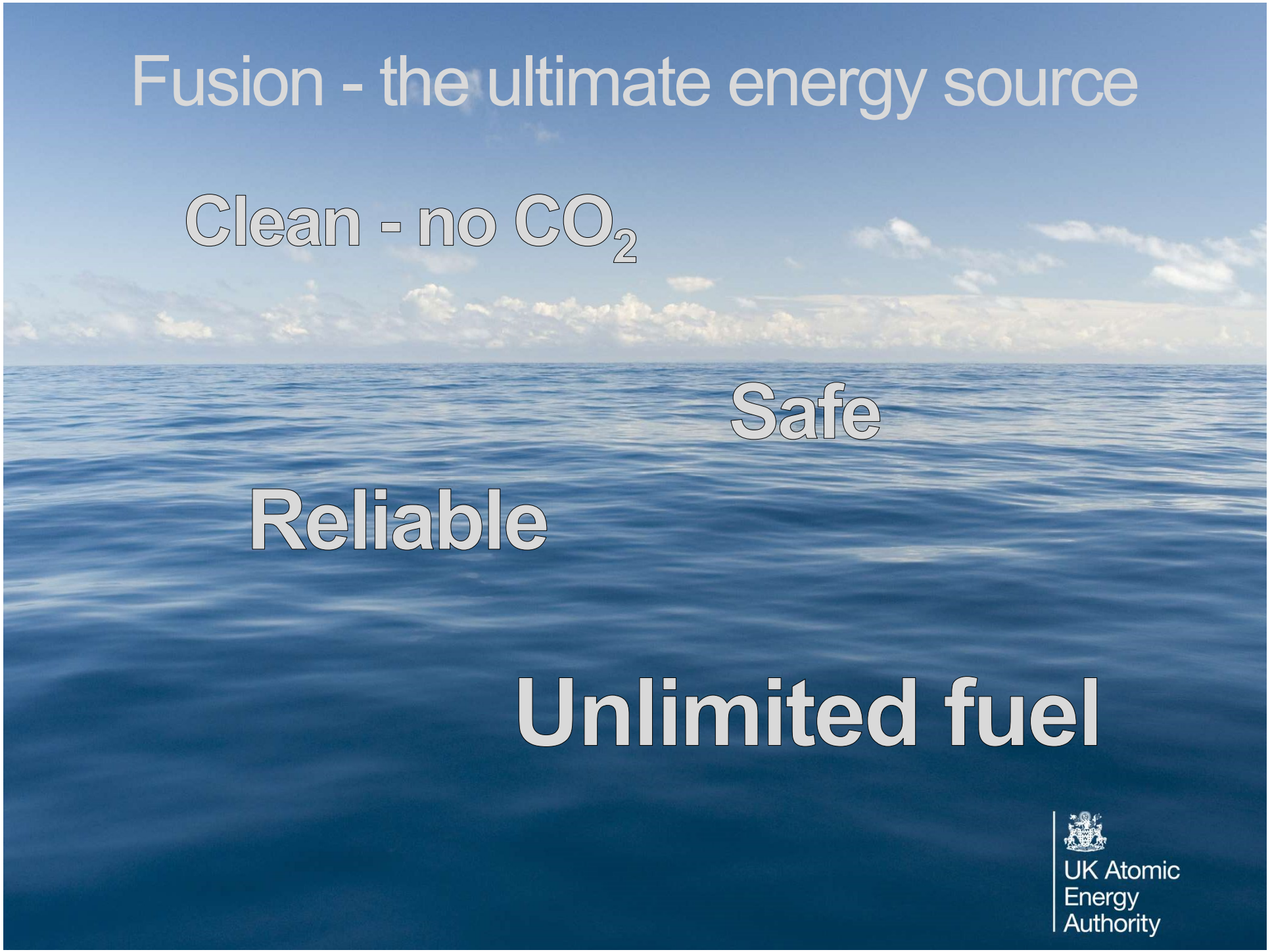
The path to delivering fusion power

Ian Chapman
UK Atomic Energy Authority


Fusion - the ultimate energy source
Clean - no CO_2
Safe
Reliable
Unlimited fuel
UK Atomic Energy Authority

Fusion is very high yield

- One person's energy use (assume 20kWh/day) for 60 years can come from fuel contained within:

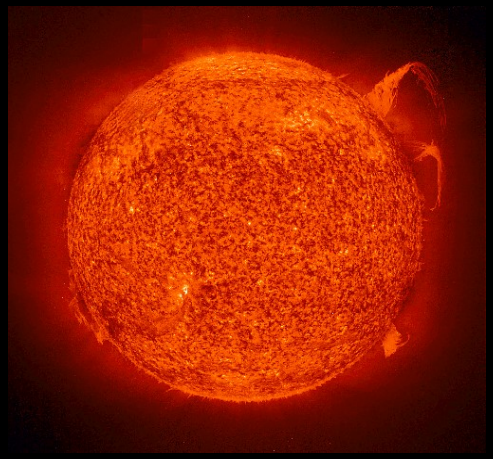
1 bathtub of water

2 laptop batteries


1600 wheelbarrows
of coal
UK Atomic
Energy
Authority

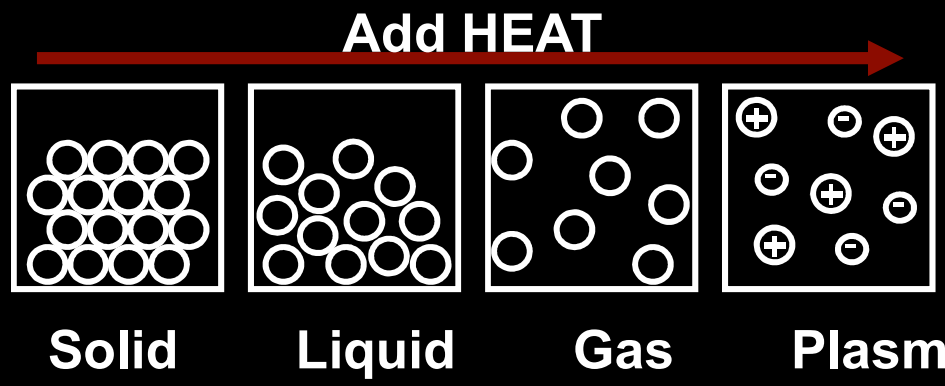
But it is really hard

- Like charges repel
- We need a balance of:
  - Density
  - Temperature
  - Confinement

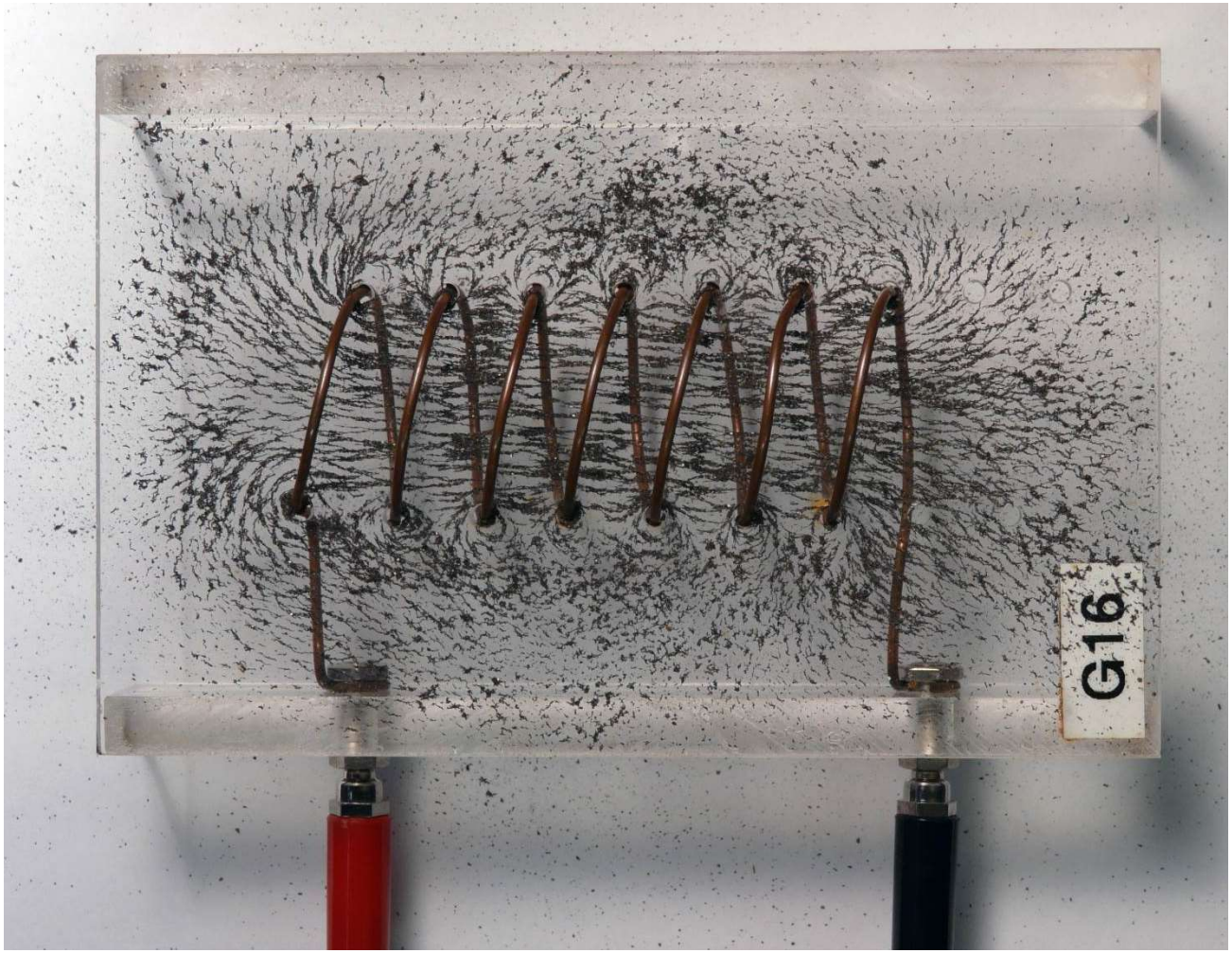


Centre of the sun = 15 million ºC

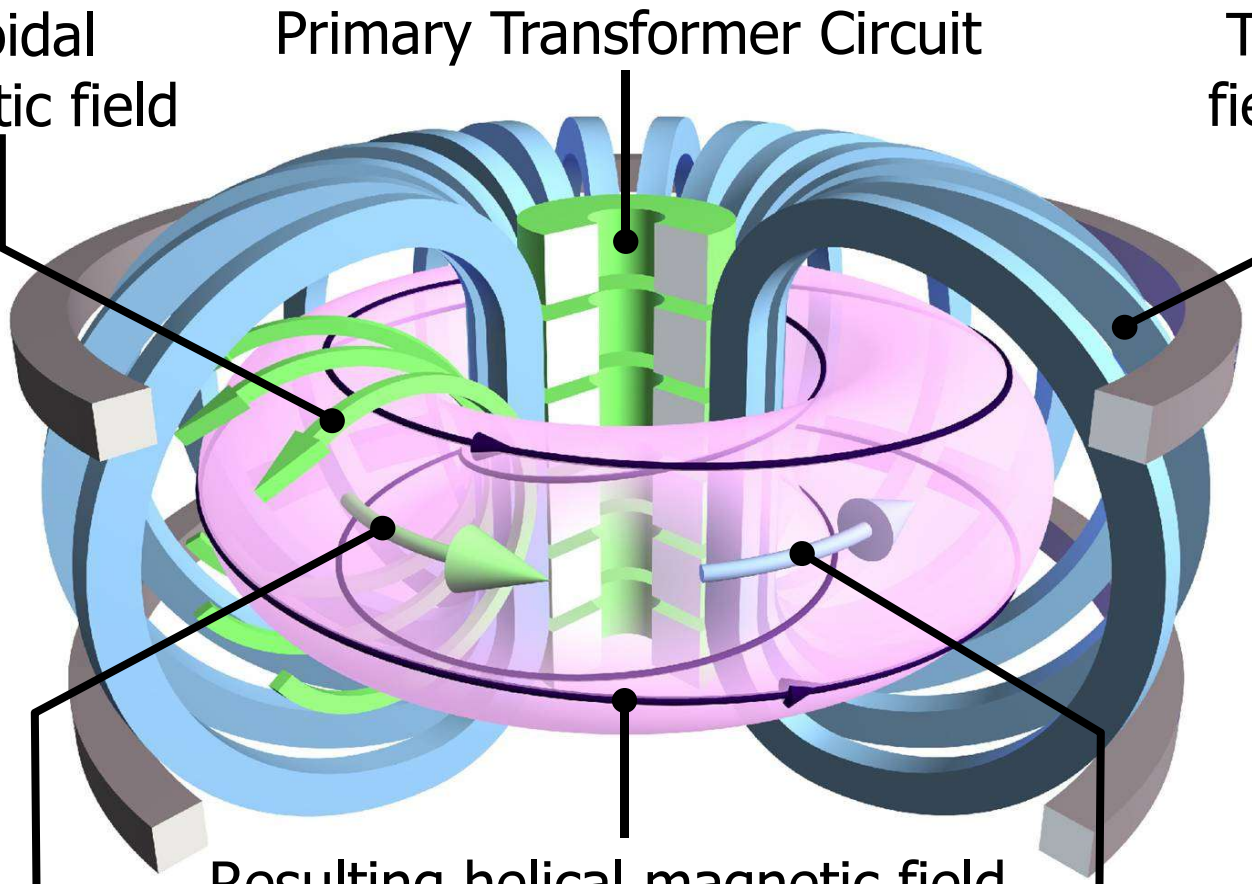
We need in excess of **150 million ºC**



Magnetic coils



How a tokamak works



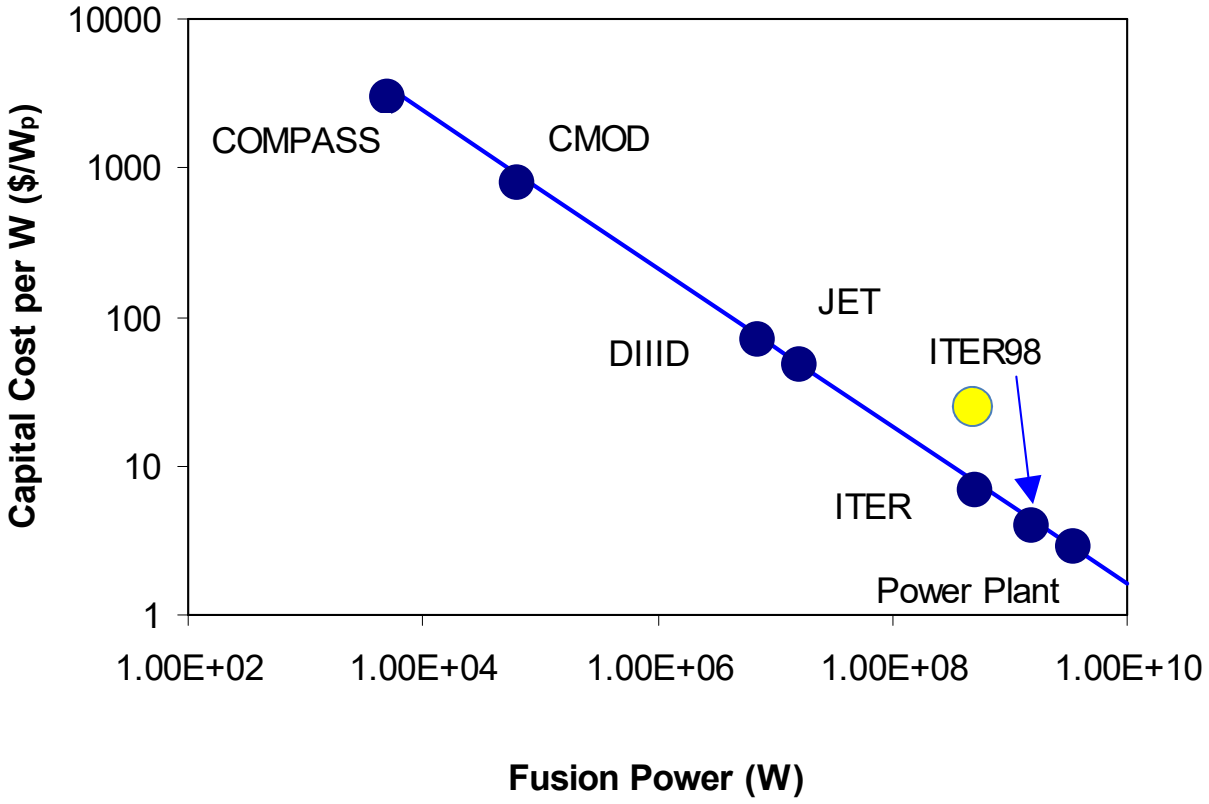
Fusion is now entering the ‘delivery era’

The challenges of fusion

What Determines the Economics of a Future Fusion Power Station?

- **Cost of the power station** – not cost of fuel which is very small
- **Power output** – depends on developments in plasma physics, materials, technology and engineering
- **Availability** – what fraction of time the plant is running, depends on design, reliability, component lifetime and maintenance schemes
- **What is the point of considering this during R&D phase?**
  - Identifying the main levers for improving economics helps to guide the R&D programme

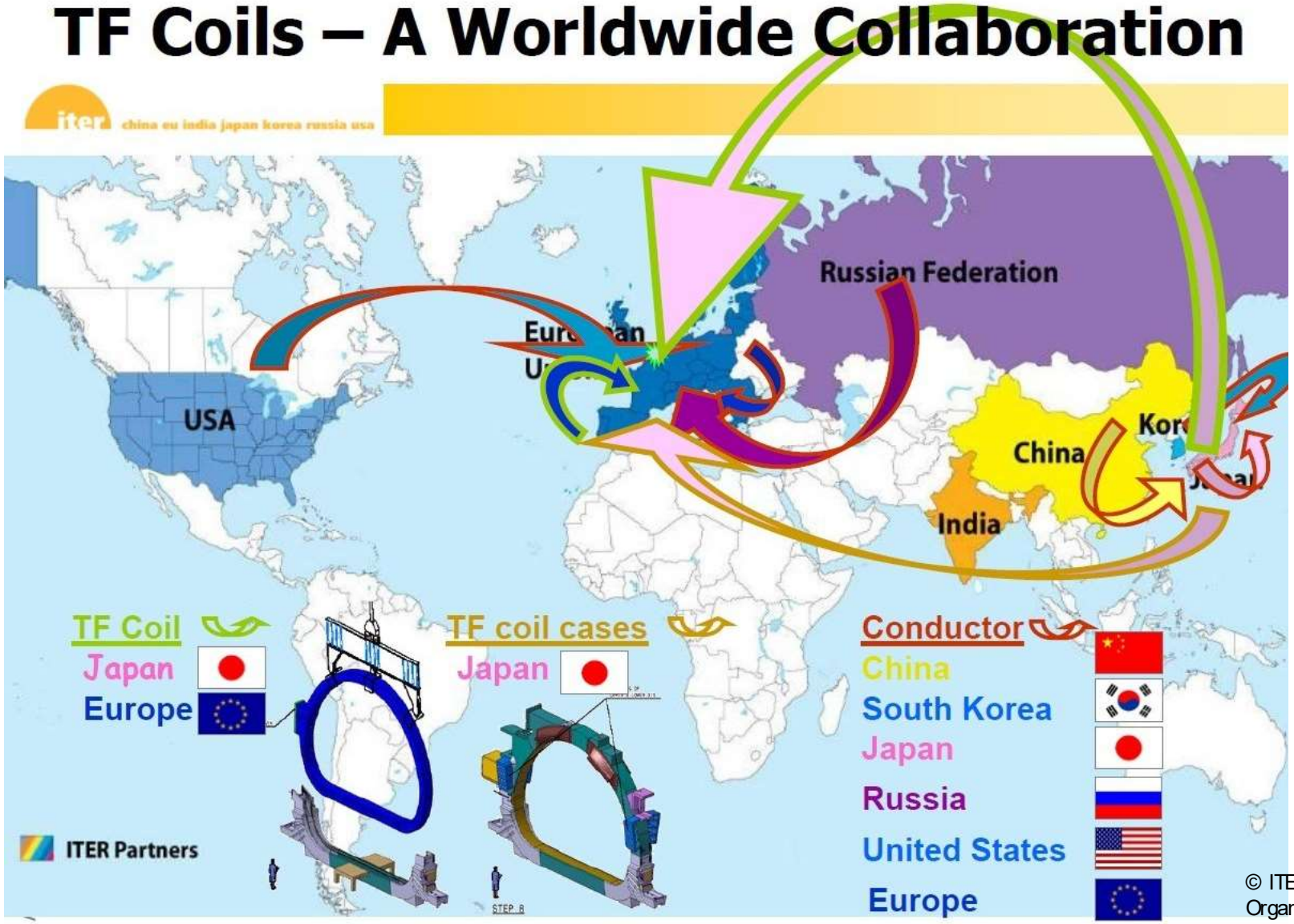
What Empirical Data on Fusion Costs Exist?



At GW scale predicts few $/$W_{th}$ (2000$)

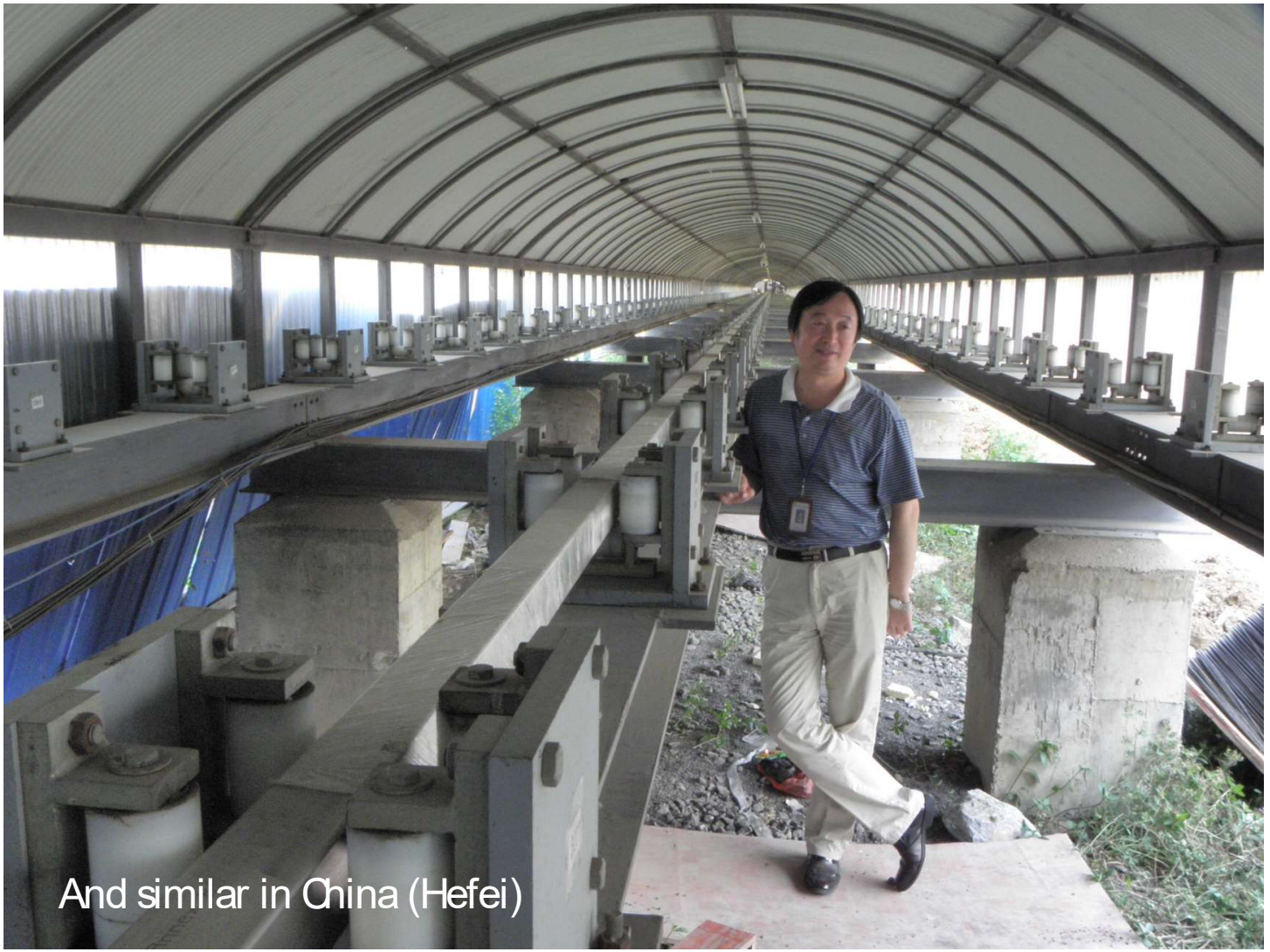
These are one off experimental devices not including power conversion equipment

TF Coils – A Worldwide Collaboration



Superconductor strand

Superconductor strand

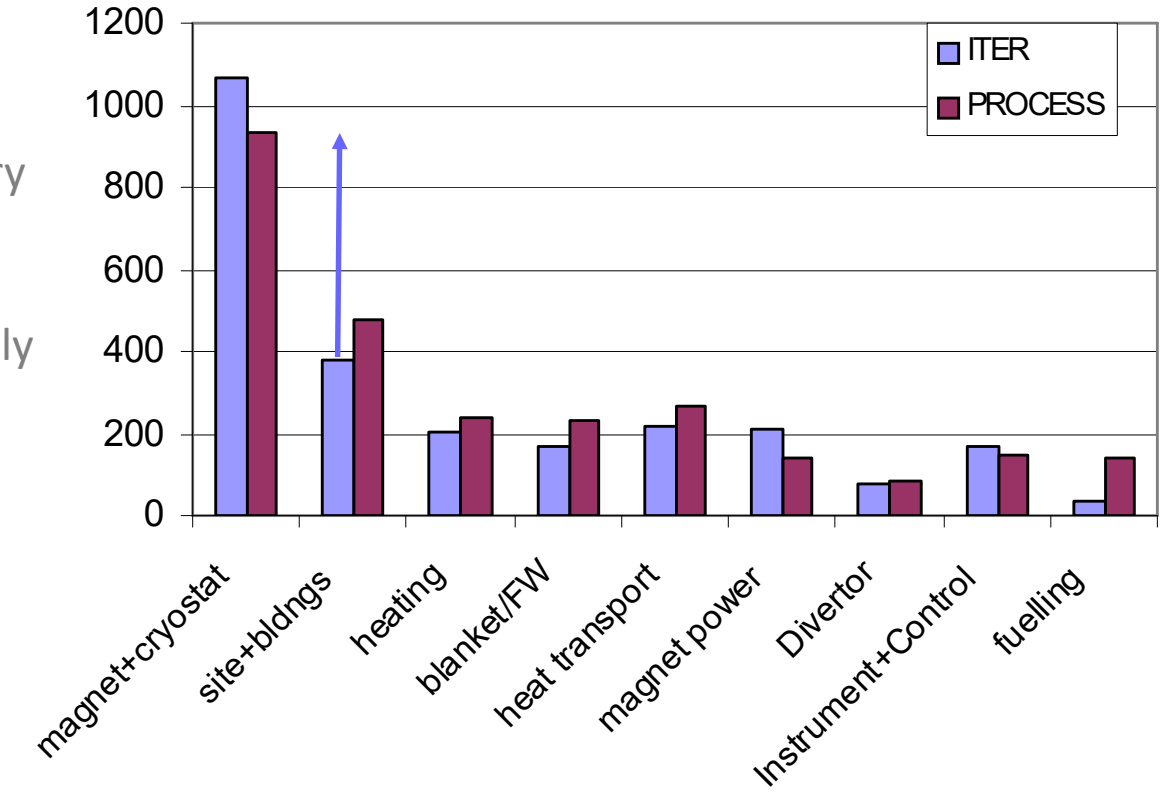


TF coil – oven to heat treat plates

Conductor after baking

Where do Costs Lie?

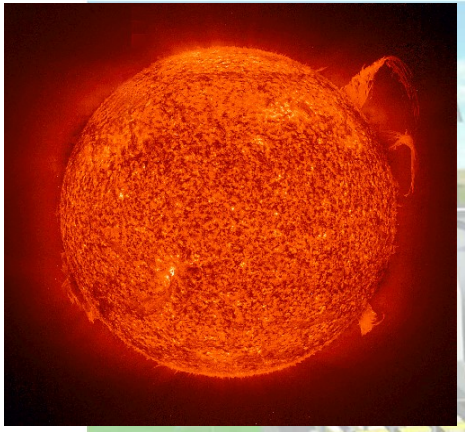
NB: Don't worry about units – qualitative comparison only



PROCESS is really set up for power-producing plants, unlike ITER, but where the systems are similar the costs appear to be similar.

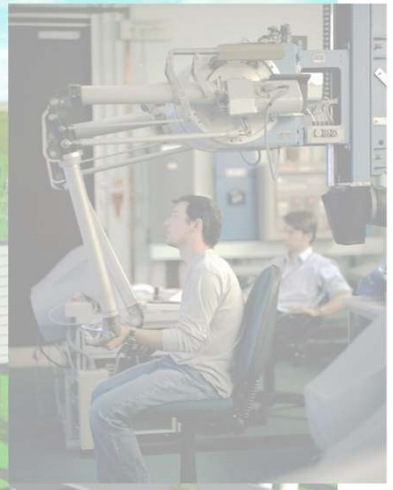
What are UKAEA capabilities to address these challenges?

Fusion requires integrated solutions



Plasma Science

Robotics

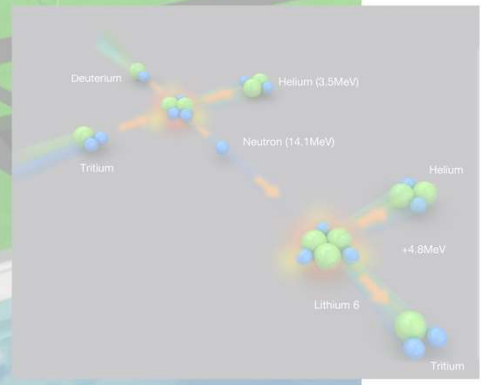


Exhaust and
High Heat Flux

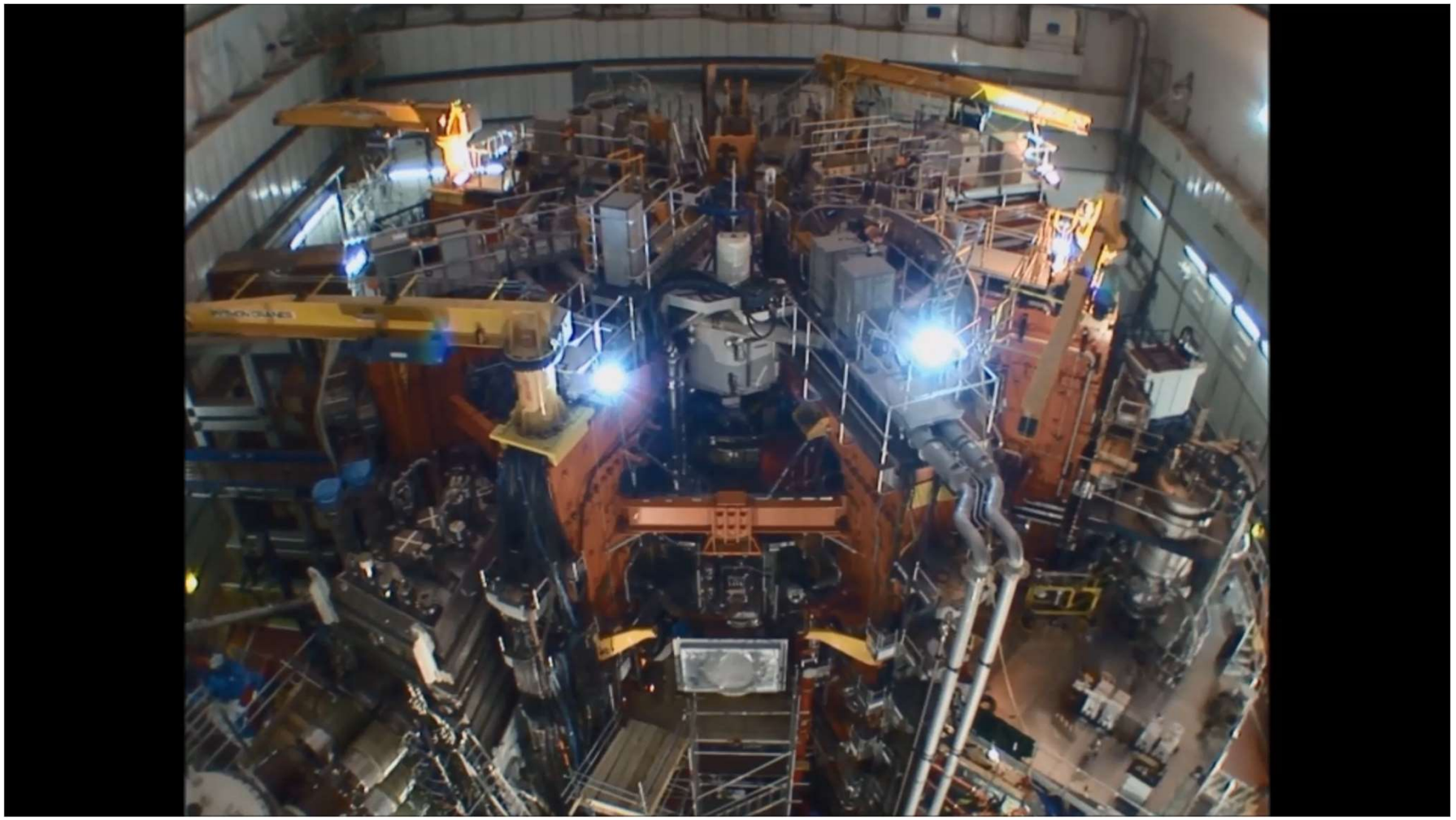
Materials Science

Technology

Tritium

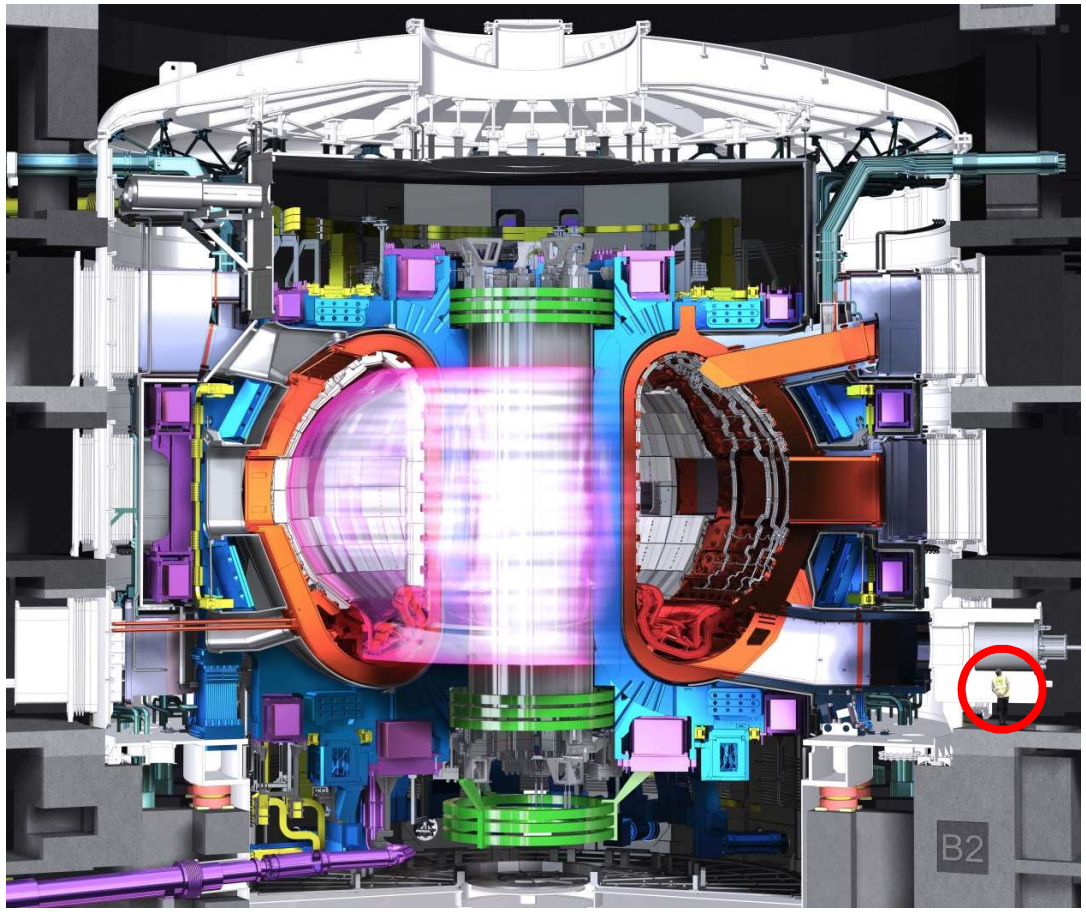


JET – the best fusion machine in the world



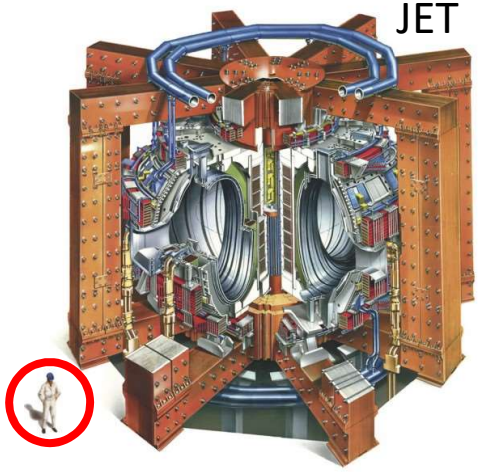
iter
china eu india japan korea russia usa

The Next Generation Tokamak

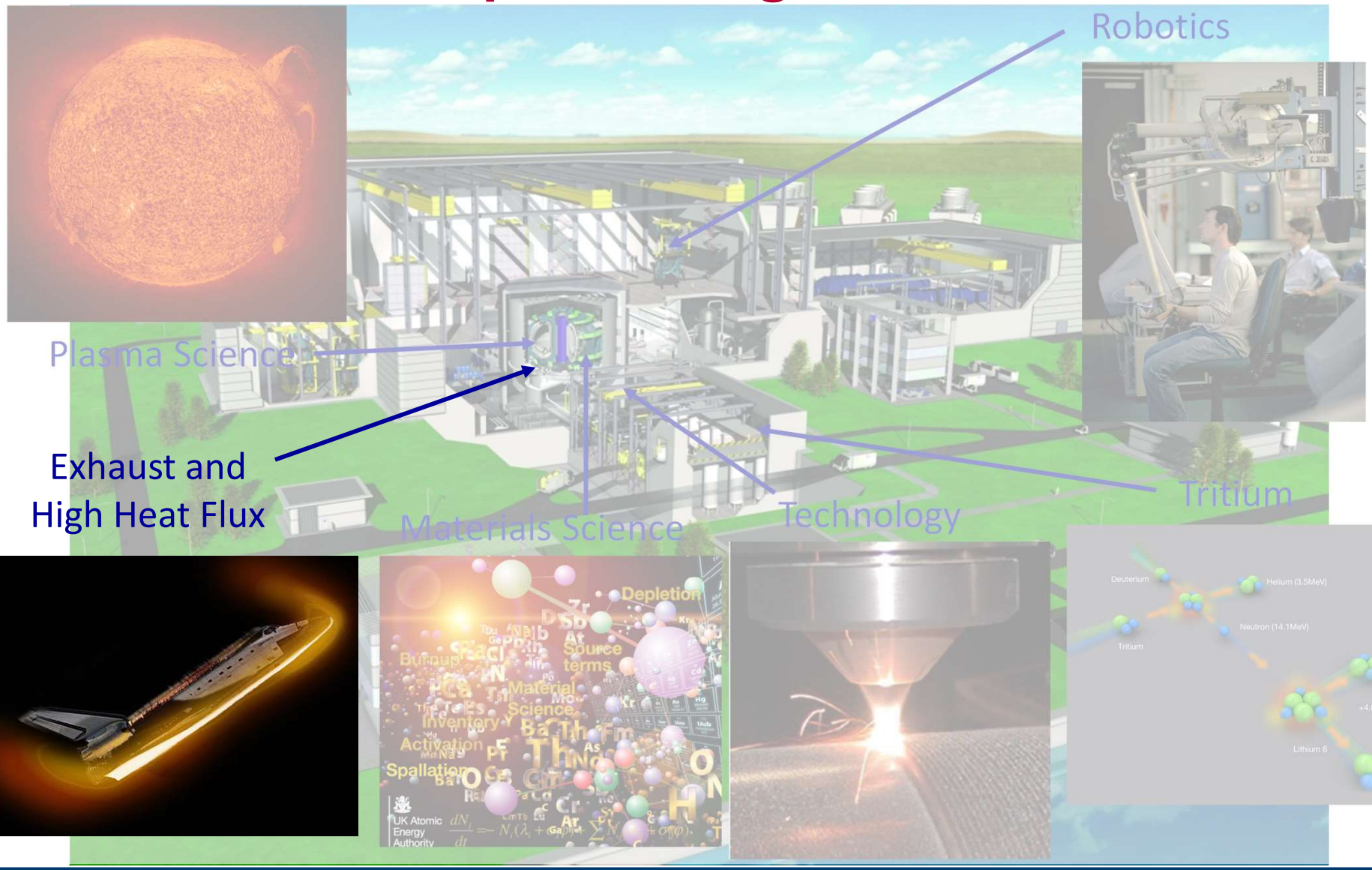


10x power gain

JET

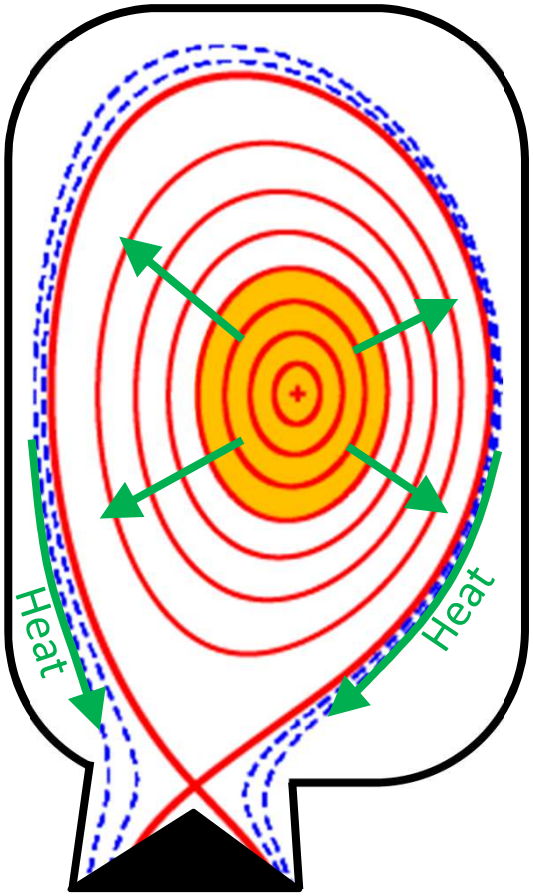


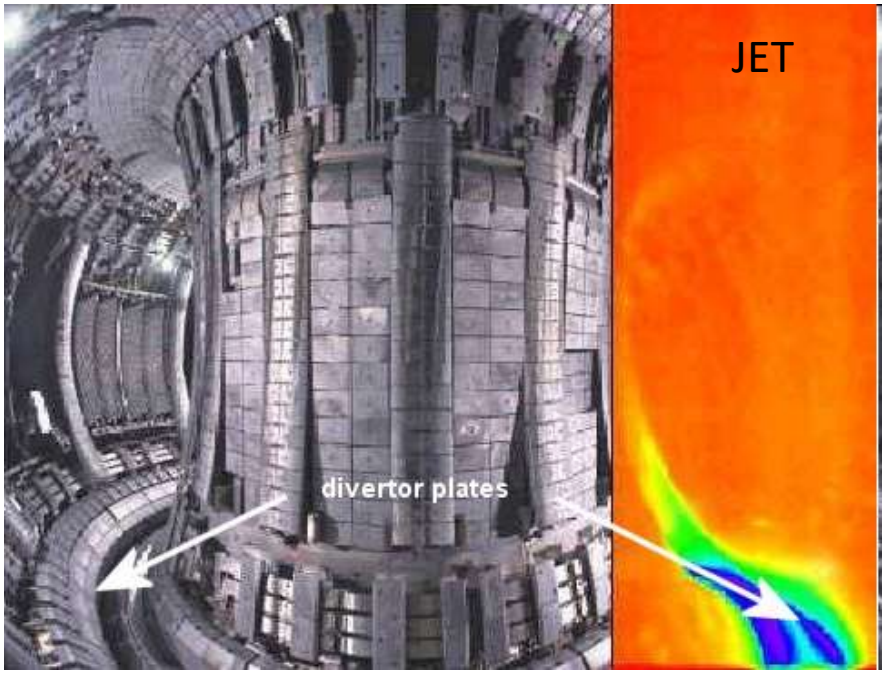
Fusion requires integrated solutions



The power exhaust problem

- In order to achieve 1GWe power plants, large heat flux will leave the confined fuel region

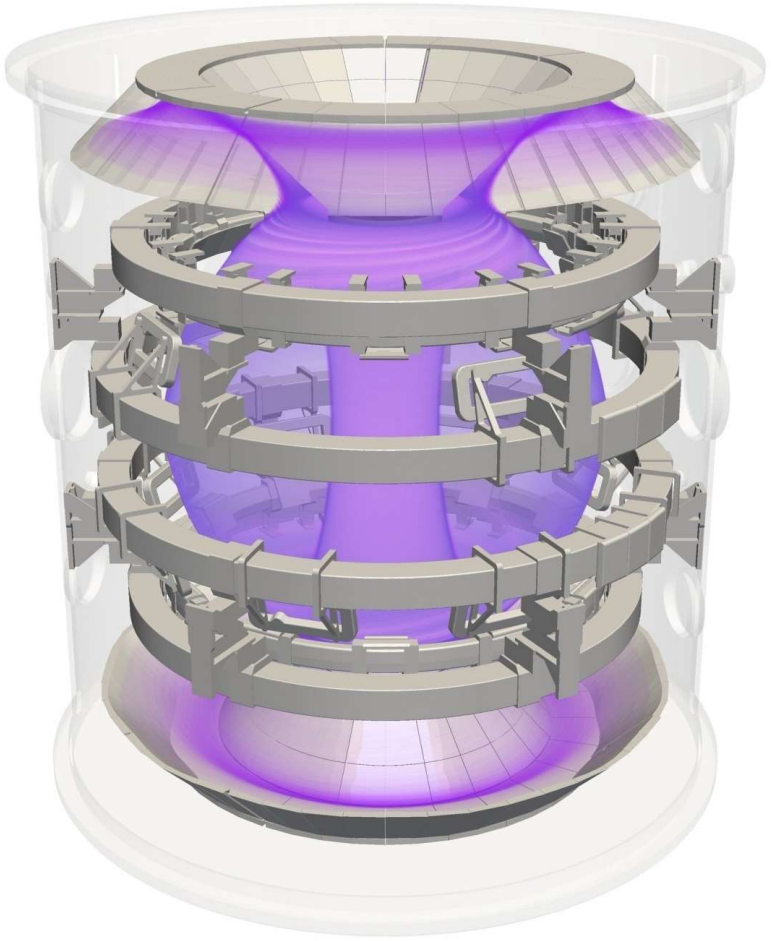


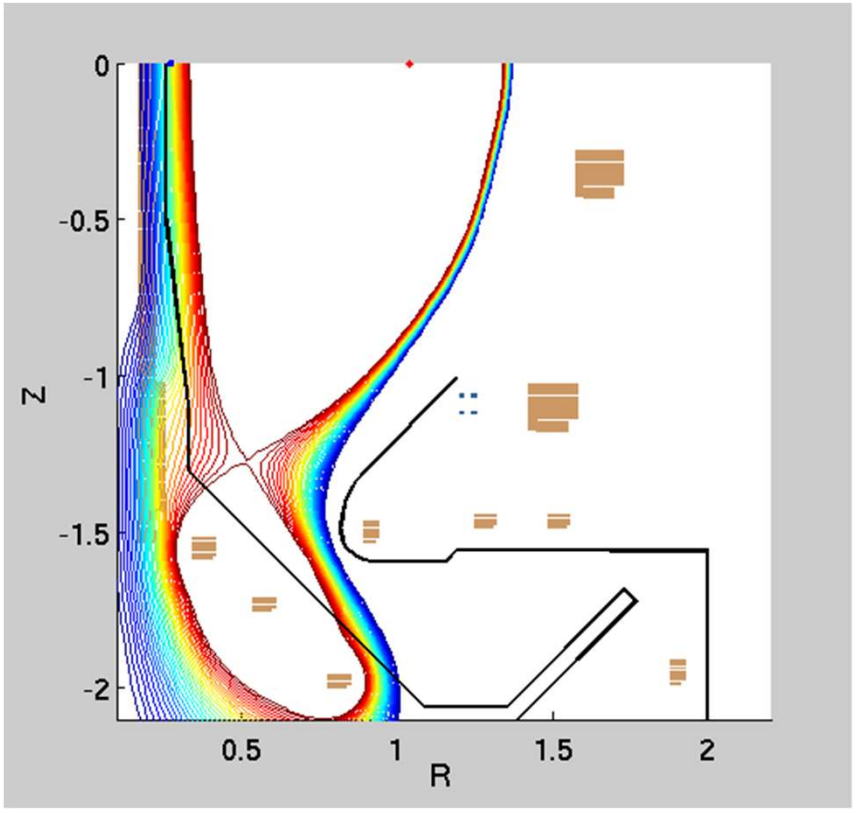


heat flux at the target:
>50 MW/m^2

MAST Upgrade

- £50M UK device to test novel ways to handle heat flux and make fusion reactors smaller and cheaper

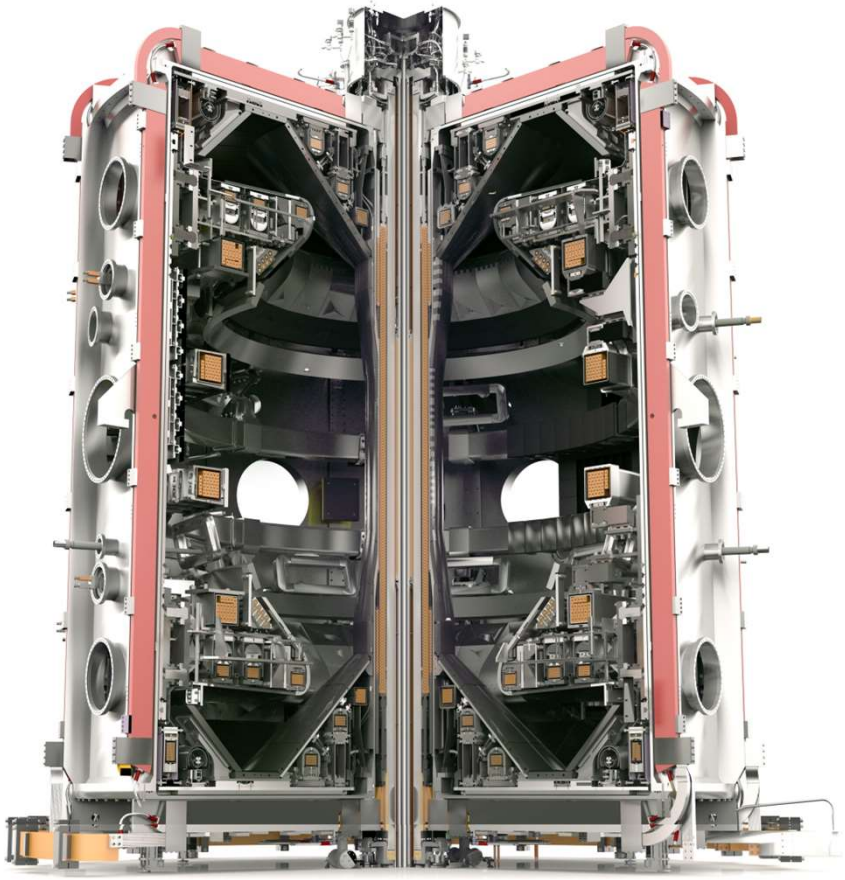




MAST Upgrade

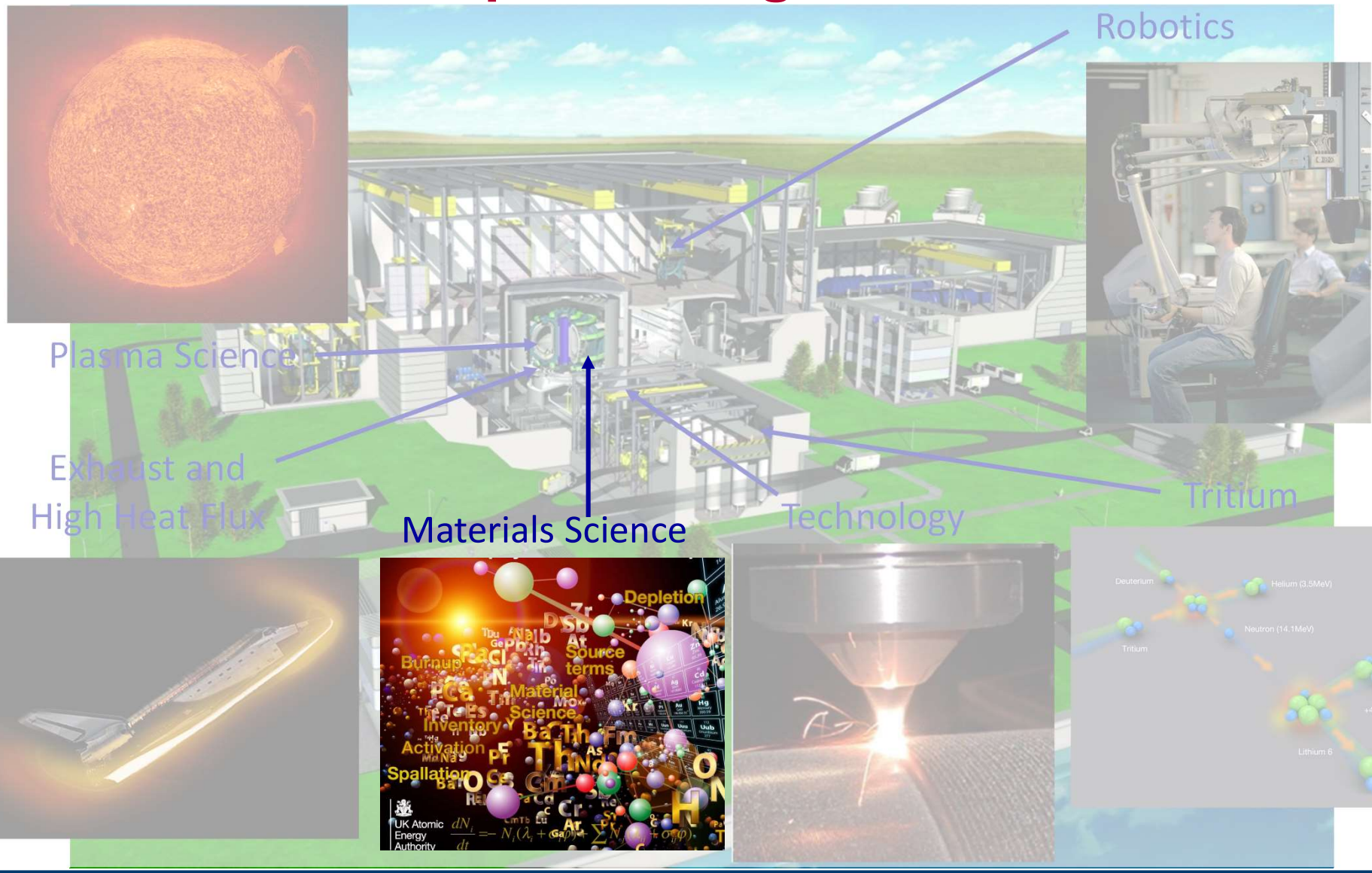
MAST Upgrade has 3 primary objectives, namely to contribute to:

1. Developing novel exhaust concepts
2. Knowledge base for ITER
3. Assessing the feasibility of the spherical tokamak as a route to power generation



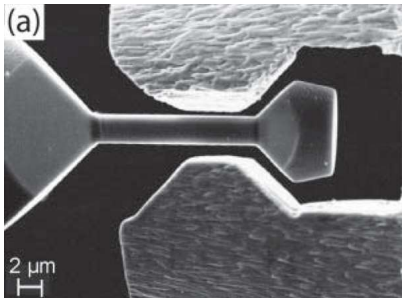
Constructing MAST Upgrade

Fusion requires integrated solutions



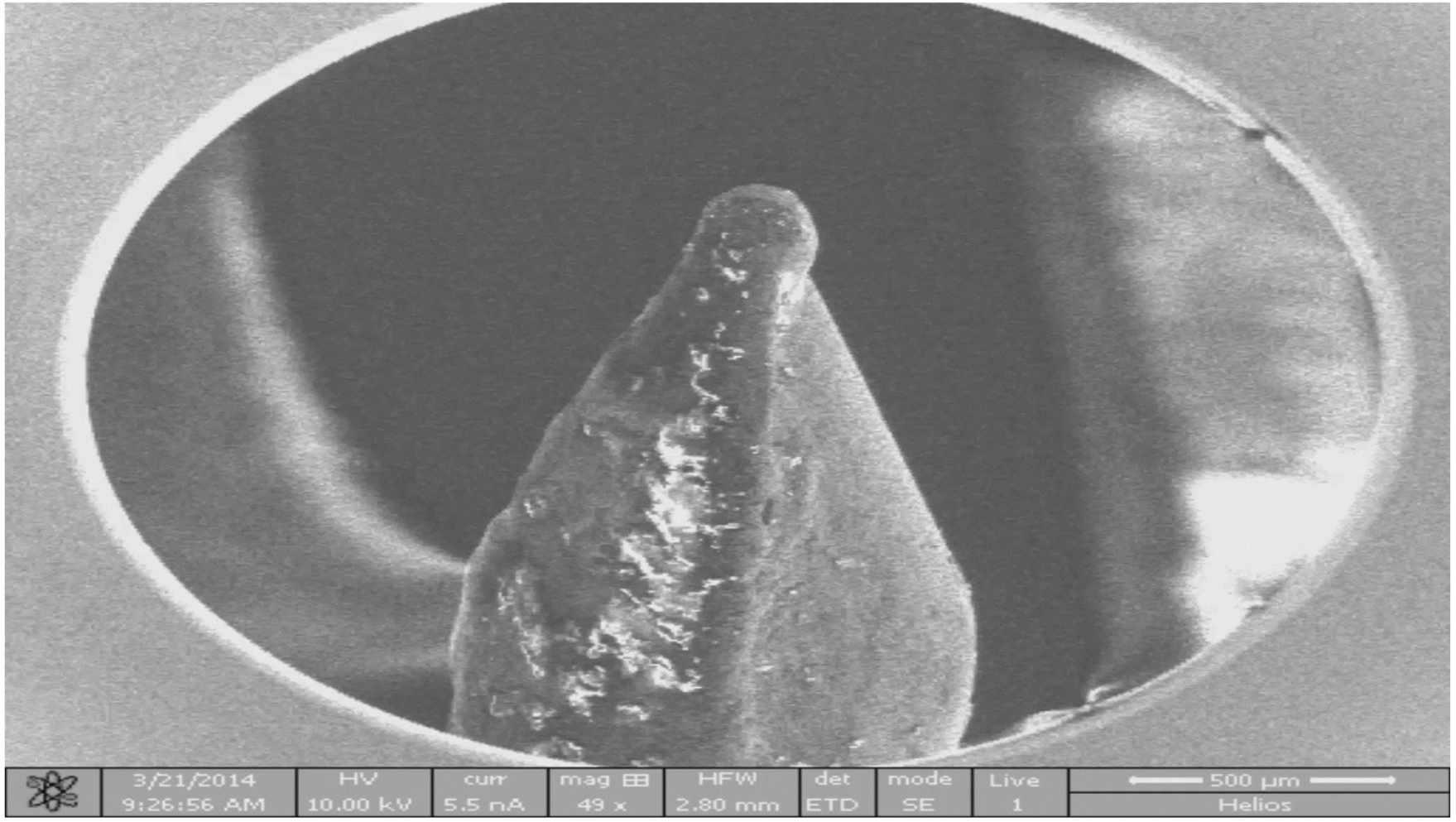
Materials Research Facility

Universities	~50 MBq (e.g. Oxford)	UKAEA	~4 TBq (Co^{60})	Sellafield
Very low activity		Medium activity, structural		Most active, fuel cycle



Processing and analysis of radioactive material and undertaking micromechnical testing of fusion and fission material samples – with UK universities and other labs

Materials testing on micro-scale



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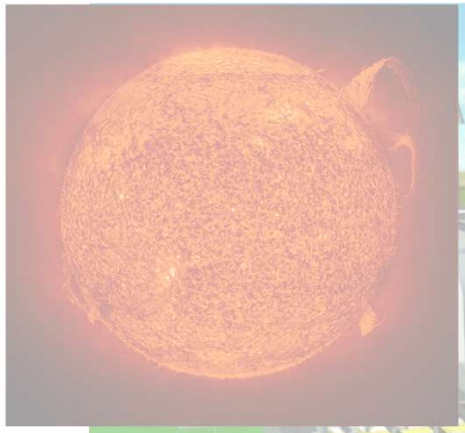

Plasma Science

Exhaust and
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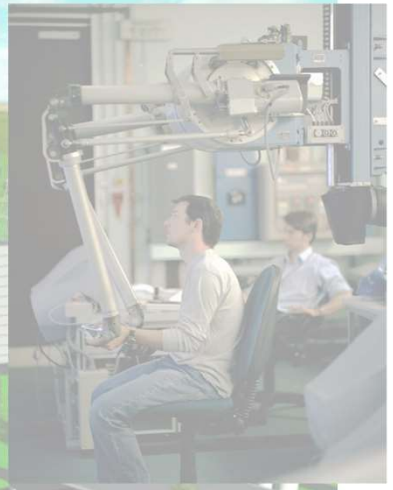
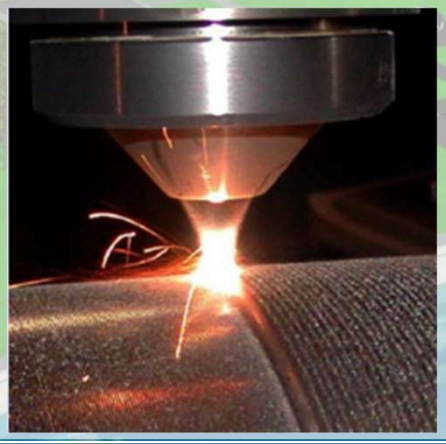
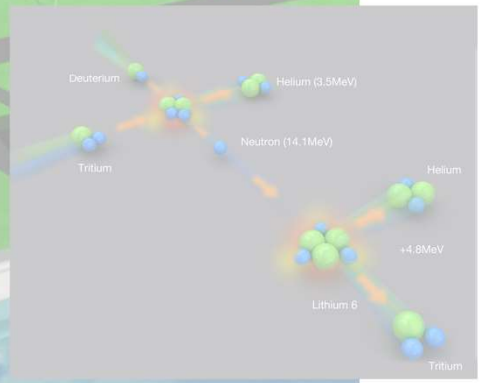
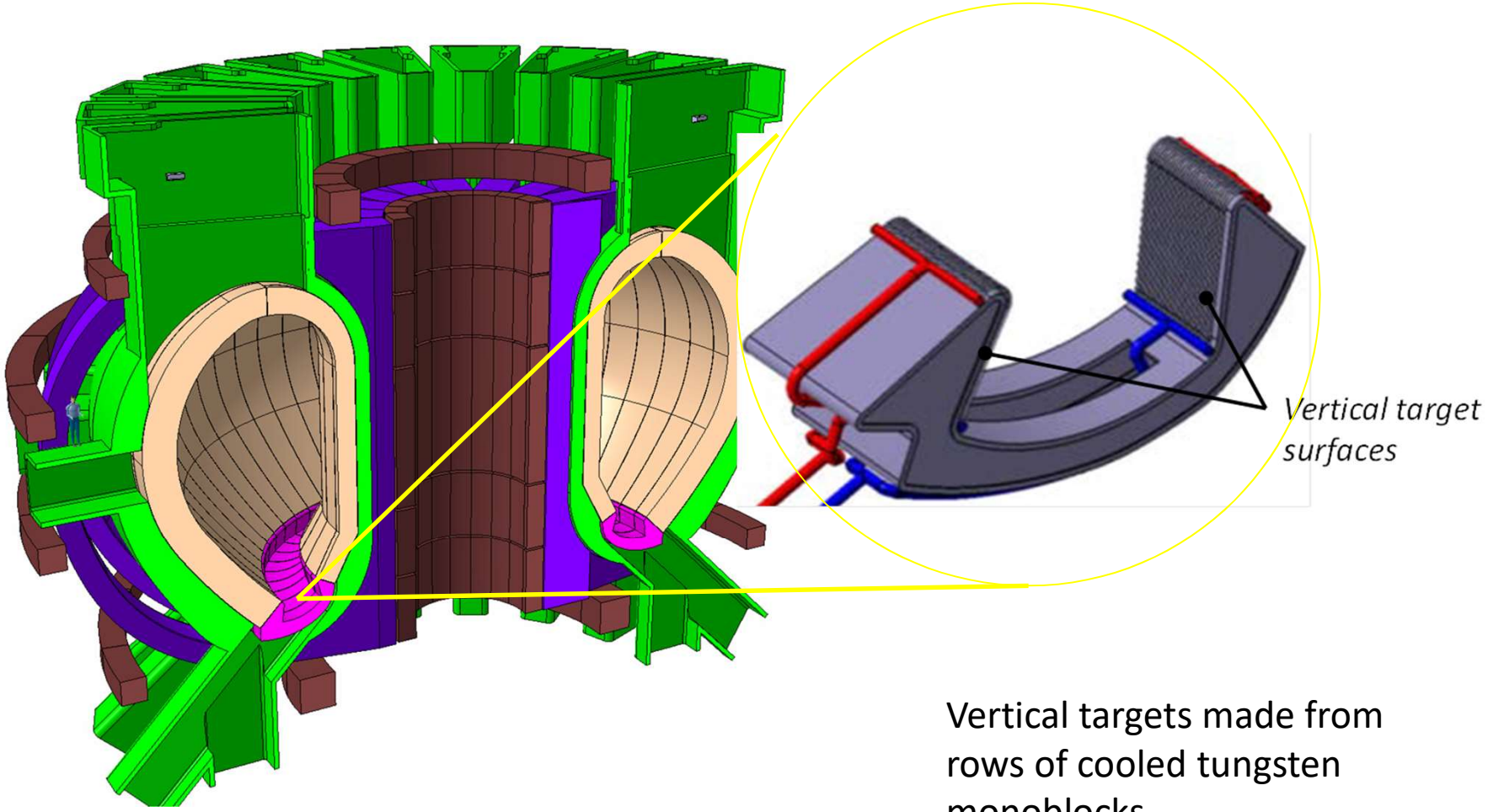


Tritium



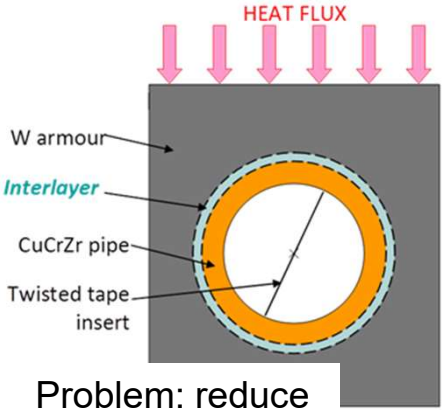


Example: Divertor Monoblock

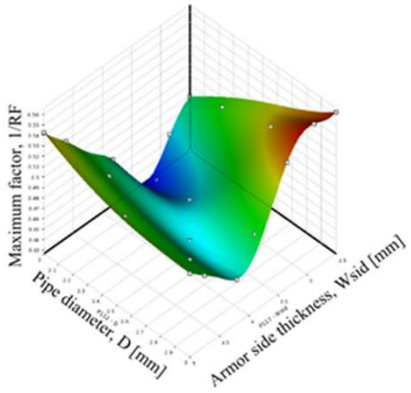


Vertical targets made from rows of cooled tungsten monoblocks

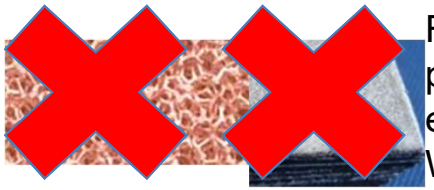
Prototyping Cycle – Virtual Engineering



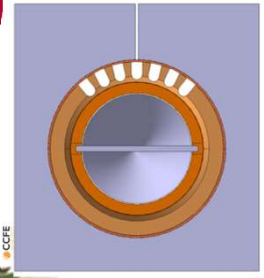
Problem: reduce stress on pipe



Design Search Optimisation - "Thermal Break" solution



Final design pipe, break embedded in W monoblock



Various options tested for manufacturability

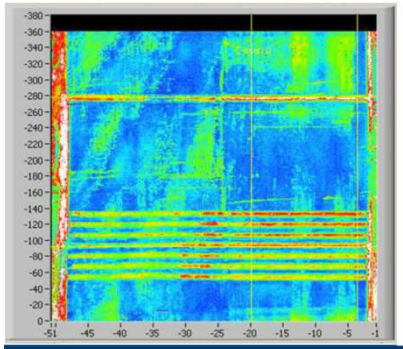
X-ray tomography of manufacture component shows flaws in contact

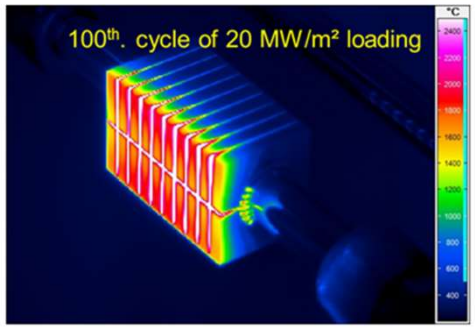
Revised Manufacturing Process

Test pieces manufactured

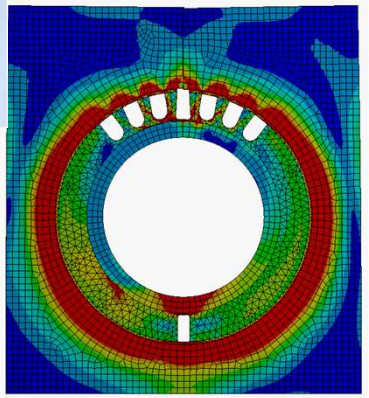
Testing

1. Ultrasonic - bond integrity
2. SATIR thermographic testing
3. HHF-GLADIS/FE200/HIVE

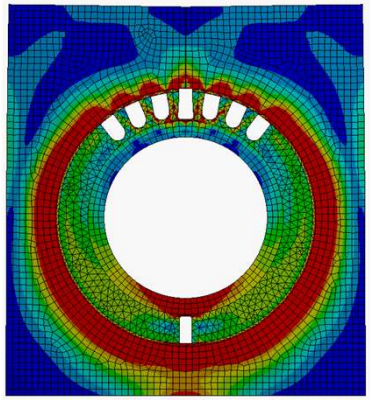




Virtual Prototyping of as-built component

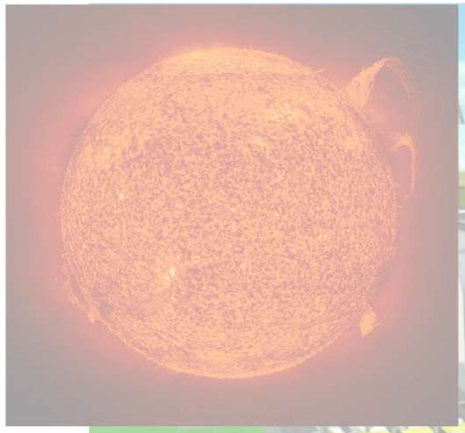


Debonded FEM



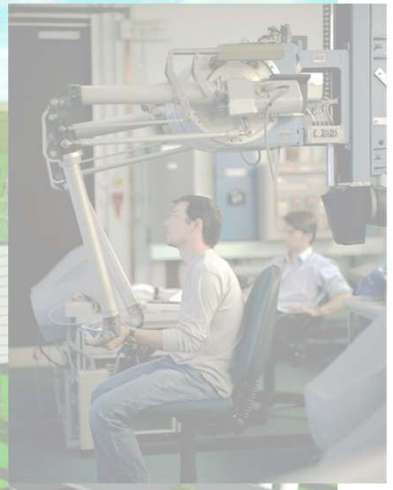
Ideal FEM

Fusion requires integrated solutions



Plasma Science

Robotics



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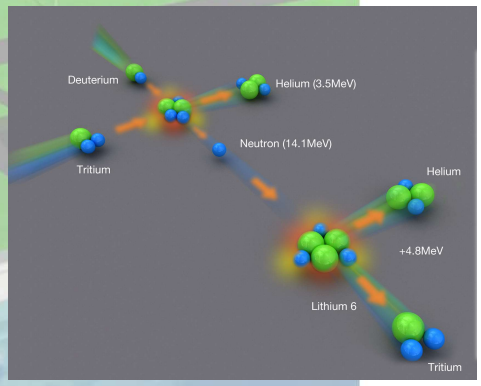
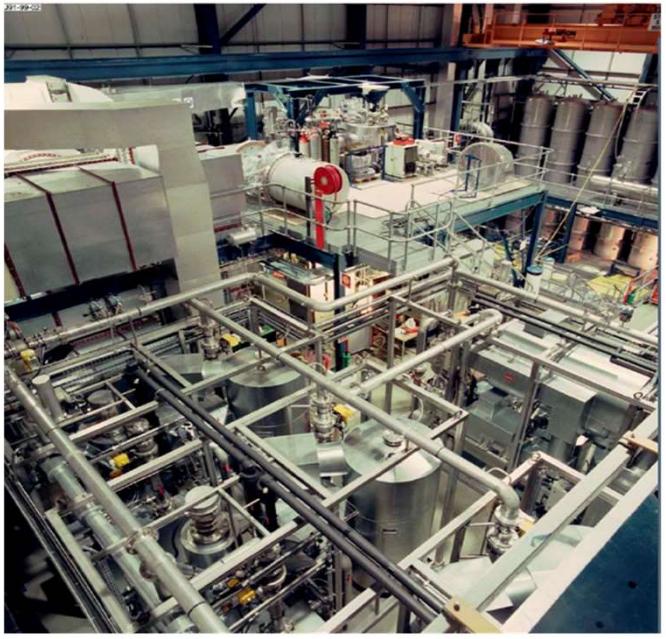


Tritium operations

- JET is the only facility with closed-loop tritium facility for fusion reactors
  - Recently developed two facilities to close the fuel cycle: Materials detritiation and Water detritiation



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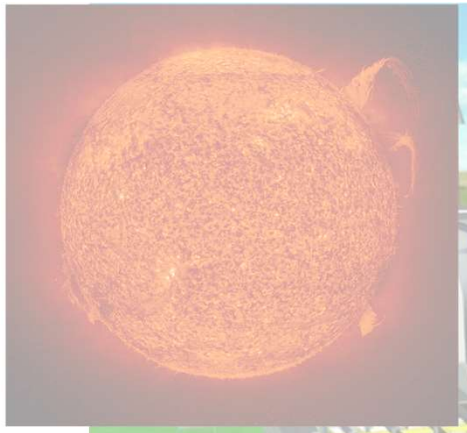

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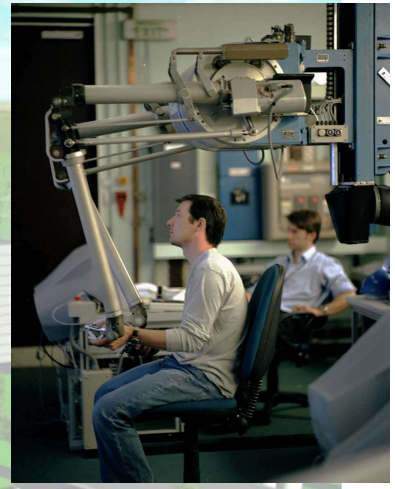

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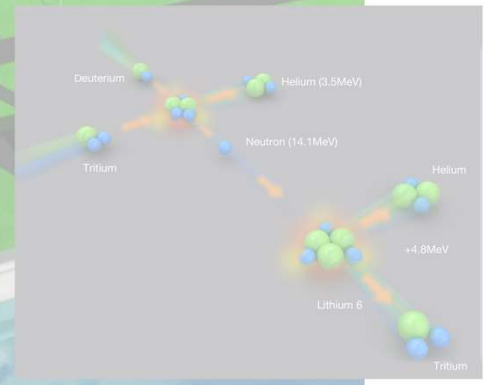
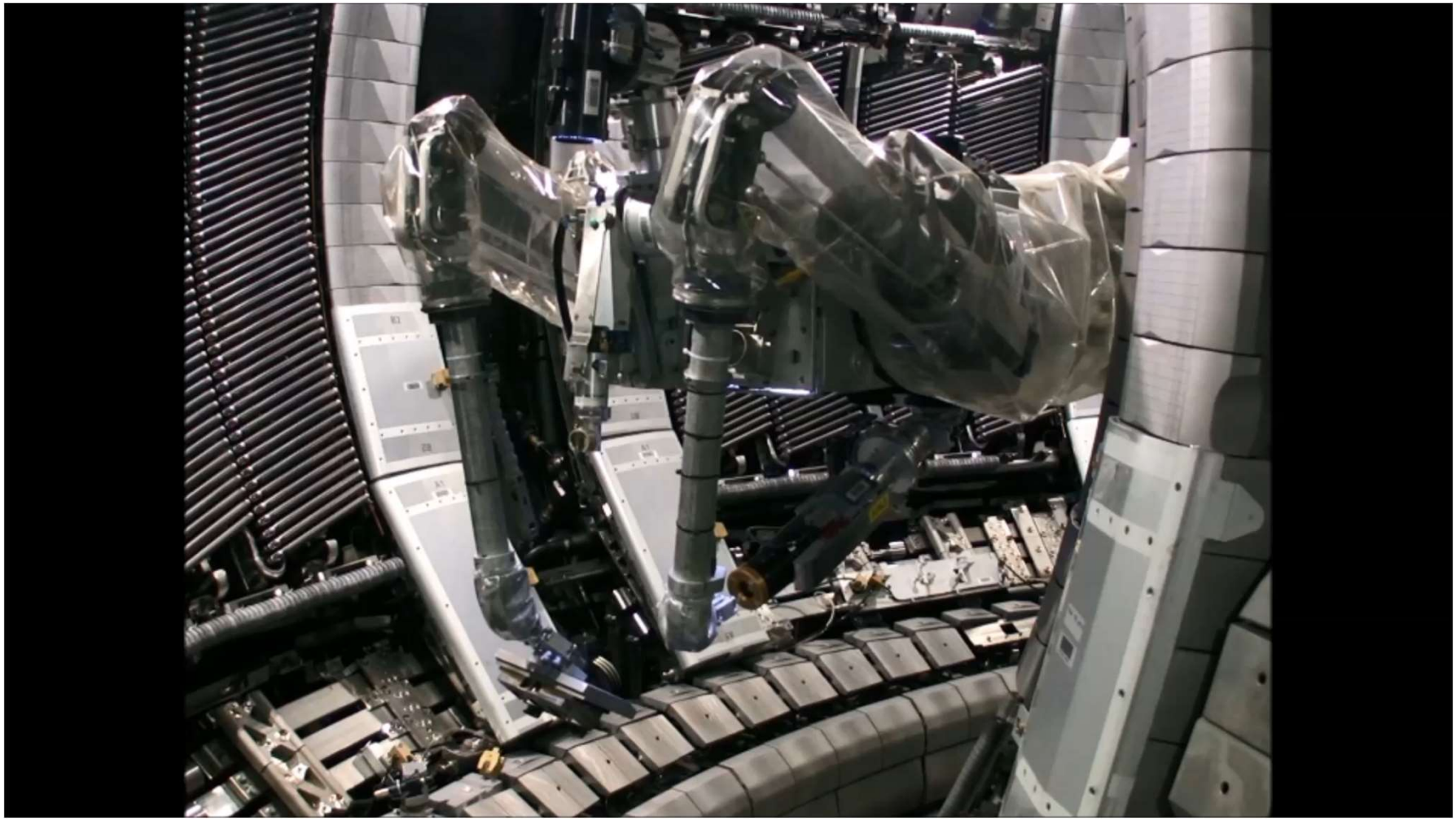


JET Remote Handling System: unique with 30,000 hours of operation



RACE

The new **R**emote **A**pplications in **C**hallenging **E**nvironments (RACE) facility is now open

It offers expertise and facilities to wider industrial partners (e.g. space, fission, autonomous vehicles etc.) – tapping into a world wide remote applications market worth billions

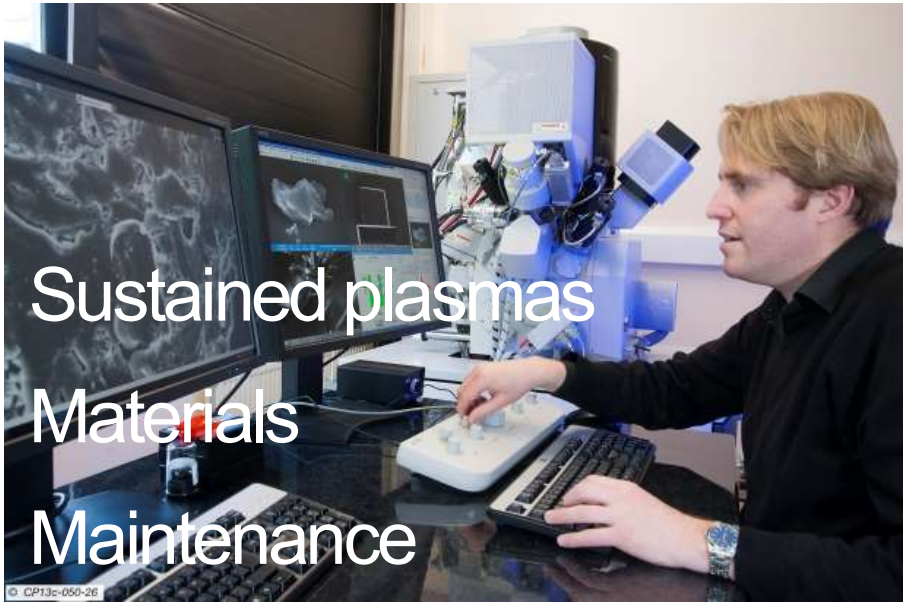
What Determines the Economics of a Future Fusion Power Station?

- **Cost of the power station**
  - UKAEA is exploring smaller and cheaper spherical tokamak fusion plants via MAST-U
- **Power output**
  - UKAEA is developing optimal ITER scenarios on JET and viable exhaust schemes integrated with high performance plasma scenarios on MAST-U
- **Availability**
  - UKAEA are testing irradiated materials properties and developing materials fabrication techniques in MRF
  - UKAEA is developing robotics maintenance schemes in RACE

UKAEA vision for delivering fusion

- A programme with priorities set by the needs for commercialisation of fusion
- UKAEA has a unique set of skills uniting all the major “device-defining” aspects of a fusion reactor
- Want the UK to remain central to international efforts

Challenges



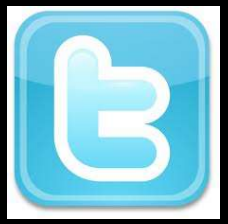
Engineers
Physicists
Materials Scientists
Computer Scientists

How to find out more…

On the web:

- www.ccfe.ac.uk
- www.eurofusion.org

Facebook
Culham Centre for Fusion Energy



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