UK Atomic Energy Authority

Robotics challenges for fusion energy

2nd edition 2023

Robotics are central to realising the goal of commercially viable fusion energy. In some cases, industries adjacent to fusion may be able to provide the robotics technologies needed to maintain future fusion plants; in other cases, fusion's challenges are unique and will need dedicated effort.

In this publication we identify 10 challenge themes for robotics, extracted from the various fusion energy projects we are involved in. If your research is relevant to these challenges and you would like to collaborate, learn more, or get support from UKAEA, please get in touch.

Robert Skilton, Robotics Fellow

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Fusion Energy

Fusion energy research themes

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

More than 80 per cent of the world's energy still comes from fossil fuels. Climate change and diminishing fuel reserves mean the race is on to find alternative, sustainable technologies to supply a growing global population. With no greenhouse gas emissions, inherent safety features and virtually limitless fuels, fusion has a key role to play in the energy market of the future.

Fusion is moving from the research phase to the delivery phase. ITER, the first industrial-scale fusion device, is under construction, and prototype power stations are already being designed around the world.

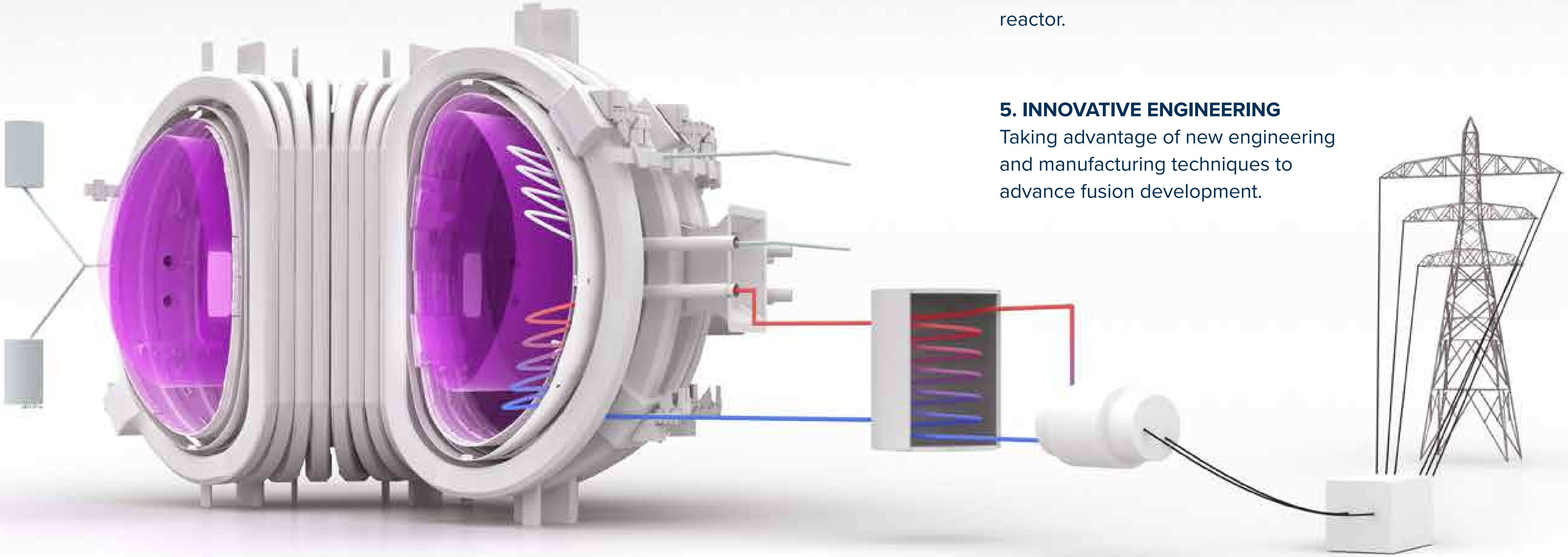
However, in order to realise fusion's potential as a source of efficient, cost-effective and reliable energy we will have to solve a series of complex science and engineering challenges.

UKAEA has identified that robotics-based maintenance is one of six essential challenges it must address.

1. PLASMA SCIENCE
Confining fusion fuel in a plasma at temperatures 10 times hotter than the sun's core.

4. MATERIALS SCIENCE
Developing materials that can withstand the demanding conditions inside a fusion reactor.

5. INNOVATIVE ENGINEERING
Taking advantage of new engineering and manufacturing techniques to advance fusion development.



2. FUEL HANDLING
Breeding and handling tritium fuel to power commercial fusion reactors.

3. PLASMA EXHAUST
Designing an exhaust system to divert heat from the plasma.

6. ROBOTIC MAINTENANCE
Maintaining the reactor entirely with robotics and remote maintenance techniques.

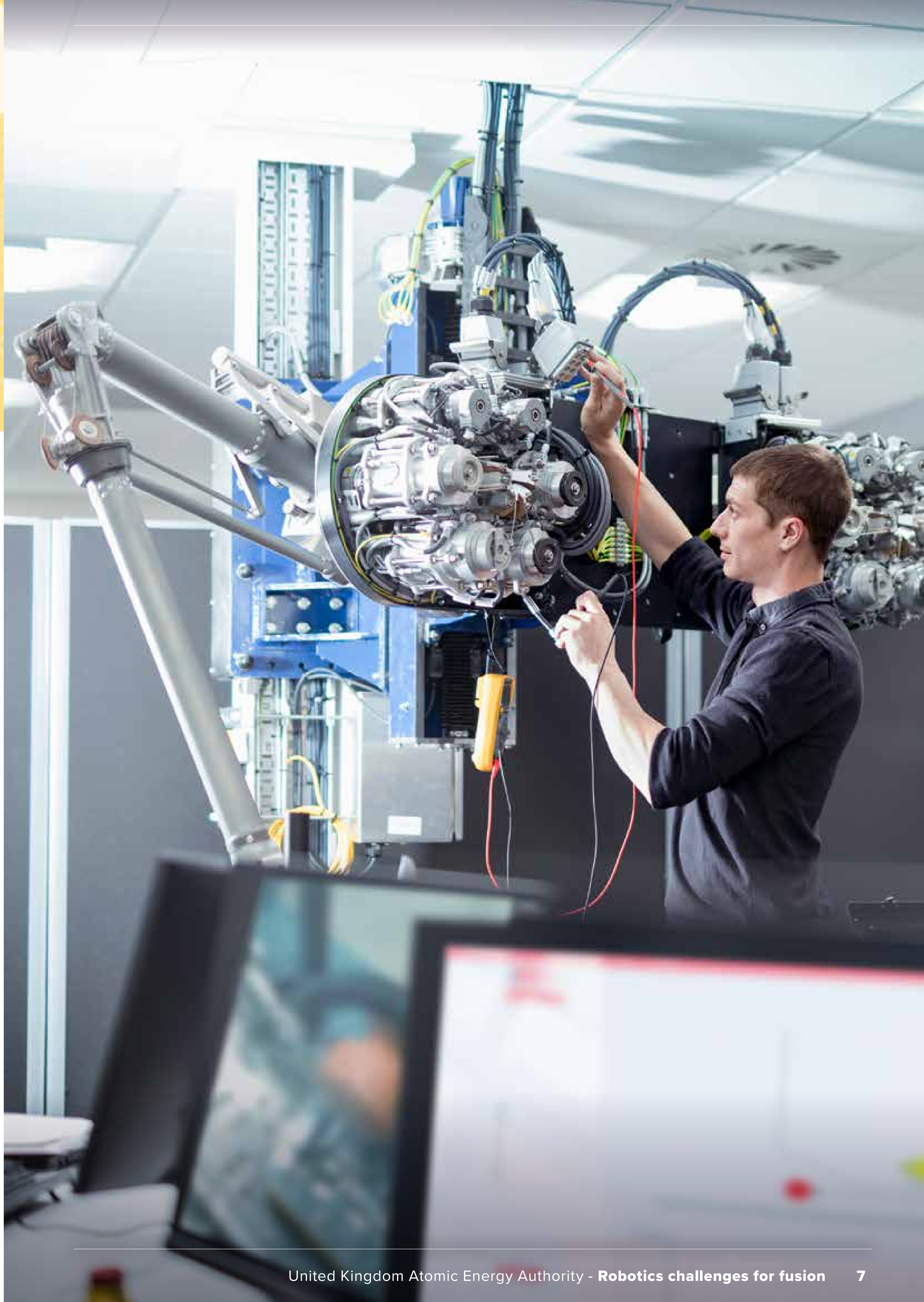
Mission and Goals

UKAEA's mission is to lead the delivery of sustainable fusion energy and maximise the scientific and economic benefit.

UKAEA researches fusion energy and related technologies, with the aim of positioning the UK as a leader in sustainable energy.

The **five interconnected strategic goals** to deliver on this mission are:

- Solve challenges of sustainable fusion energy - from design through to decommissioning - with world-leading science and engineering.
- Enable partners to design, deliver, and operate commercial fusion power plants.
- Drive UK economic growth and a thriving industry that exports fusion technology around the world.
- Create clusters that accelerate innovation in fusion and related technologies
- Develop the talented, diverse people needed to deliver fusion energy.



Remote Applications in Challenging Environments

RACE is the UKAEA's centre for Remote Applications in Challenging Environments.

Robotics and remotely operated tools are a fundamental part of operating fusion power plants.

The requirement to maintain fusion devices remotely is now considered to be device-defining – meaning the architecture of a fusion power plant must be designed to be inspected, maintained, and upgraded remotely using robots. It is also mission-critical because reliable, fast intervention is necessary to maximise plant availability and hence achieve commercial viability.

RACE is a world-leading centre for robotics in fusion. It brings together the technology and expertise to develop the robotics and people who will deliver commercially viable fusion and, through its collaborative approach, is enabling an innovation pipeline of UK and international organisations which can serve the fusion mission.

RACE is therefore central to delivering on the UKAEA's mission.

RACE is more than fusion: the skills and talent it develops have impact on the UKAEA's goals beyond fusion by contributing to UK economic growth and technical capability. RACE creates impact and benefits from partnerships in other sectors with challenging environments, for example Space and Nuclear Decommissioning.

RACE operates across the full lifecycle of remote maintenance systems and associated technologies, from pre-concept through to decommissioning.

RACE collaborates with others to develop the capability needed for fusion:

- Develops capability in remote operations and associated technologies
- Deliver capability to programmes and facilities internationally
- Transfers capability to others through training and partnership

How we operate

We collaborate on research to align with expertise, understand use cases, and maximise real-world impact

We host and provide test facilities and hardware platforms to facilitate cost-effective research

We make fusion challenges accessible to leading researchers by facilitating easy access to knowledge and facilities

We align our programme with wider needs outside of fusion to maximise mutual benefits, engage broader expertise, and leverage available funding

We act as a hub to connect end users, researchers, suppliers, and funders for mutual benefit

We form a ‘Viable Innovation Pipeline’ for organisations who understand our problems and can provide solutions

We work pro-actively to remove barriers to progress and engagement

RACE
Research Team

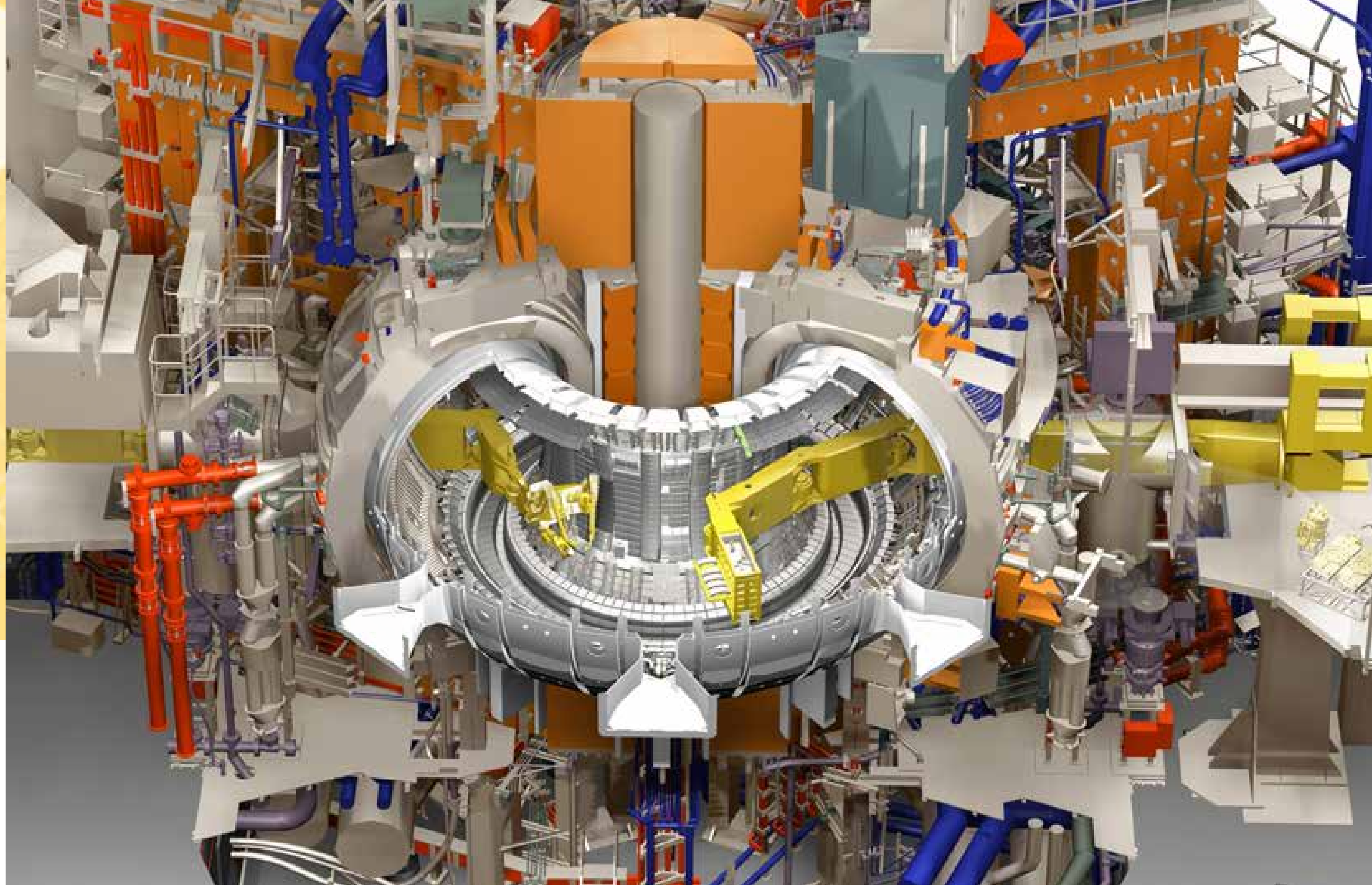
RACE has two core teams: a Research Team focused on early-stage technology development (TRL 2-5) and an Engineering Team focused on delivering that technology (TRL 4-8).

The RACE Research Team is focussed on the future, with a 5-15 year forward view. It engages the required research and academic collaborations to achieve UKAEA's robotics mission. Its role is to develop new knowledge and capability that supports delivery in the medium- to long-term, and bring together new technologies from universities and other industries to meet the RACE challenges.

The RACE Research Team has two primary goals:

1. To attract and enable the world's leading researchers across a wide range of fields to work on the UKAEA mission of enabling fusion through robotics and maintenance.
2. To reduce and remove barriers to technology and capability in other areas relevant to fusion.

The Research Team works closely with the Engineering teams to understand the real-world challenges and constraints inherent in the development of fusion energy plants. They work to translate scientific developments, research progress and emerging technology areas to impact the development of new reactors. They act as an "intelligent customer" for research output, and maintain awareness of a wide range of emerging technologies and fields of research.



In developing systems for challenging environments, RACE takes a holistic approach to the systems it develops. Building robotics for these environments needs support from many other areas of engineering:

- Materials that can withstand the extremes and still function within an electromechanical system in well-defined ways
- Cutting and joining technologies that robots can carry out autonomously at a distance with complete safety
- Structural engineering to support and autonomously move heavy loads with high accuracy
- Control systems that can coordinate the actions of multiple devices to achieve complex maintenance tasks
- Adaptive systems and AI decision tools trustworthy enough to be used to plan and optimise when and how tasks are carried out
- User Interfaces that keep operators informed and in control without being overloaded

These diverse areas of engineering must be integrated into systems that will need to last the decades-long lifetimes of the reactors they maintain, and in some cases they cannot be removed once they are installed.

Global RACE

RACE is part of a global effort to create sustainable fusion power and is directly involved in both the UK and European efforts to build sustainable fusion reactors.

JET is the UK-based European experimental fusion device. After reaching a significant milestone in 2022, producing a record-breaking 59 megajoules of sustained fusion energy, RACE is looking ahead to the decommissioning phase.

ITER is under construction in Cadarache in the south of France, and is the most advanced fusion project. ITER is expected to reach its first deuterium-tritium operations in 2035.

STEP is the UK's fusion prototype power plant. It will include much of the infrastructure and facilities seen on any operational power station. Completion of construction is targeted for around 2040.

DEMO is the planned European successor to ITER, and aims to produce 500 MW of electrical power to the grid, a similar level of output to a standard electrical power plant. DEMO and should be online in the middle of the century.

RACE is involved in providing robotics-based remote maintenance in all these projects, each of which requires robotics for long-term maintenance. RACE collaborates globally to develop the robotics to meet the engineering and scientific challenges of these vital projects.

ITER


Credit © ITER Organization, http://www.iter.org

ITER is the next generation fusion research device being built in the south of France that will achieve 'a burning plasma'. This is one of the required steps on the way to commercial fusion power.

Remote Handling (RH) has an essential role to play in the ITER Tokamak. Once fusion begins, changes, inspections and repair of the machine components in activated areas will only be possible using Remote Handling techniques. Through the ITER Robotics Test Facility hosted at RACE is working with ITER to develop RH equipment and processes. Under this programme we demonstrate the feasibility of remote maintenance activities at ITER. RACE is also supporting industry in delivering dedicated RH systems. This is helping to de-risk complex, first-of-a-kind designs and operations.

ITER provides some seriously challenging environments for robotics: high radiation dose; elevated temperatures; limited access; large reactor components; and some very challenging inspection and maintenance procedures to implement fast and reliably.

STEP

STEP is a UKAEA programme that will demonstrate the ability to generate net electricity from fusion. Key challenges for the STEP programme include determining how the plant will be maintained through its operational life, and proving the potential for the plant to produce its own fuel.

RACE leads the development of remote maintenance processes and technologies, from in- and ex-vessel maintenance through to decontamination, storage and disposal of activated components. RACE's remote maintenance engineers are integrated in the STEP team, and are bringing their knowledge to the design of components for remote maintainability.

RACE has a key set of capabilities which will be required by STEP to meet the demands of an acceptable through life affordability, both in construction, operation – including maintenance and waste handling – as well as onward decommissioning. Indeed, the through life cost is one of the critical KPIs which will be monitored in the overall business case.

The objective is to produce a feasible scheme for the maintenance of the STEP Prototype Reactor (SPR) at a conceptual level that demonstrates, with feasible technology development, that the critical and vulnerable components can be replaced.

This work provides the STEP programme with confidence that the proposed reactor's operation, control and maintenance strategy is safe, affordable, available, and technically credible.

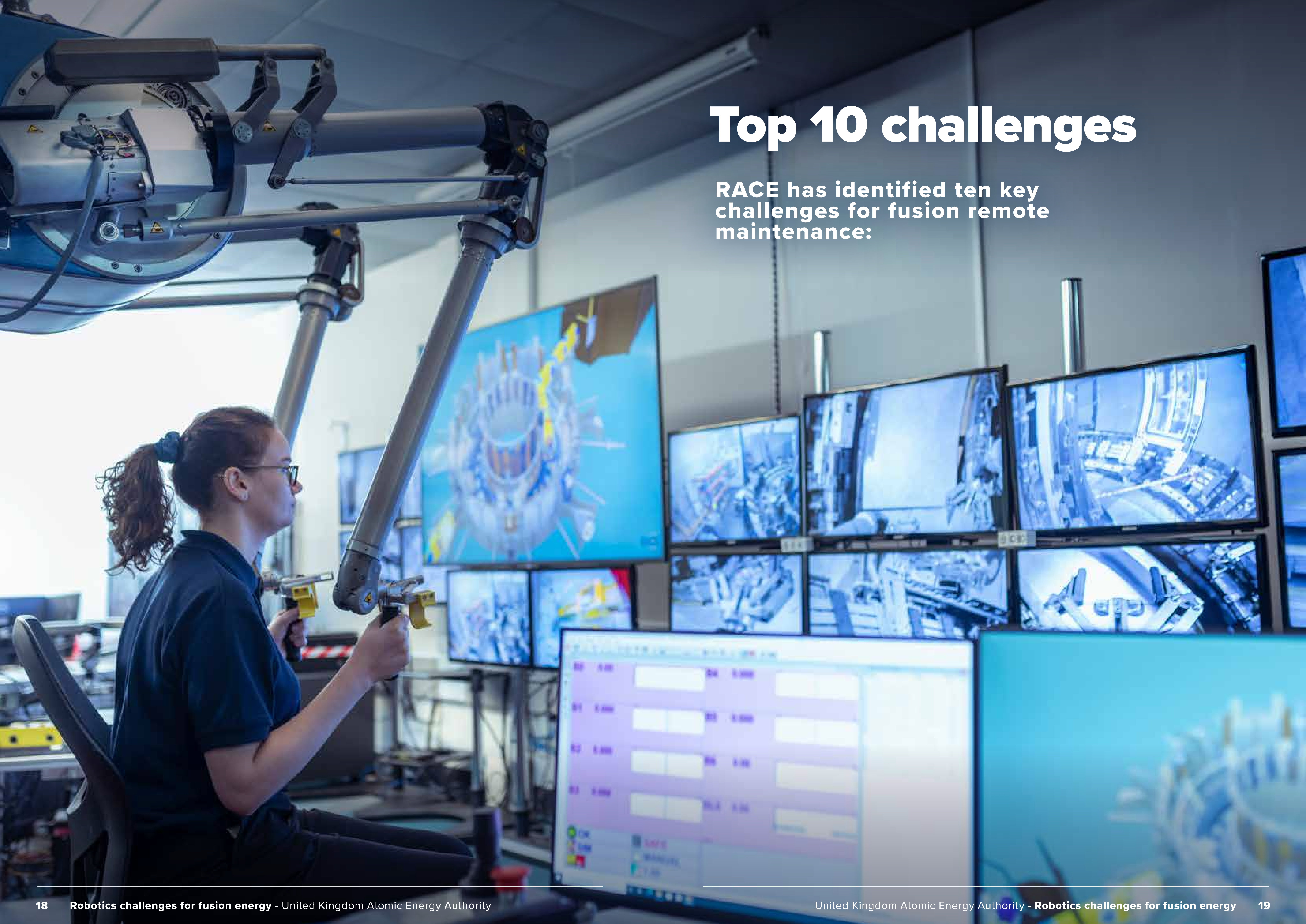
DEMO

DEMO (or EU-DEMO) is the European successor to ITER – a proposed grid-connected fusion device that will demonstrate safe and consistent generation of electricity.

RACE is the lead laboratory for EU-DEMO's Remote Maintenance Work Package, and is responsible for leading the development of remote maintenance technologies, and integrating enabling technologies developed across the EU and the UK.

Minimising plant down-time and maximising availability will reduce the cost of electricity. An effective remote maintenance strategy for DEMO is crucial for the commercialisation of fusion energy. Remote Maintenance is 'device-defining', driving the plant architecture.

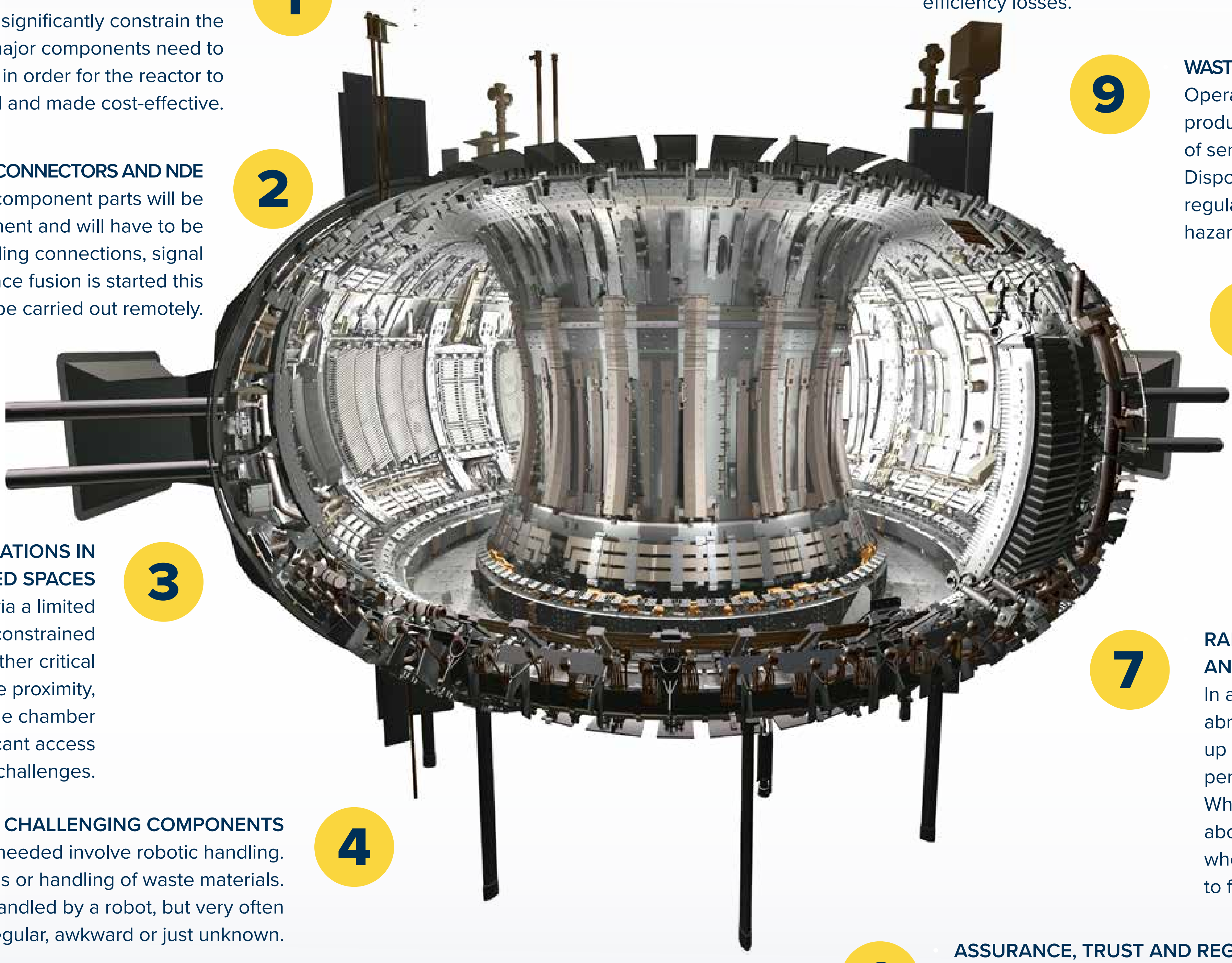
Where the remote maintenance strategy requires novel solutions, RACE leads the development of the technologies to meet the challenges.



Top 10 challenges

RACE has identified ten key challenges for fusion remote maintenance:

Key challenges for robotics in fusion & beyond



1 ARCHITECTURE OPTIMISATION INCLUDING DESIGN FOR REMOTE MAINTENANCE

The physics of fusion reactions significantly constrain the architectural design of the reactor. The major components need to have specific sizes, positions and shapes in order for the reactor to work. However it must also be maintained and made cost-effective.

2 SERVICE JOINING INCLUDING PIPES, BOLTS, CONNECTORS AND NDE

Over the lifetime of a reactor many component parts will be degraded by the extreme environment and will have to be replaced: pipes, flange bolts, earth bonding connections, signal connectors, seals and many more items. Once fusion is started this regular maintenance work will have to be carried out remotely.

3 SLENDER MECHANISMS AND OPERATIONS IN CONFINED, CRAMPED SPACES

Access into the fusion chamber is via a limited number of access ports with dimensions constrained by toroidal field magnets and other critical structures. Outside the vessel, in close proximity, are support systems that access the chamber through the ports. This results in significant access challenges.

4 HANDLING OF CHALLENGING COMPONENTS

All of the remote maintenance tasks needed involve robotic handling. Handling of components, handling of tools or handling of waste materials. Tools and parts can be designed to be handled by a robot, but very often a robot has to handle parts that are irregular, awkward or just unknown.

5 ENVIRONMENTAL COMPATIBILITY INCLUDING RADIATION, VACUUM, MAGNETIC FIELDS

The operating environment in which robots must carry out maintenance and inspection tasks is extreme: neutron fluences, high levels of gamma radiation, powerful magnetic fields, vacuum conditions, high temperatures, and thermal cycles

6 ASSURANCE, TRUST AND REGULATION

In addressing these challenges the physical and digital systems that are deployed to make fusion possible must be trustworthy. Not just trustworthy when they are built but trustworthy afterdecades of operation.

7 RAPID RESPONSE INCLUDING INSPECTION AND IN-SITU REPAIR

In any complex system there will be operational abnormalities. These abnormal events will be picked up through long-term and short-term monitoring and by periodic inspections, most often conducted remotely. When an issue is identified a decision must be made about the need for rapid and immediate intervention where there will not be an opportunity to transition to full shutdown.

8 MAINTENANCE PRODUCTIVITY

Future fusion power plants will need to be productive enough to ensure sufficient return on investment by providing reliable, sustained electricity generation. This in turn relies on the high availability of the reactor and its support systems.

9 WASTE MANAGEMENT

Operating a fusion power plant creates waste either as by-products of the fusion process or by parts being taken out of service and refurbished or by decontamination work. Disposal must be done safely and in compliance with regulations around the management of hazardous materials.

10 THROUGH-LIFE COST REDUCTION FOR LONG-LIVED FACILITIES

Lifetime cost is a critical factor in the success of fusion-based electricity generation. Over its lifetime, a fusion plant will have a high potential for loss of efficiency and the chance that sub-optimal operations will drive up operating costs. These effects may be compounded over long lifespans where changing teams, technology obsolescence, and altered operational requirements create unforeseen efficiency losses.

Challenge 1:
Architecture optimisation including design for remote maintenance

The physics of fusion reactions significantly constrain the architectural design of the reactor. The major components need to have specific sizes, positions and shapes in order for the reactor to work. However it must also be maintained and made cost-effective.

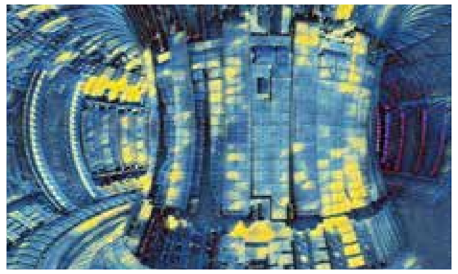
Designing a reactor architecture therefore presents a complex set of challenging trade-offs between different design requirements: too sharp a focus on fusion performance and it might be unmaintainable, too sharp a focus on maintainability and it may not operate efficiently. To date there is no perfect solution.

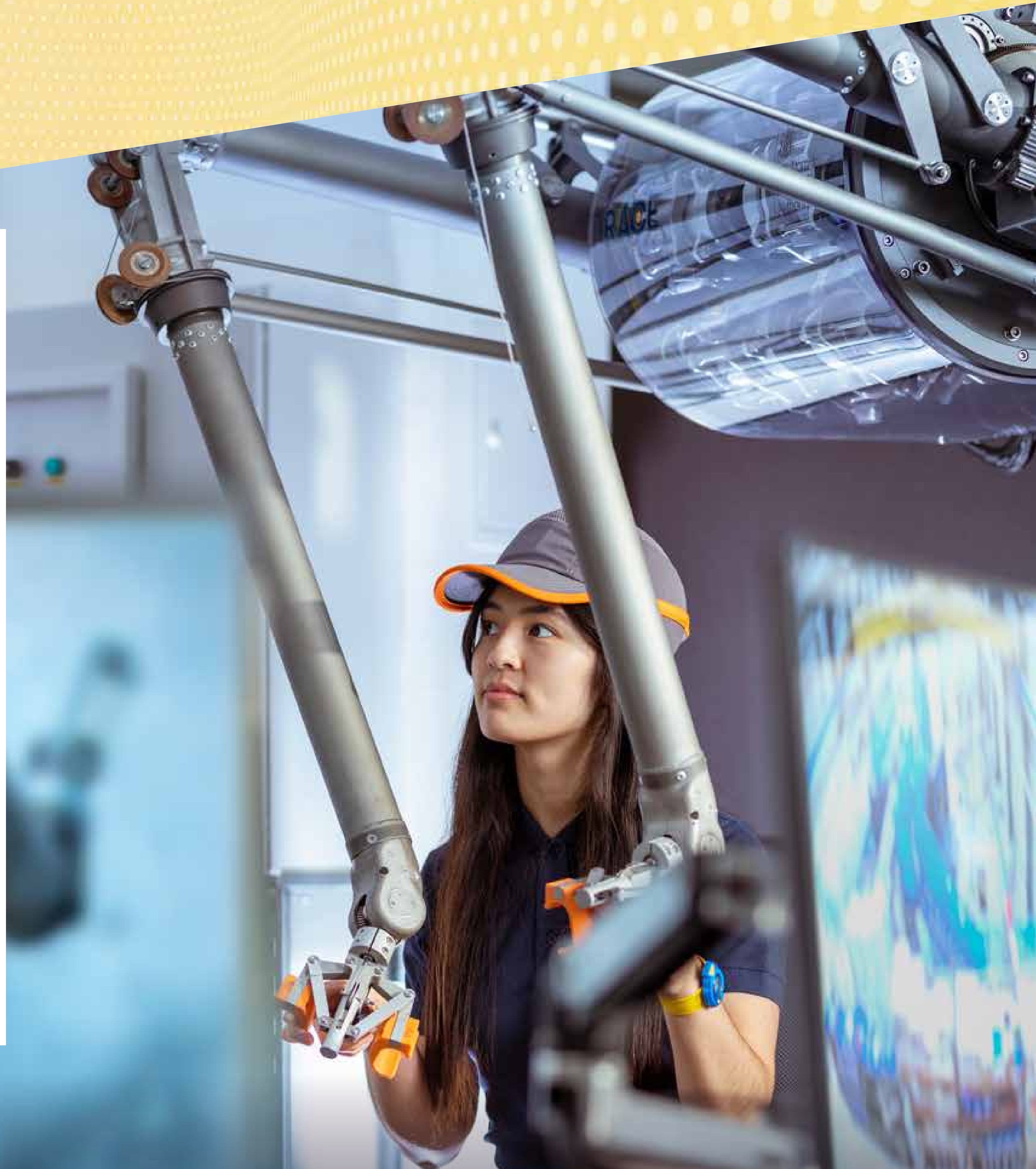
Added to this, many of the design parameters are interdependent and constrained by the physics. Part of the reason for building JET, ITER, STEP and DEMO is to explore the space of possible operating architectures, to find the “sweet spot”. Traditional approaches to design optimisation require too many trial and error experiments, are too costly and will take too long.

RACE needs to understand not only how to build remote maintenance systems but how the architecture of the whole system can be balanced to provide efficient maintainable operation over long periods of time. It needs to find new ways of converging on feasible design architectures, of exploring and testing designs and developing tools to “sound out” operation before construction.

Example research areas

- Methods for automated parametric design of robotic systems
- Architectural standards to promote operational agility
- Hardware interfaces to promote ease of remote operation
- Service connections designed for remote operation
- AI-driven automated architecture development





Challenge 2:
Service joining including pipes, bolts, connectors and NDE

Over the lifetime of a reactor many component parts that make up its support systems will be degraded by the extreme environment and will have to be replaced. This will involve disconnecting and reconnecting: pipes, flange bolts, earth bonding connections, signal connectors, seals and many more items. Once fusion operations begin, regular maintenance work will have to be carried out remotely.

Service systems involving removal and reconnection must continue to maintain regulatory compliance and each task outcome must be validated before operation can recommence. For example, pipes that are reconnected by welding will need to have the welds remotely validated, often where access is only possible from one side of the pipe wall.

RACE needs to understand the best way to carry out these operations with systems operating at a distance. The way to assess the condition of parts, how to cut, weld, connect and disconnect services, how to assure that each time this work is done it can be validated and how contamination and waste generated by the process can been minimised to a level that will not compromise future operation. These challenges of space, time and quality are the core of this challenge.

Example research areas

- Novel methods for pipe joining
- Radiation-compatible NDE methods
- Remote pipe end preparation for welding
- Swarf control technologies
- Computational weld modelling
- In-situ weld repair techniques

Challenge 3:
Slender mechanisms and operations in confined, cramped spaces

Fusion systems that require maintenance are tightly packed together resulting in significant access challenges for robotics. Access to the inside of the fusion chamber is via a limited number of access ports with dimensions constrained by toroidal field magnets and other critical structures. Maintaining, inspecting or replacing in-vessel components typically involves reaching through these narrow, congested ports. This has historically led to designs involving long, slender robotic boom systems which exhibit a range of constraints, including strength and payload issues, vibration and flexible deformation, and mechanical constraints imposed by the connections to power and signals needed to operate.

Outside the vessel, in close proximity, are support systems: heating systems, diagnostics, magnets and associated systems, cryogenic systems, pipes and cooling systems, fuel injectors, electrical power systems and support structures. Maintenance and inspection of these systems is made more challenging in areas with a range of radiological and chemical hazards. This combined with the limited access and confined spaces mean that human maintenance is often impossible.

RACE needs to understand how to design and build systems that can operate at a distance in extreme environments. How they can carry out complex functions over long periods of time with very high levels of reliability. How they can adapt as their working environment changes over time and how to plan and execute tasks able to assess and maintain in both planned and unplanned missions.

Example research areas

- Control strategies for reducing flex and vibrations in long manipulators
- Mechanical damping systems for boom arms
- Novel methods for automated design of long-reach arms
- Planning algorithms that account for highly confined spaces
- Human interface enhancements for collision prevention

Challenge 4:
Handling challenging components

All of the remote maintenance tasks needed involve robotic handling. Handling of components, handling of tools or handling of waste materials. Sometimes tools and parts can be designed to be handled by a robot, but very often a robot has to handle parts that are irregular, awkward or just unknown. For example, parts may contain liquids which alter their centre of gravity as they move; parts may articulate and move unpredictably; and waste products may have unknown fragilities.

Even regular maintenance tasks – such as the handling of electrical cables, a welding torch or a valve – present significant manipulation challenges. In the fusion environment every scenario has to be examined, including the possibility that remote maintenance will be needed on systems where no maintenance requirement was designed in or where it was assumed that humans would be able to carry out the tasks but cannot now do so.

Lifetime events may alter what is possible and what needs to be done remotely, and new technology may provide opportunities for remote handling that do not currently exist.

RACE needs to understand how robots can be built to handle complex objects and tools and do so with very high levels of reliability and trust. It needs to understand how to design handling systems that are able to deliver dexterity while keeping the forces and moments imparted under control. It needs to understand how to design for the unexpected.

Example research areas

- Control methods for robust handling of arbitrarily shaped objects
- Visual methods for grasp detection in challenging environments
- Methods for enhancing human tele-operated handling
- Reinforcement learning-based methods for handling delicate objects and cables
- Modelling methods to enable accurate handling of objects containing fluids
- Methods for autonomous brushing, swabbing, and wiping

Challenge 5:
Environmental compatibility including radiation, vacuum, and magnetic fields

The operating environment in which robots must carry out maintenance and inspection tasks is extreme: neutron fluences, high levels of gamma radiation, powerful magnetic fields, vacuum conditions, high temperatures, and thermal cycles.

Sometimes there will be a need for rapid inspection to resolve the unexpected with direct intervention. Robots must then be able to operate at the extremes created when there is no time to “normalise” the operating environment.

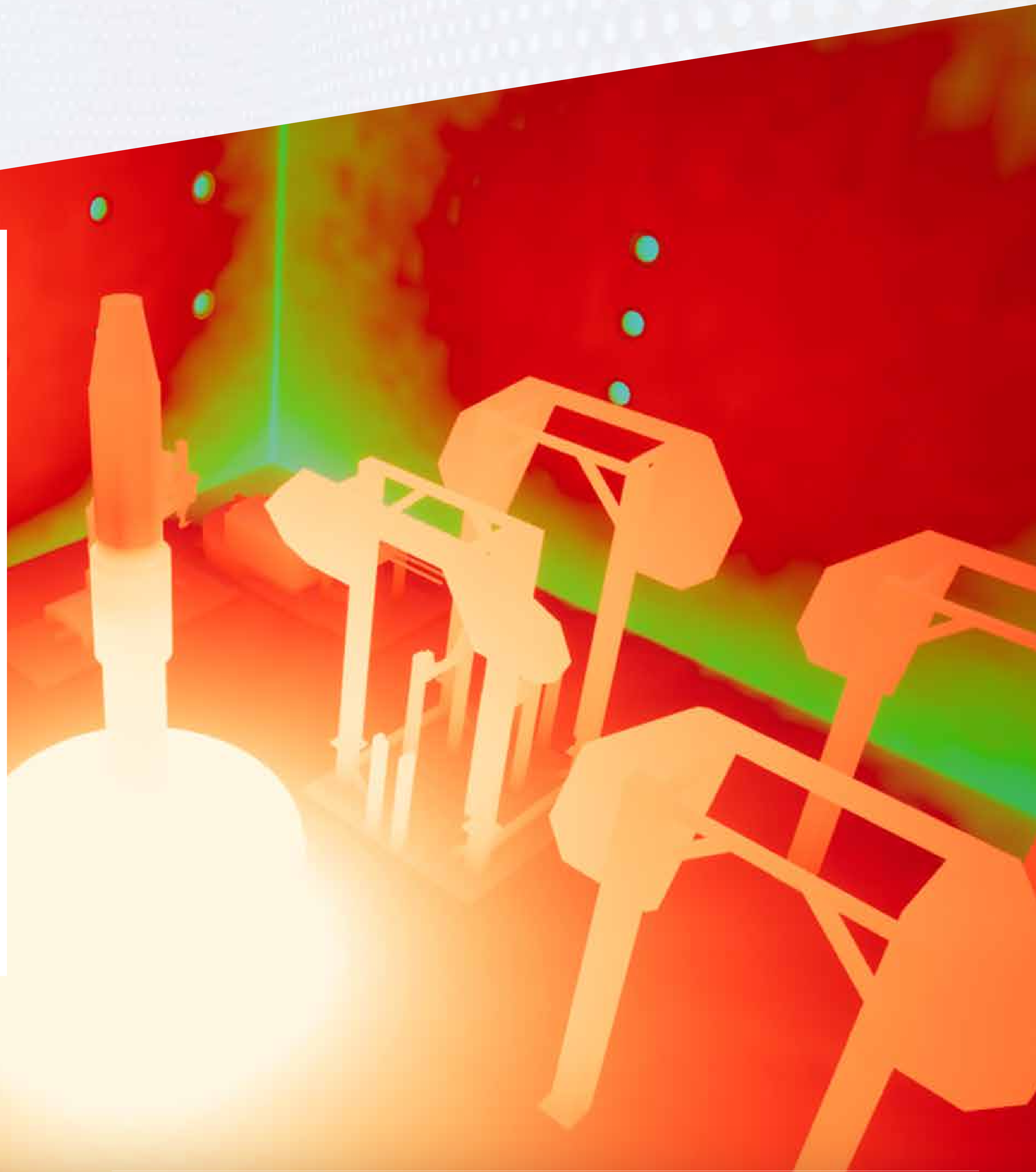
Even during planned maintenance within the vessel robots will encounter high gamma radiation from activated components, residual magnetic fields or high ambient temperatures.

Outside the vacuum vessel environment, there are still a wide range of hazardous conditions to contend with based on proximity to sources in-situ, or while being transported to maintenance areas.

RACE needs to understand the materials that can withstand these conditions and how to make robots from these materials, how sensors can continue to operate and how actuators and structures can be designed for these extreme environments.

Example research areas

- Highly radiation-hard sensors (>10MGy)
- Radiation-hard communications interfaces
- Vacuum-compatible robotics
- Magnetic-field-compatible servomotors
- Strategies for leveraging magnetic fields



Challenge 6: Assurance, trust, and regulation

The other challenges set out clear needs for engineering and science to address, describing systems that do not yet exist and may take decades to perfect. In addressing these challenges, the physical and digital systems that are deployed to make fusion possible must be trustworthy. Not just trustworthy when they are built but trustworthy after decades of operation.

Conventional safety systems are designed to protect people by detection or exclusion. In the systems needed for fusion it is also the plant that must be protected. In systems of equivalent complexity some degree of failure is expected, and fail-safe systems are “built in” with the expectation that faults can be fixed. In fusion this is not always an option.

Apart from being able to trust the machines and the software systems that drive them there is the need to trust the work they carry out: weld quality, seal integrity, connection reliability etc. and to validate at a distance after repeated operations on the same plant over decades of operation. Here trust and regulation go hand in hand.

In the future, if AI systems are used to adapt robots over time as they degrade, or as their environment degrades or changes, then they will have to continue to be trustworthy after self-adaptation has taken place.

RACE needs to understand how to develop new methods for verification and assurance of hardware and software systems, including AI based systems, not just within the context of nuclear safety, conventional safety, and commercial investment protection but also with regard to the challenges of fusion robotics. Part of this also needs to examine how to protect these systems against sophisticated malicious attacks including threats of cyber-terrorism.

Example research areas

- Explainable AI solutions
- Methods for verification of advanced robotic planning algorithms
- User interfaces that enhance operator trust
- Assessment of present operator perceptions of dependability
- Assurance of AI decision-support technologies
- Transition to increasingly autonomous operations

Challenge 7:
Rapid response, including inspection and in-situ repair

In any complex system there will be operational abnormalities. These abnormal events will be picked up through long term and short-term monitoring and by periodic inspections, most often conducted remotely.

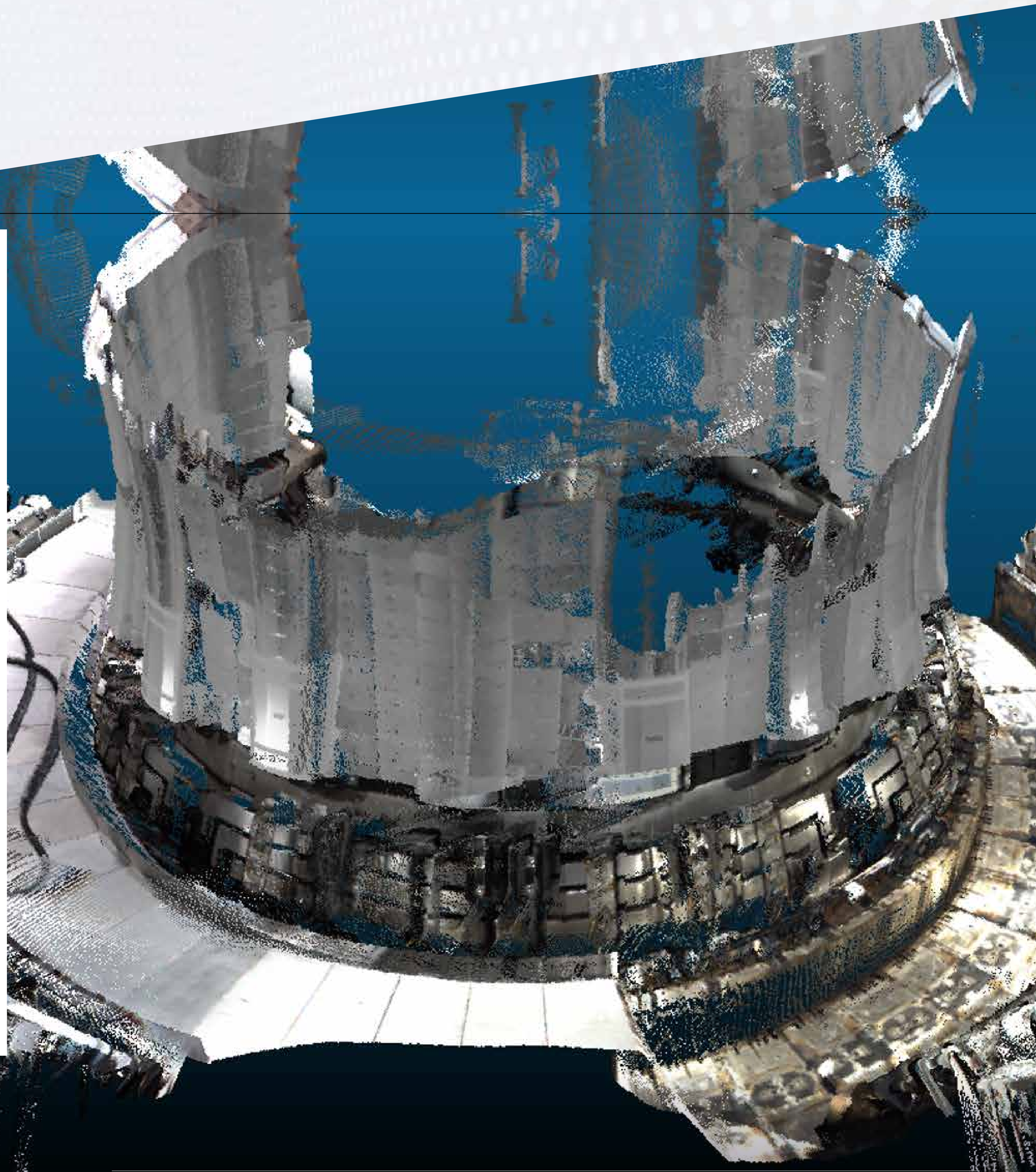
When an issue is identified a decision must be made about the need for rapid and immediate intervention where there will not be an opportunity to transition to full shutdown. This would include discharging superconducting magnets, restoring ambient atmosphere, allowing thermal and radiological conditions to reduce, and removing any equipment obstructing port access.

It is therefore necessary to design for rapid intervention and in-situ repairs that can be completed with the minimum of downtime and as rapidly as possible. Fast inspection and intervention systems have to be developed to withstand the most extreme of conditions present in fusion and be readily deployable. These interventions are likely to include inspection and survey, including visual inspection and high sensitivity geometric measurement, as well as in-situ first wall repair.

RACE needs to understand how systems can be designed to withstand these extreme conditions, how highly accurate inspection can be carried out in-situ and how repair processes can be carried out reliably, safely and remotely. Coupled to this is a need to understand how to develop planning systems that can be adapted to different types of failure so that the process of inspection does not create further unwanted impact.

Example research areas

- Methods for in-situ additive repair of metallic reactor components
- Systems for rapid inspection in extremely high thermal, vacuum, and radiation fields
- Methods for highly accurate in-situ geometric metrology to detect erosion and deposition
- Window cleaning
- Methods for routine inspection and repair of vessel components



Challenge 8: Maintenance productivity

Fusion power plants are complex systems that need to operate for decades to provide a return on investment. They will need regular maintenance, and these periods of maintenance must be as short as possible to maximise plant uptime. Plants must be productive enough to ensure sufficient return on investment through reliable, sustained electricity generation. High levels of availability are therefore essential.

Currently envisaged maintenance regimes for fusion plants indicate maintenance durations longer than desirable due to the large numbers of sequential actions, the transport logistics for components and maintenance equipment, and the durations required for shutdown, maintenance and restart processes. Additionally, where these must use “human-in-the-loop” approaches they are limited by human capacity.

RACE needs to understand how to optimise maintenance and inspection tasks, how to optimise design, how to configure and sequence tasks to minimise down time and how to inspect and maintain systems so that lifetime operation is maximised.

Example research areas

- Dynamic schedule optimisation algorithms
- Faster deployment devices
- Rapid service connection mechanisms and processes
- Time-efficient remote maintenance operations, for example pipe cutting and welding
- Automation of common, dexterous handling tasks

Challenge 9:
Waste management

Operating a fusion power plant creates waste either as by-products of the fusion process or by worn parts being taken out of service or by decontamination work. Disposal must be done safely and in compliance with hazardous material regulations. Processes including removal, processing, recycling and disposal, with contaminated and activated waste having to be processed in a hot cell. In an ideal scenario the goal is to find non-destructive processes for disassembly, decontamination, maintenance and reassembly, but this is not currently possible.

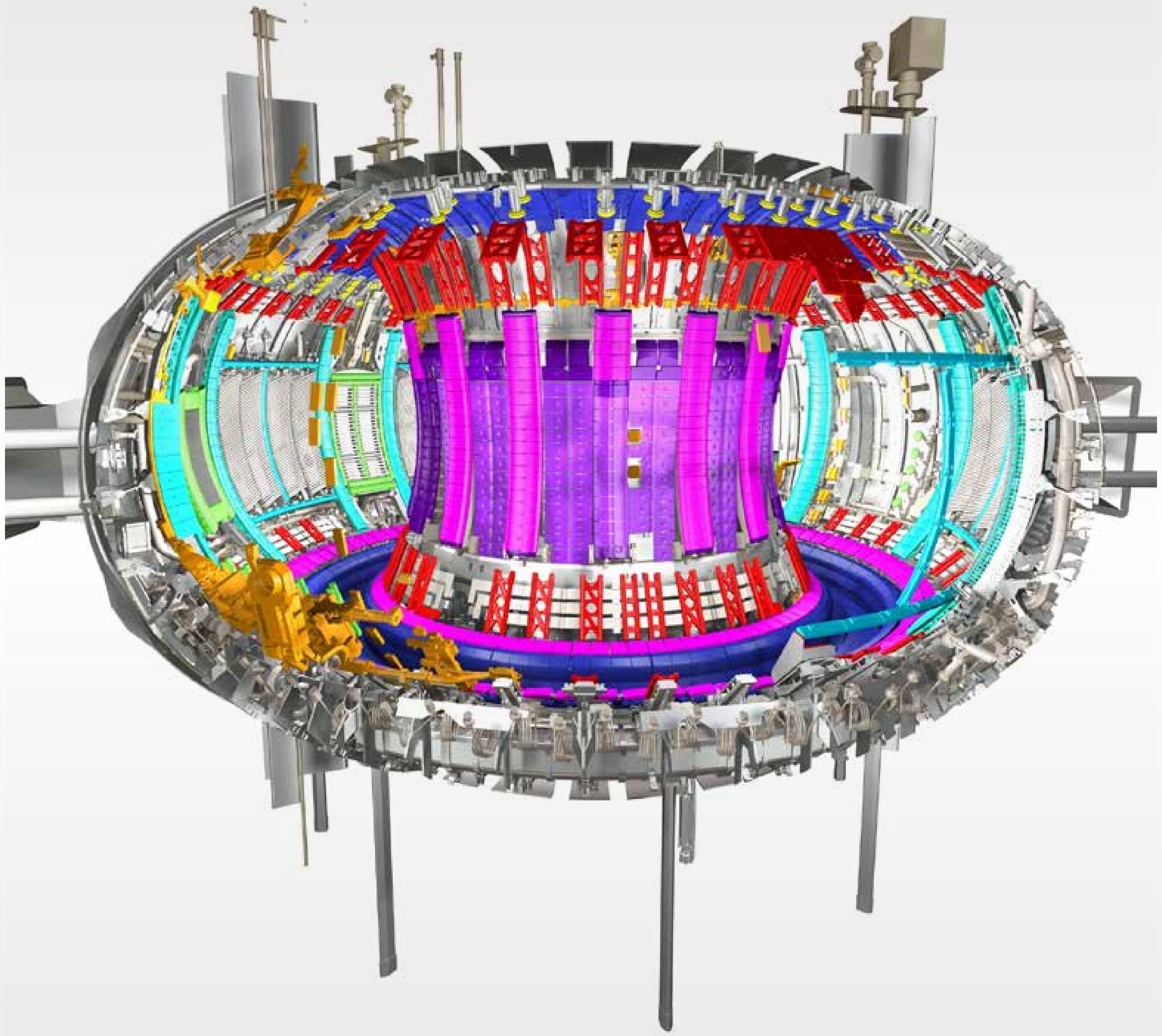
Some of the specific challenges faced include the optimal size reduction and packing of complex, composite, in-vessel components, the characterisation of waste, and the sorting and segregation of waste. Optimising waste processing to minimise the unnecessary progression of waste into higher-level waste categories is a key objective, as is the need for contamination management, including the efficient detection and removal of surface contaminants.

Solving these challenges results in significant benefits for safety and waste management efficiency. Processing waste and refurbishing parts has an impact on operating costs and must be carried out economically with respect to both material use and operational downtime.

RACE needs to understand how to optimise waste handling and keep within regulatory requirements, how to refurbish and process parts and how to assess contamination and to process and segregate waste using remote systems.

Example research areas

- Autonomous dexterous handling of unstructured waste components
- Methods for removal of surface contaminants from vessel components
- Sensors and algorithms for automatic contamination detection
- Methods for automated non-destructive disassembly of complex structures
- Regulation-compatible contamination estimation



Challenge 10: Through-life cost reduction for long-lived facilities

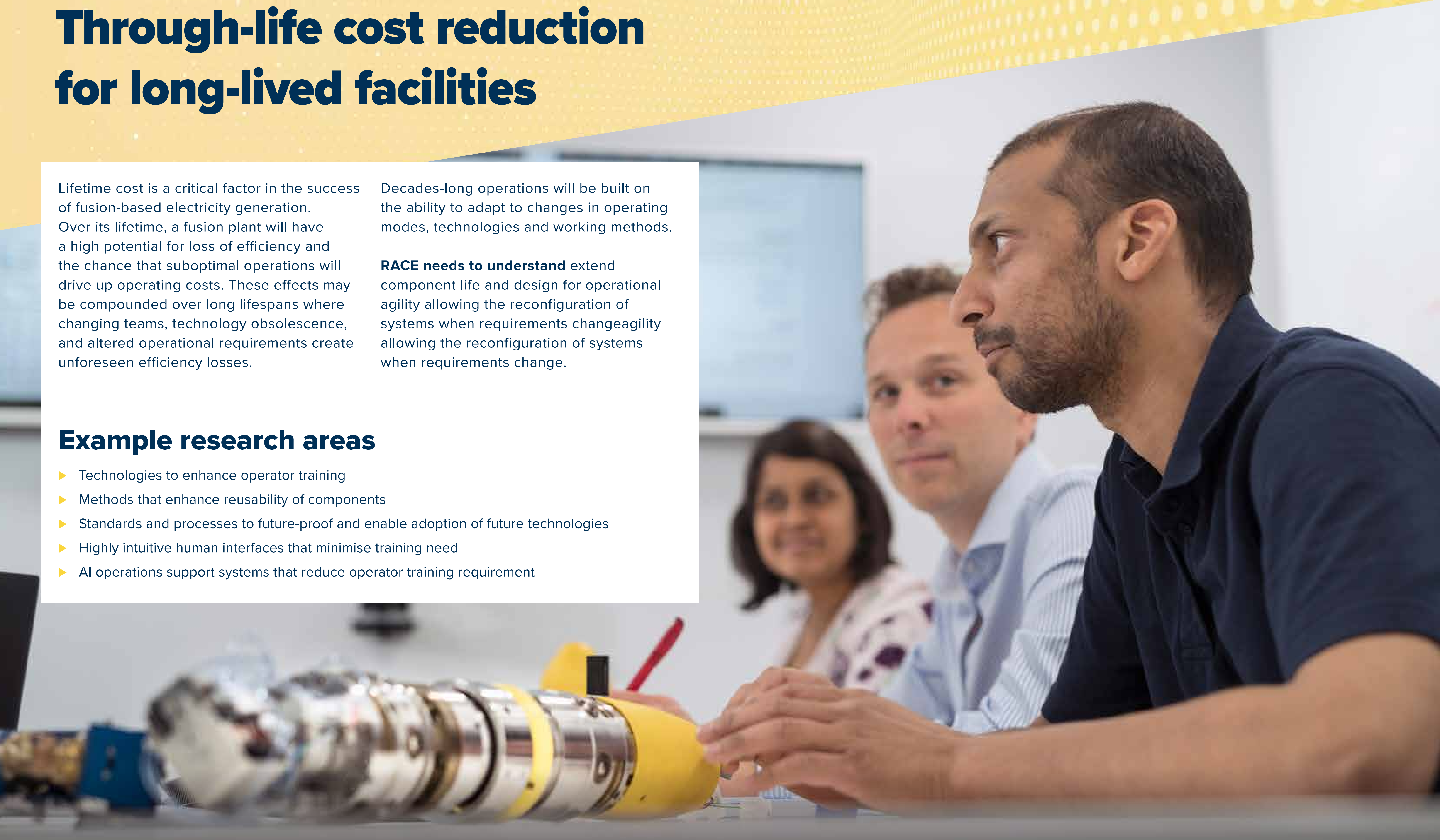
Lifetime cost is a critical factor in the success of fusion-based electricity generation. Over its lifetime, a fusion plant will have a high potential for loss of efficiency and the chance that suboptimal operations will drive up operating costs. These effects may be compounded over long lifespans where changing teams, technology obsolescence, and altered operational requirements create unforeseen efficiency losses.

Decades-long operations will be built on the ability to adapt to changes in operating modes, technologies and working methods.

RACE needs to understand extend component life and design for operational agility allowing the reconfiguration of systems when requirements changeagility allowing the reconfiguration of systems when requirements change.

Example research areas

- Technologies to enhance operator training
- Methods that enhance reusability of components
- Standards and processes to future-proof and enable adoption of future technologies
- Highly intuitive human interfaces that minimise training need
- AI operations support systems that reduce operator training requirement



How RACE can support your work

Assistance with defining use cases and explaining impact
We are happy to advise your project, including helping to define how your research can benefit fusion energy, as well as helping to explain and quantify its real-world impact.

Access to expertise
We have over 350 experts in all aspects of fusion robotics engineering and operations including a unique and highly experienced team of remote operations engineers who specialise in planning and performing remote robotic operations.

Access to physical facilities
We have a number of facilities available to academic research including robot platforms, sensors, and other test facilities that may be useful in supporting your work.

Access to data, software, and digital models
Access to data and digital assets can be extremely valuable to robotics research. We have a collection of data and models that represent the unique challenges of fusion and related environments, as well as software platforms that may be of benefit to your research.

Funded PhDs
Each year RACE funds PhDs in areas of priority to the fusion mission. We would be happy to discuss any potential proposals, as well as support with promoting fusion-relevant PhD projects.

Hosting secondments and placements
We offer the opportunity for researchers to be immersed in the fusion robotics world by sitting alongside the RACE team. Secondment and placement opportunities are available at our Culham and Whitehaven sites.

Supporting experiments and deployments
We can support experiments with advice and equipment, as well as providing expert operators as participants. We may also be able to facilitate deployment trials in real or representative fusion environments.

Giving lectures and talks and supporting workshops
We are happy to explain fusion challenges and our latest research to your teams through lectures and talks, as well as contributing to workshop sessions with subject matter experts.

Please get in contact to have an informal discussion about how you can help solve some of the top challenges of robotics in fusion energy, or how we can support your research.

contactus@race.ukaea.uk

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

Contact us

- For collaboration opportunities
- To learn more about fusion research challenges
- To access test facilities
- To discuss support to fusion-relevant research projects

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