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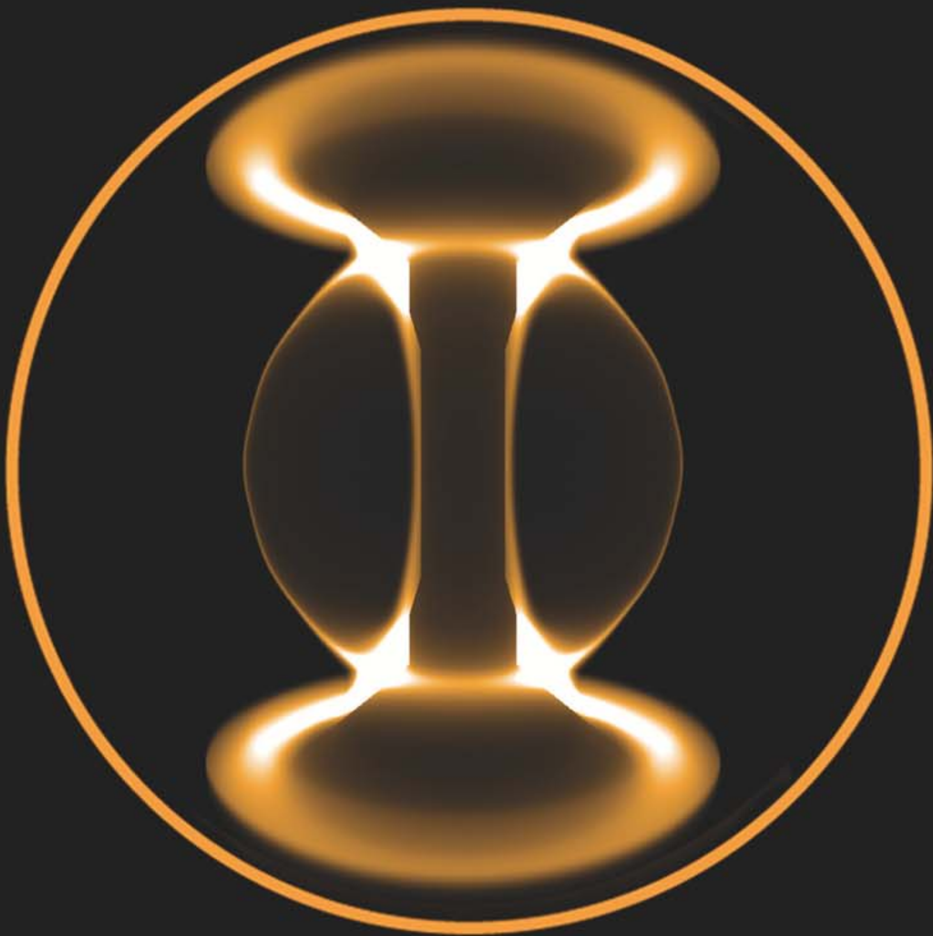
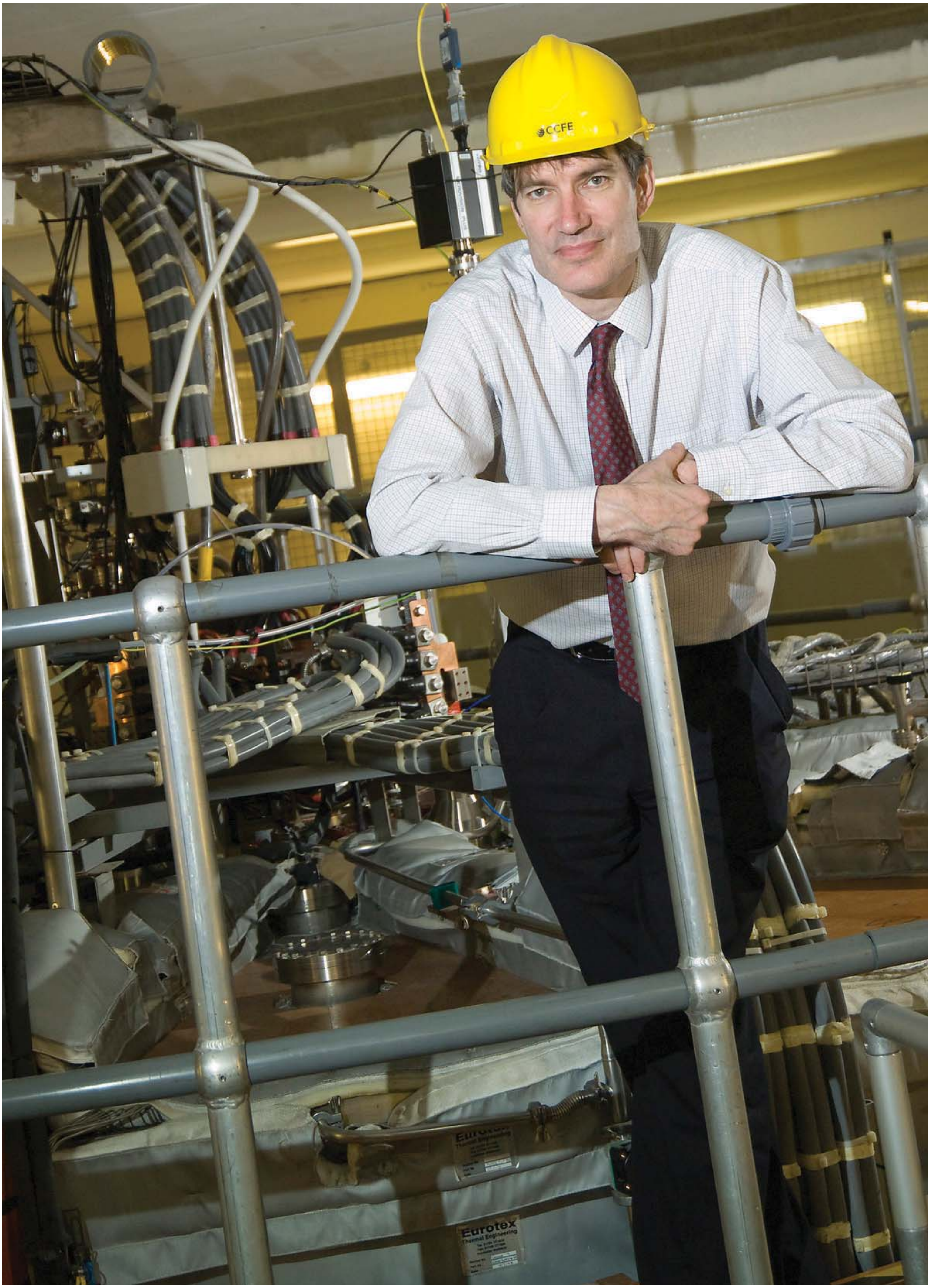


MAST Upgrade

Advancing compact fusion sources


CCFE
Eurotex
Thermal Engineering

MAST

The cutting edge of fusion

The Mega Amp Spherical Tokamak (MAST) is the centrepiece of the UK's fusion research programme. It has led studies into the spherical tokamak, a compact fusion concept pioneered at Culham and since developed around the world. Now a major machine upgrade has begun that will enhance MAST's role in international research and keep the UK at the cutting edge of innovation. It will also put the UK in a leading position to develop engineering systems for the future fusion power economy.

MAST Upgrade will be a 'user facility' providing excellent opportunities for collaborations – both in the experimental programme and in spherical tokamak development. More than 20 universities and fusion laboratories are already benefiting from working on MAST and we want to strengthen and widen this collaborative input. Our partners will advance their own physics and fusion engineering studies by joining us in developing MAST Upgrade and then exploiting its capabilities. Collaborators will bring expertise and equipment to enhance MAST Upgrade. In return, we will provide a machine uniquely equipped to trial innovative diagnostics and to explore a wide range of key plasma physics areas.

As well as the best collaborators, we want to attract the best industrial suppliers to work on the project. The upgrade will generate significant contract opportunities for industry. Companies can use MAST Upgrade as a stepping stone to greater involvement in the fusion sector and, in particular, the commercial opportunities offered by the ITER project.

For many years, the UK fusion programme has made major contributions to fusion research. MAST Upgrade will build on this progress, providing a truly world-class device capable of near-fusion conditions.

Read on to explore the possibilities offered by the new MAST, and find out more on our website: **www.ccfe.ac.uk.**

Professor Steve Cowley

Head of EURATOM/CCFE Fusion Association

'More than 20 universities and laboratories are already working on MAST. We want to strengthen and widen this collaborative input.'

MAST Upgrade

At the heart of international fusion research

MAST Upgrade has three main objectives that are central to the drive towards commercial fusion power.

1. **Making the case for a fusion Component Test Facility (CTF).** A CTF would allow crucial verification of fusion engineering and technology systems for the DEMO prototype power plant. MAST Upgrade will explore the suitability of the spherical tokamak as a candidate for a CTF – looking at start-up, current drive, steady state behaviour, handling of high heat flux, plasma confinement, high beta operation, and performance reliability. It will also look at the viability of the spherical tokamak as a compact design for fusion power plants.

2. **Adding to the knowledge base for ITER,** the international experiment that will be the precursor to the first fusion power stations. MAST Upgrade will help to resolve important plasma physics questions and develop predictive models to help enhance ITER's performance and ensure its success.

3. **Testing reactor concepts.** MAST Upgrade will be the first machine to include the Super-X divertor design, an innovative plasma exhaust system that, if successful, could be adopted by future fusion devices, including DEMO. MAST Upgrade will also test plasma initiation without a solenoid and steady state operation with current driven by neutral beams.

The MAST Control Room at Culham

Main features of MAST Upgrade:

Super-X divertor

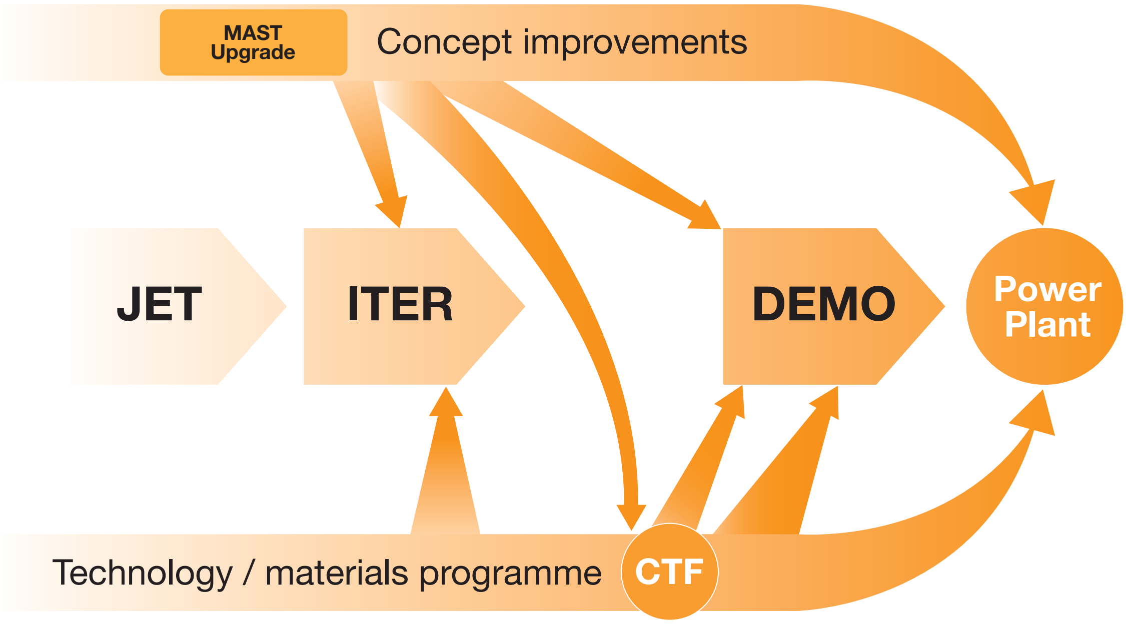
MAST Upgrade will help to develop high power exhaust systems for tokamaks by incorporating a Super-X divertor. The plasma exhausted from the core will be steered along magnetic fields in such a way that it travels a long distance before interacting with the targets designed to withstand the power loads. The increased distance and the configuration of the magnetic fields allow the particles to be radiatively cooled and spread over a larger area. This will significantly reduce the power loads on the targets. This Super-X configuration will allow MAST to study the reduction in power loadings that will be required to handle the plasma exhaust in a CTF and future reactors. MAST Upgrade will also be equipped with a 'classic' divertor which will allow the two systems to be compared.

Sustained plasma performance

The upgraded machine will provide high performance plasmas with pulse lengths of five seconds (up to ten times longer than the present duration). Plasma shape, temperature and density and current profiles will be sustained in steady state conditions, allowing study of stable operating regimes that could be used for the design of future fusion machines.

Fusion threshold plasma parameters

Improved parameters approaching fusion conditions will enable highly accurate scaling of plasma confinement models to DEMO, ITER and CTF. Target deliverables – including temperature up to 50 million degrees Celsius and density over twice that of the existing machine – will allow experiments at significantly higher plasma pressure.



MAST Upgrade's place in the international fast-track fusion programme
(IFMIF and satellite tokamak removed for simplicity)

MAST PARAMETERS	Before upgrade	Stage 1 upgrade	Stage 2 upgrade
Peak power injected	Up to 5 MW	Up to 7.5 MW	Up to 12.5 MW
Toroidal magnetic field	0.55 T	0.84 T	0.84 T
Energy deposited in plasma at high current	Up to 5-10 MJ	Up to 30 MJ	Up to 63 MJ
Pulse length at high current / field	~ 0.5 seconds	~ 4 seconds	~ 5 seconds
Profile control (I_p , pressure, flow)	None	Moderate	Extensive
Particle control	None	Active	Active
Plasma current	1.2 MA	2 MA	2 MA

'The elements that make MAST attractive internationally are the openness of the team, the accessibility to the programme, the flair and the quality of the science.'

Professor Fritz Wagner, IPP Greifswald, Germany
Chairman of the International MAST Programme Advisory Committee

The new MAST

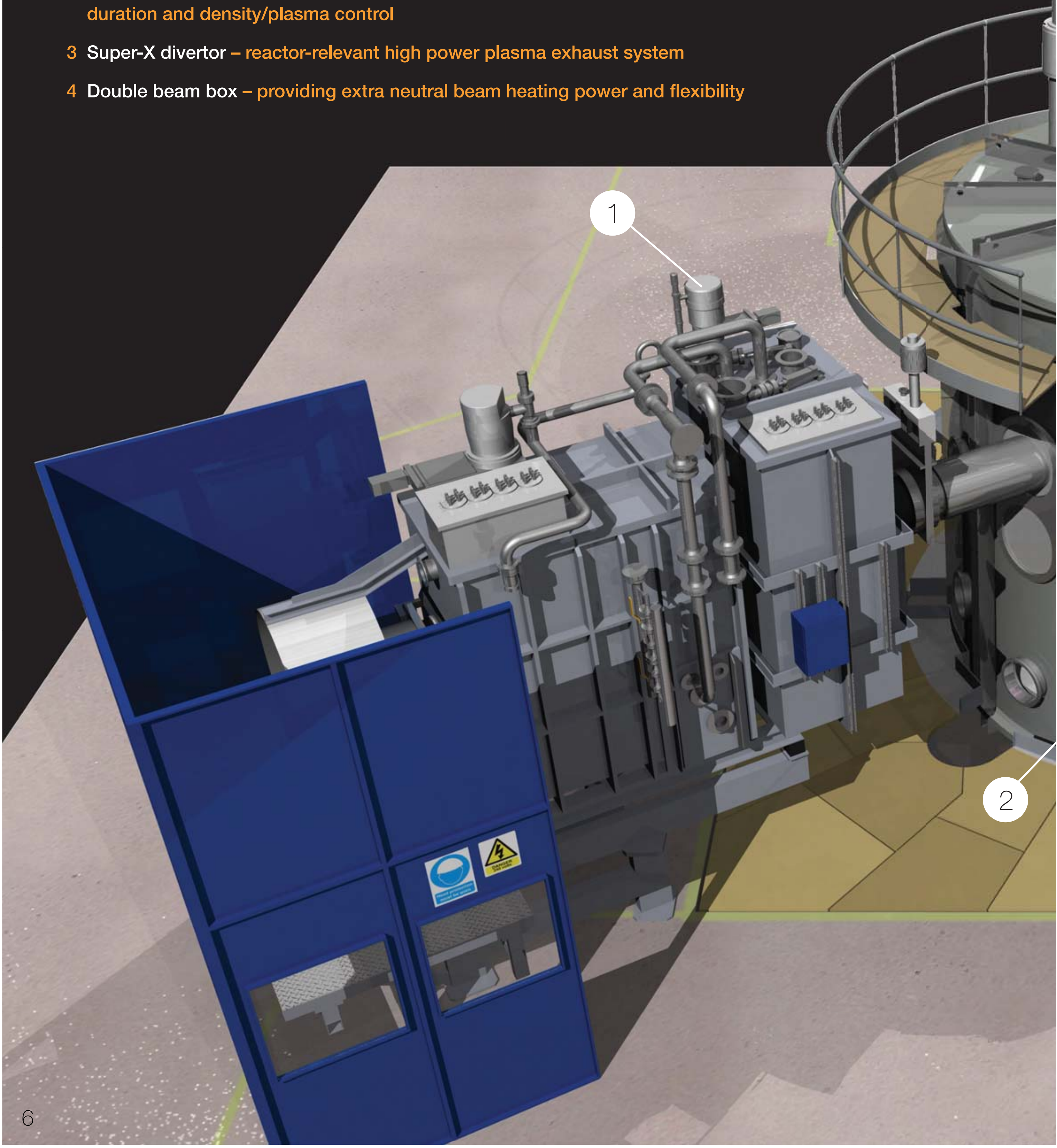
Key features of MAST Upgrade – Stage 1

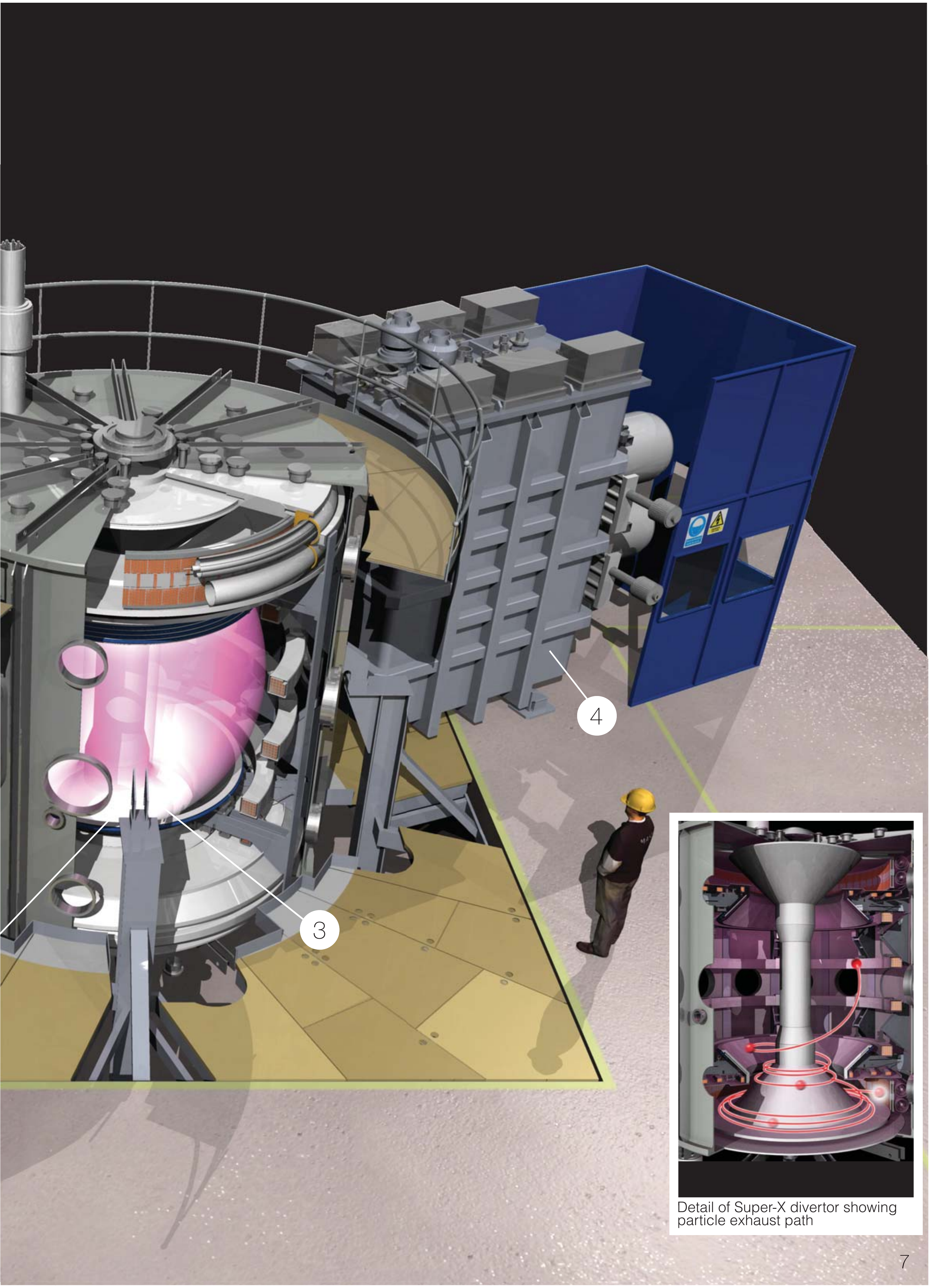
1 Off-axis neutral beam – providing greater flexibility for tailoring the heating and current drive profile

2 New centre column and divertor coils, cryopump and power supplies – enabling greater plasma duration and density/plasma control

3 Super-X divertor – reactor-relevant high power plasma exhaust system

4 Double beam box – providing extra neutral beam heating power and flexibility





Detail of Super-X divertor showing particle exhaust path

Opportunities for collaboration

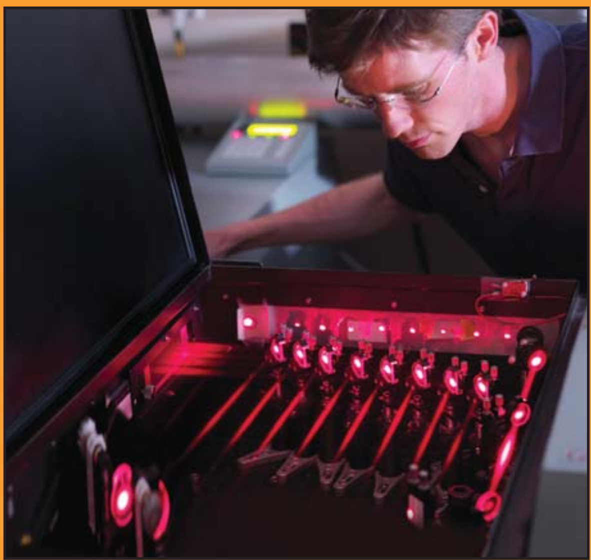
Get involved in MAST Upgrade

MAST Upgrade will offer many possibilities for researchers to collaborate with CCFE on areas of mutual interest, both in physics and in tokamak engineering. (See pages 10 and 11 for scientific deliverables of the upgrade.)

The MAST programme already involves 14 European fusion associations, five laboratories from the US and Russia, and nine UK and overseas Universities. These institutions are taking advantage of MAST's capabilities, particularly its excellent array of diagnostic equipment. Many of the diagnostics have been implemented with collaborators, including the recent major upgrade to MAST's Thomson scattering system, a joint project with the University of York. CCFE will seek similar partnerships to design and build diagnostics and other systems for MAST Upgrade.

When completed, MAST Upgrade will enable significant input from collaborators on experimental campaigns. Scientists using MAST Upgrade will benefit from the expertise of the UK's world-leading plasma theory programme, which will be fully involved in the project. In addition, facilities for remote collaboration are available – the University of York has already set up a remote control room at its campus, allowing researchers to run experiments and analyse data.

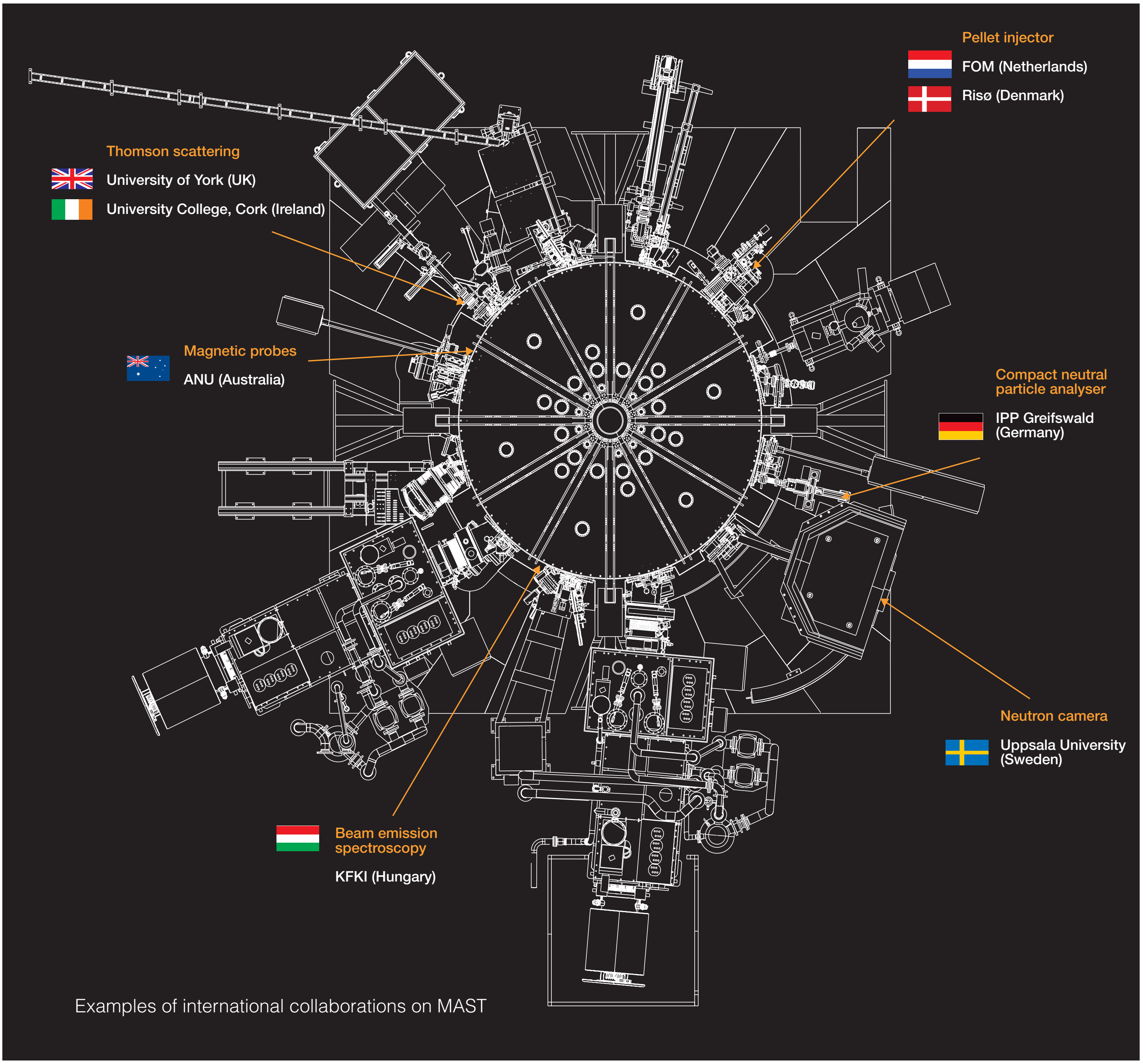
For more information on MAST Upgrade collaborations, please contact Dr Derek Stork at CCFE (see back cover for contact details).



Laser room for the upgraded Thomson scattering system

'MAST is a flexible facility with an international reputation, that is very accessible for universities. That capability will only increase in the future as MAST Upgrade comes online.'

Professor Howard Wilson, University of York



Examples of international collaborations on MAST

Industry involvement

Building MAST Upgrade will require a range of engineering services offering commercial opportunities to industry. As well as the short-term economic benefits of winning contracts, experience shows that working on projects at CCFE helps companies build expertise and skills which lead to further opportunities in the field and in other markets. With ITER expected to be worth at least €4 billion to European industry, there is no better time to get involved and MAST Upgrade is an excellent way to establish a foothold in fusion.

Companies can stay in touch with commercial opportunities by registering with CCFE's Fusion and Industry Team at: www.fusion-industry.org.uk.

Stage 1 upgrade target dates

Start of procurement:	2011
Shutdown for installation:	2013 – 2015
Start of first experimental campaign:	2015

MAST

Upgrade plan

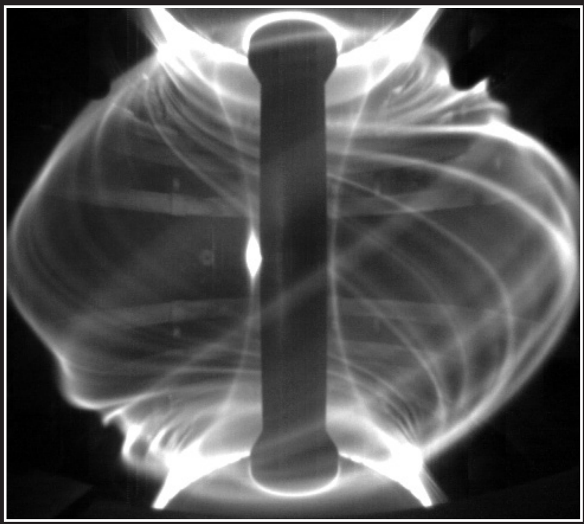
MAST Upgrade will be implemented in two stages. The first stage will be ready for plasma operations in 2015, with the second phase following two to three years later subject to funding.

Stage 1 upgrade

- A new central solenoid with cyanate ester insulation and a new system to pre-chill centre column components, allowing extended pulse lengths;
- An increase in MAST's neutral beam power from 5 MW to 7.5 MW, including on- and off-axis beams allowing heating in different configurations;
- An upgrade of the main toroidal field from 0.55 T to 0.84 T, with a new 133 kA power supply and centre rod;
- A complete set of new divertor coils, and accompanying power supplies to fully control the plasma in both a 'standard' and a 'Super-X' divertor configuration;
- A supercritical helium cryopump for the divertor, with accompanying cryoplant and transfer lines;
- New shaping coils;
- Completely new plasma-facing armour.

There will be new diagnostic systems, particularly divertor diagnostics, and accompanying infrastructure improvements.

Stage 1 will address all the relevant scenarios and issues for plasmas that have reached steady conditions. It will enable normalised plasma pressures (β) to be reached in excess of those required for CTF and DEMO.



Plasma image from high-speed camera on MAST. The plasma is about three metres across.

Stage 2 upgrade

Key features of the Stage 2 upgrade include:

- A high repetition rate pellet injector for deuterium ice-pellets, for density profile control;
- External coils to control edge instabilities (ELMs);
- An upgrade to 12.5 MW neutral beam heating power, including counter current injection for rotation control;
- 2 MW system to test microwave plasma current drive methods;
- Enhanced diagnostics for fast particle studies.

Key scientific deliverables – Stage 1	
Deliverable	**Relevance**
Proven physics concept for high heat load reactor divertor – testing Super-X	DEMO, CTF
Sustained stable operation at high plasma pressure (β) with high fast particle pressure	ITER, DEMO and CTF
Use of current profile control to enable stable high performance operation, including definition of the neutral beam current drive efficiency	ITER, DEMO and CTF
Start up of a hot plasma without a solenoid	CTF

Key scientific deliverables – Stage 2	
Deliverable	**Relevance**
Control of density profile via pellet fuelling and pumping	ITER, CTF
Control of edge instabilities (ELMs) via external (reactor-relevant) coils	ITER, DEMO and CTF
Microwave methods of current profile control	CTF
Extended power loading divertor testing	DEMO, CTF
Extended high plasma pressure performance and fast particle instability tests	ITER, DEMO and CTF

Once the Stage 2 programme is completed, in around 2020, it would be possible to install tungsten plasma-facing components and divertor targets to test aspects of tungsten operation in a CTF or DEMO.

Fusion research at Culham is funded by the UK Engineering and Physical Sciences Research Council and by the European Union under the EURATOM Treaty.

For more information on MAST Upgrade including collaboration opportunities, please contact:

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