. All gain from this collaborative environment. RACE also hold more formal knowledge sharing events like the 'RACE Symposium' ensuring that teams don't become 'siloed' within their own projects, and that valuable know-how benefits the whole team. More formal training and professional development is actively encouraged, and in the year that I have been at RACE, I have taken the opportunity to gain a lot of new skills.

Whilst the concise description of the work at RACE is 'Remote Applications in Challenging Environments' with the goal of sustainable fusion energy, in practice this covers a diverse field of work. From solving the practical issues of decommissioning the retired 'JET' experimental fusion machine, to turning fusion plant concepts like the DEMO and STEP into real-world designs (along with many other fascinating projects). RACE endeavour to match staff to projects and roles that suit their strengths and interests, with so many inspirational projects available makes for an engaged and highly motivated workforce.

This has been a career changing opportunity. Enabling me to use my skills as an engineer and contribute towards the inspirational – and some might say 'world-changing' – work of RACE.

Christa Davies



The UK Atomic Energy Authority's mission is to lead the delivery of sustainable fusion energy and maximise scientific and economic benefit.

UK Atomic Energy Authority

Find out more
www.gov.uk/ukaea

United Kingdom Atomic Energy Authority
Culham Campus
Abingdon
Oxfordshire
OX14 3DB

t: +44 (0)1235 528822

Follow @UKAEAofficial

CPS24.648