Shaping fusion power for the future - Mega Amp Spherical Tokamak (MAST) Upgrade summary video

0:00– 0:16

UK Atomic Energy Authority

CCFE
CULHAM CENTRE FOR FUSION ENERGY

MAST Upgrade
Shaping fusion power for the future

UK Atomic Energy Authority

UKAEA

The Engineering behind a Fusion Energy Experiment

Navdeep Mehay

IET Savoy Place, London

16th May 2023

UK Atomic Energy Authority

Navdeep Mehay CEng FInstMC

Machine Control & Protection Group Leader,
MAST-U Engineer-in-Charge,
Authority to Operate Holder (ATOH) for the 1st campaign

Standards Maker for BSI & IEC on ‘Measurement and Control Devices’

Chair, InstMC Special Interest Group – Standards

UKAEA’s Mission

UK Atomic Energy Authority

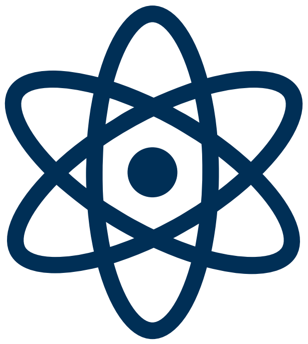
“

To lead the delivery of sustainable fusion energy and maximise scientific and economic benefit

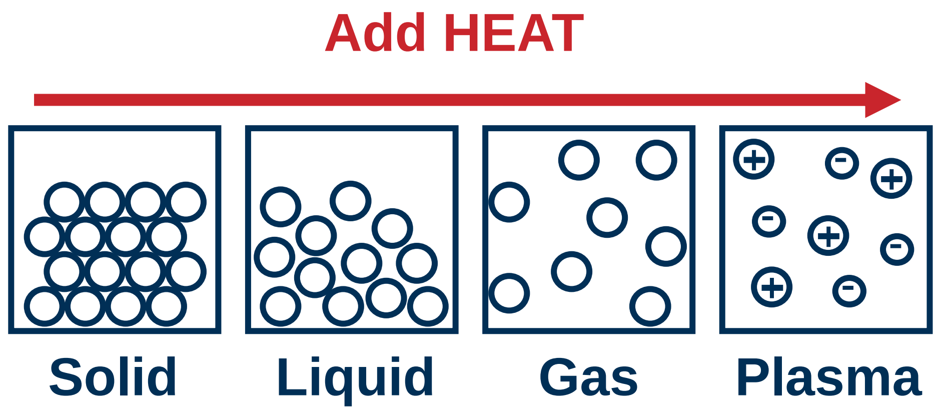
”

What is Fusion?

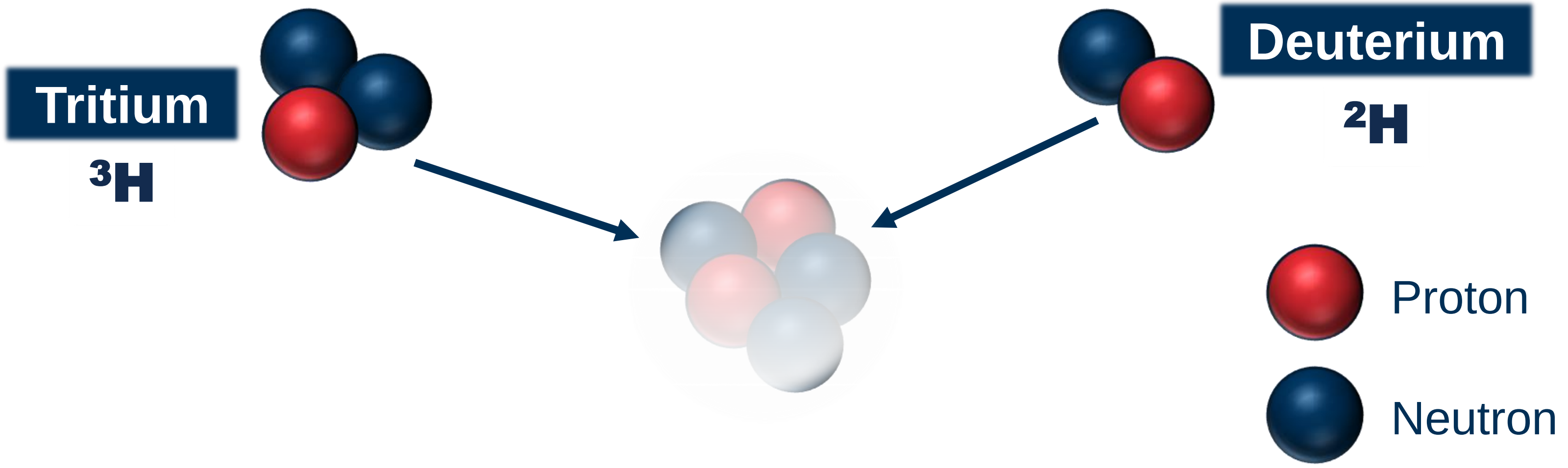
What is Fusion?



1 Hydrogen gas is superheated until it becomes a plasma.

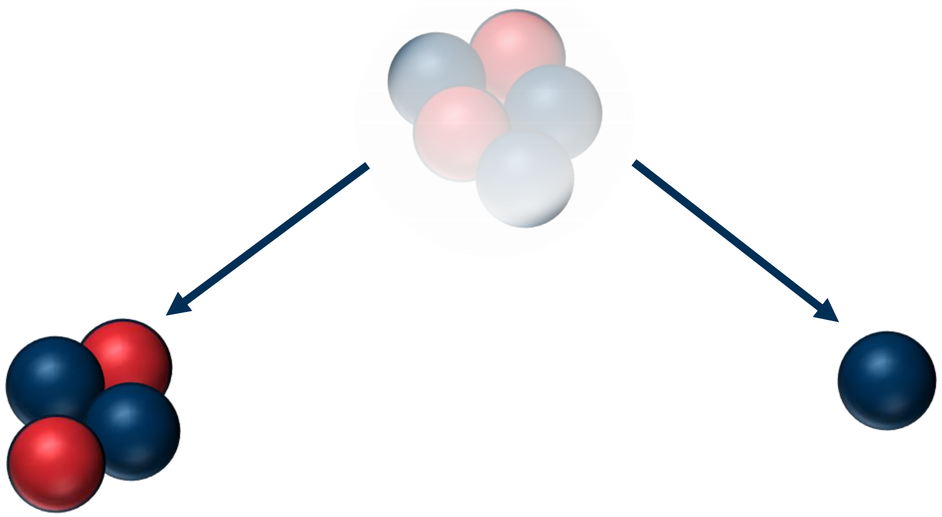


2 Two nuclei collide with enough energy to overcome their electrostatic repulsion

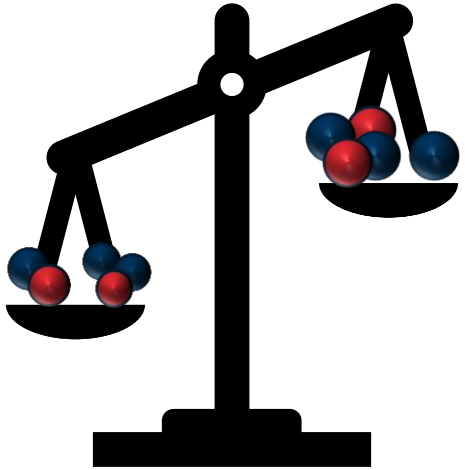


What is Fusion?

3 The nuclei fuse together to create a single Helium nucleus



4 The Helium nucleus has less mass than the two individual Hydrogen nuclei



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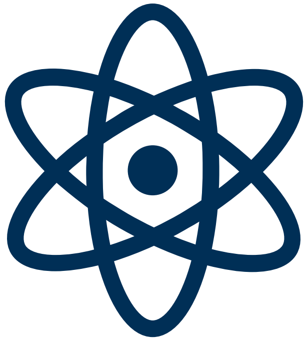
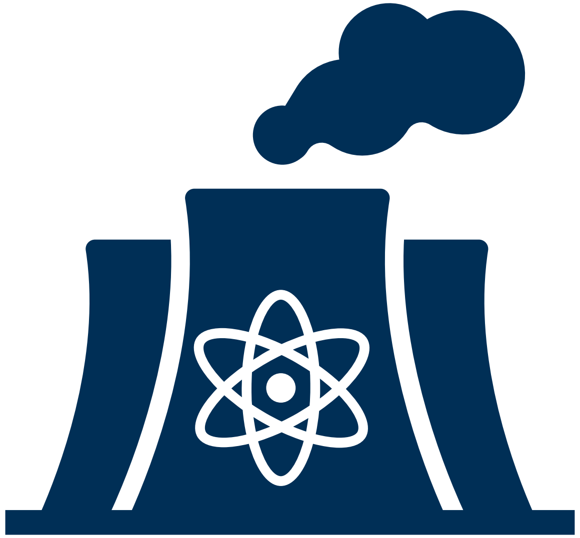
What is Fusion?



5 The difference in mass is converted to energy and released

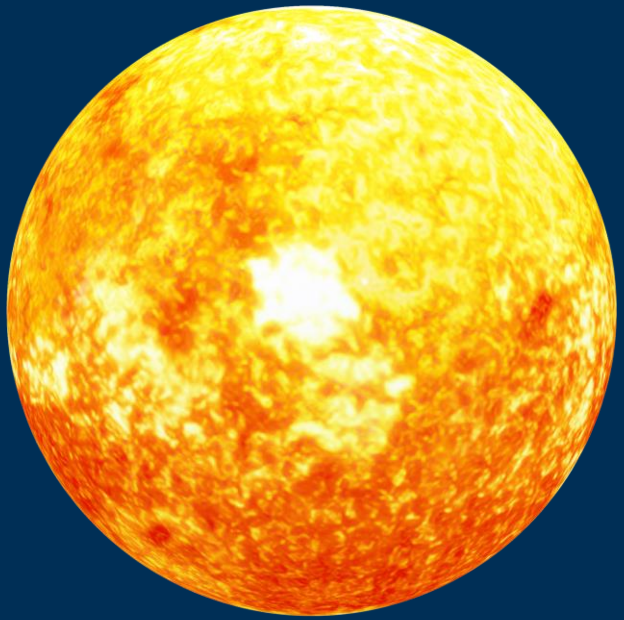
$$E = mc^2$$

6 We can harness this energy in a fusion power plant to generate electricity!

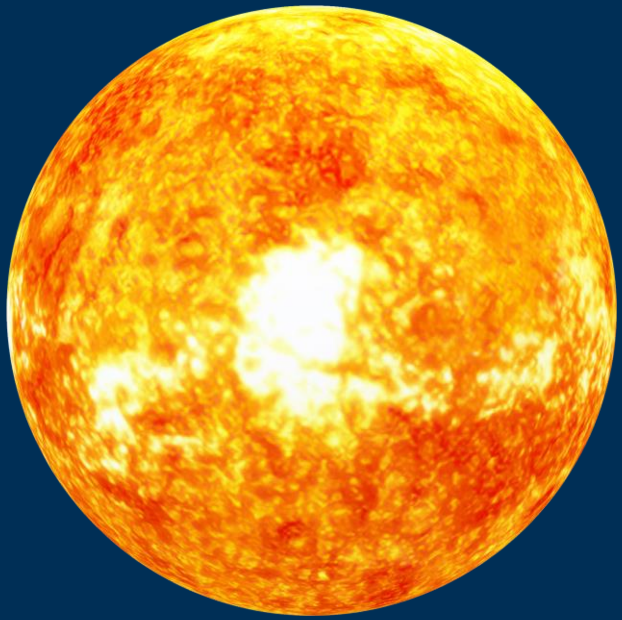


But fusion is really hard…

But fusion is really hard...

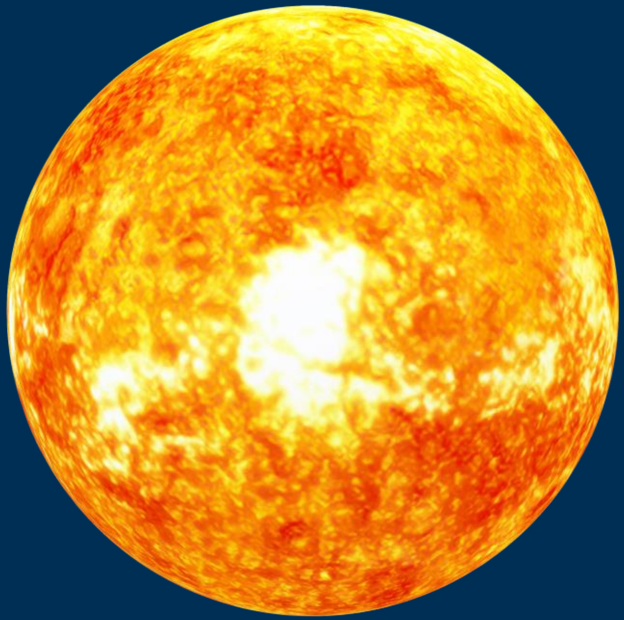


Naturally occurs inside the Sun



High Temperatures

The centre of the Sun is around 15 million degrees!

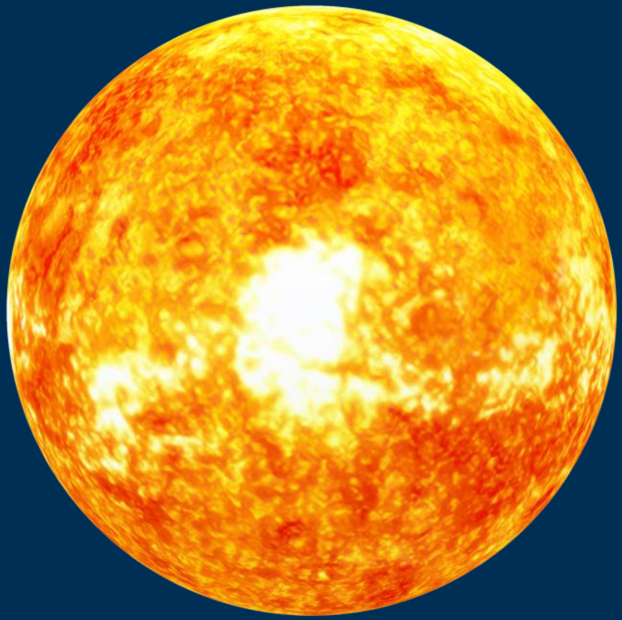


Strong Confinement

Huge gravitational forces hold the Sun together!

High Temperatures

The centre of the Sun is around 15 million degrees!



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High Density

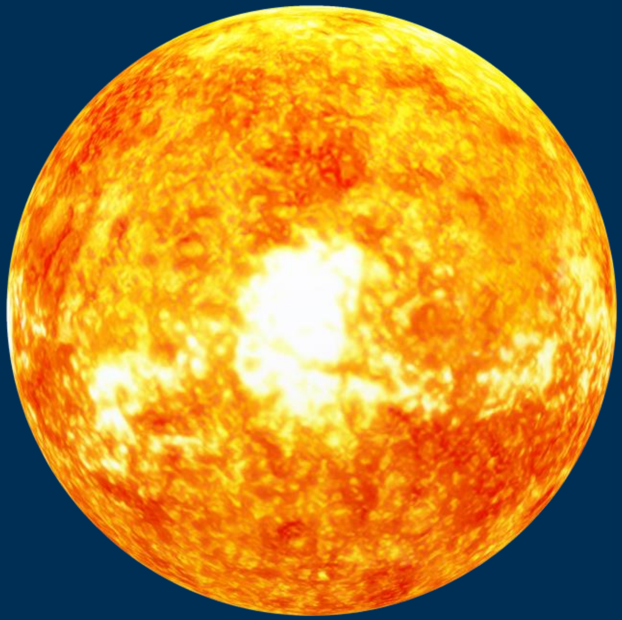
The Sun’s core is 20 times more dense than Iron!

Strong Confinement

Huge gravitational forces hold the Sun together!

High Temperatures

The centre of the Sun is around 15 million degrees!



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The centre of the Sun is around 15 million degrees!

Challenge:

How do we recreate the conditions required for Fusion on Earth?

High Temperatures:
Nuclei must overcome their repulsion

Strong confinement:
Hot plasma must be contained

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How do we recreate the conditions required for Fusion on Earth?

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Challenge:

How do we recreate the conditions required for Fusion on Earth?

High Temperatures:
Nuclei must overcome their repulsion

Strong confinement:
Hot plasma must be contained

Solution:

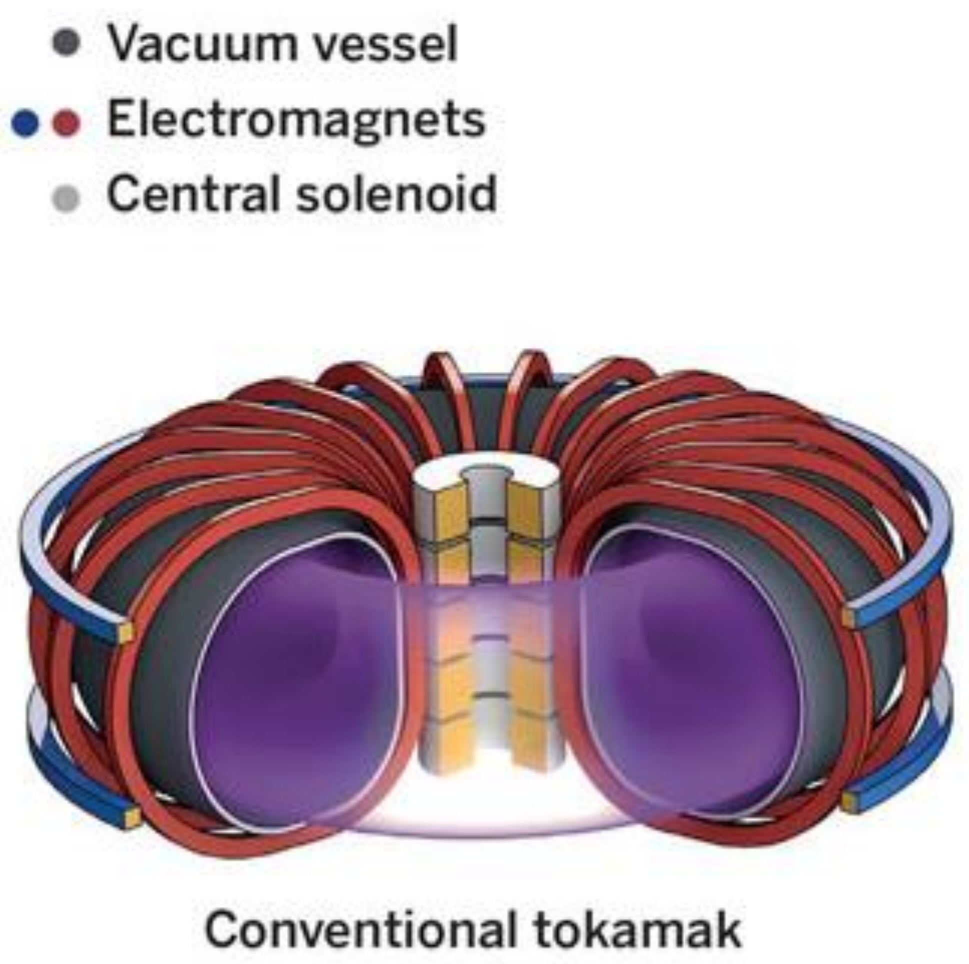
Use a Tokamak!

High Temperatures:
Can heat plasma to 150 million degrees

Strong confinement:
Uses magnetic fields to hold the plasma

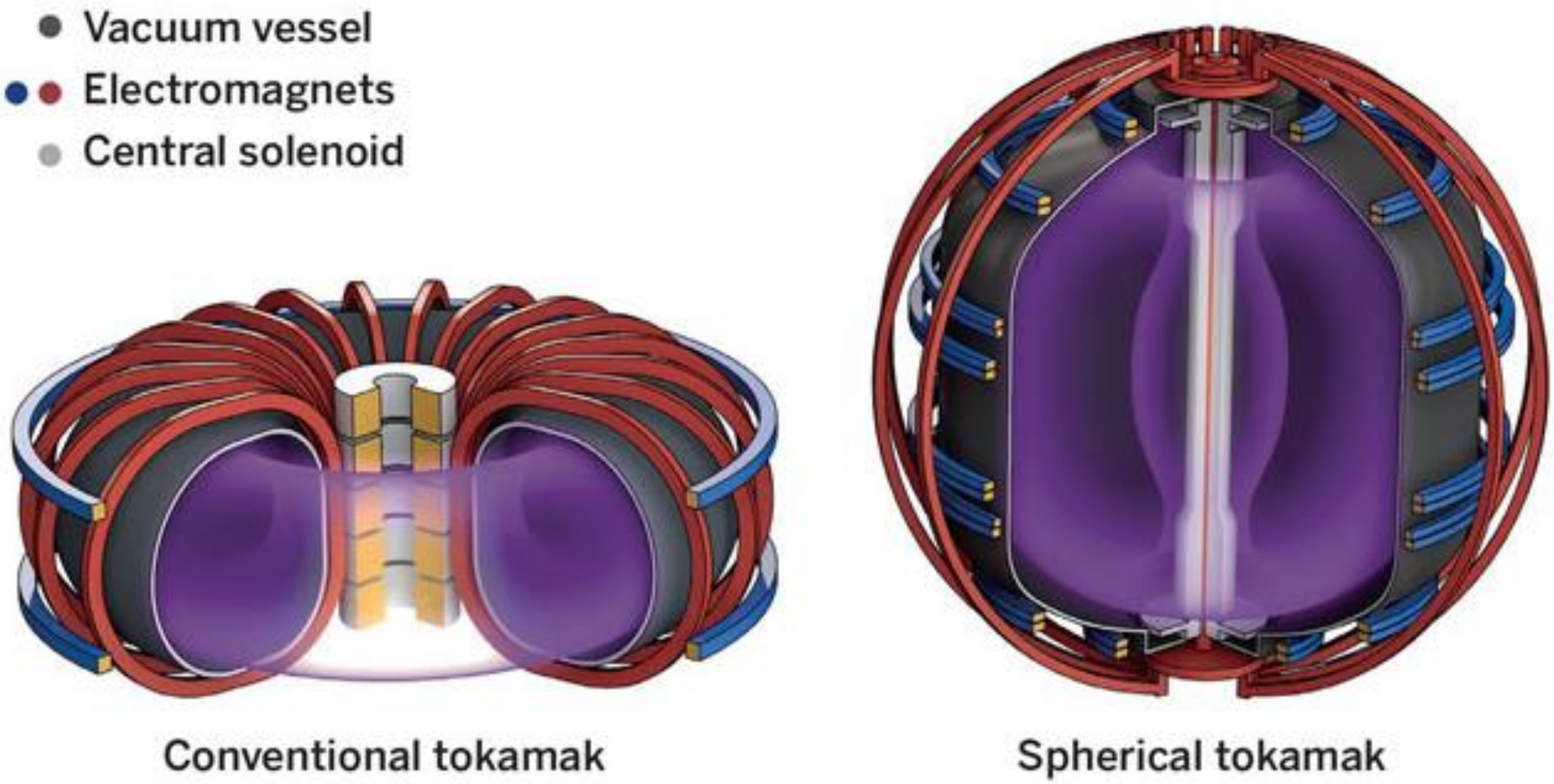
Tokamak

[Toroidal chamber with magnetic coils]



Tokamak

[Toroidal chamber with magnetic coils]



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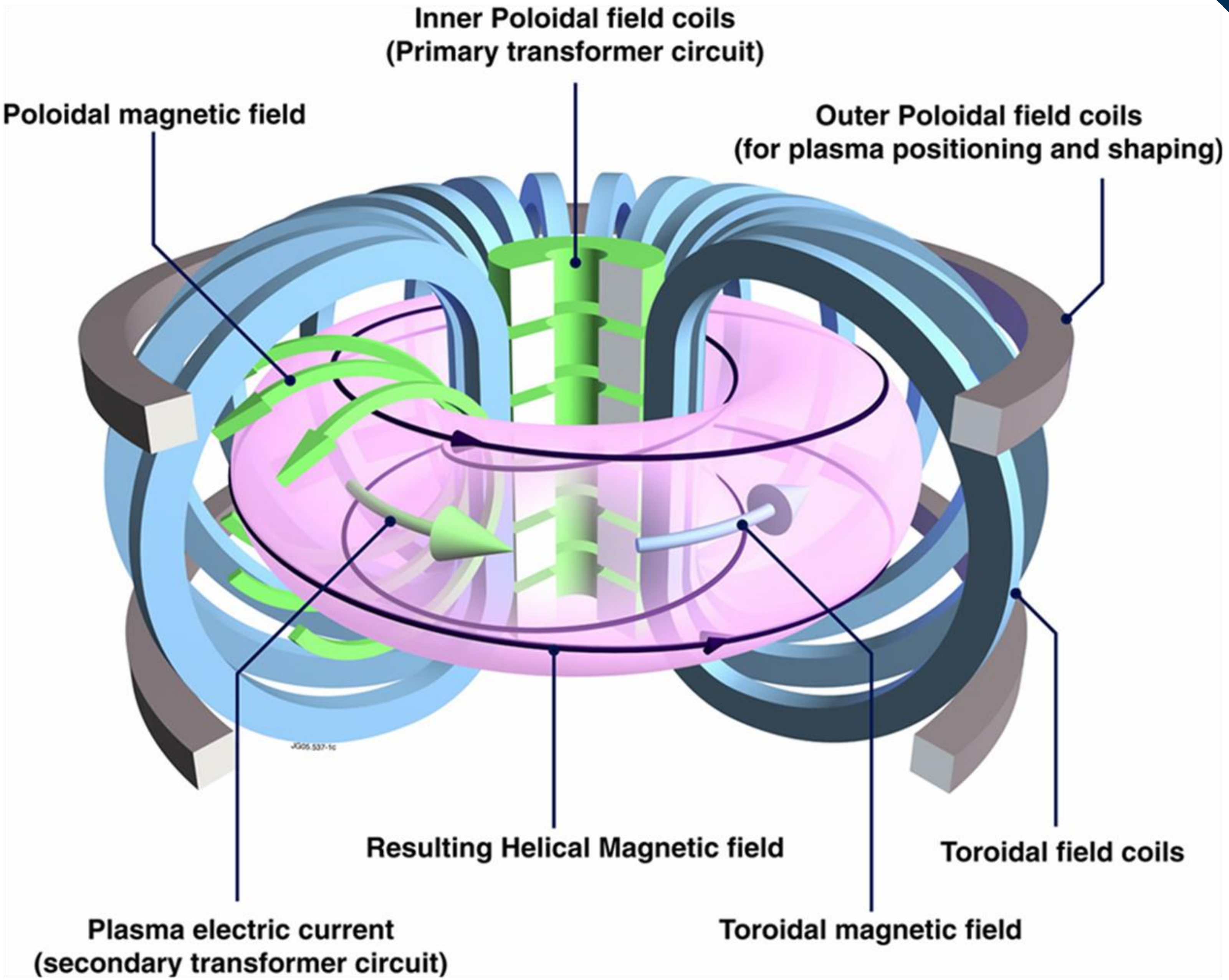
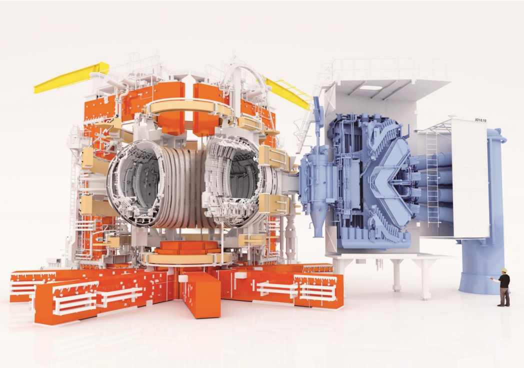
Tokamak

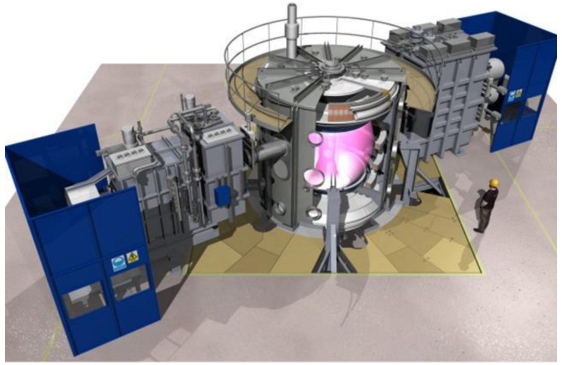
[Toroidal chamber with magnetic coils]

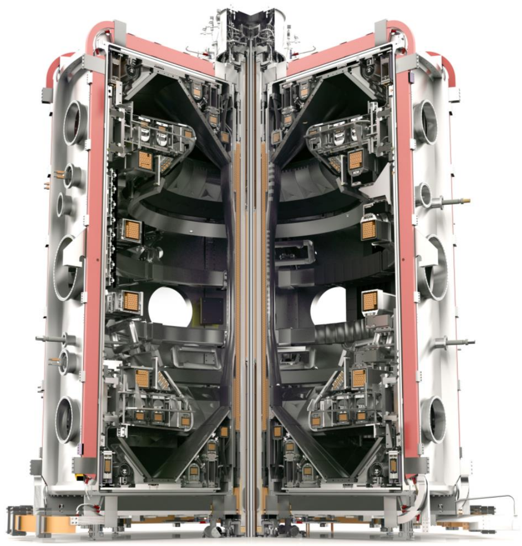


Timeline of UKAEA's Research

UK Atomic Energy Authority







1983

JET

UK

1999

MAST

UK

2020

MAST-U

UK

Joint European Torus

World's Largest Tokamak

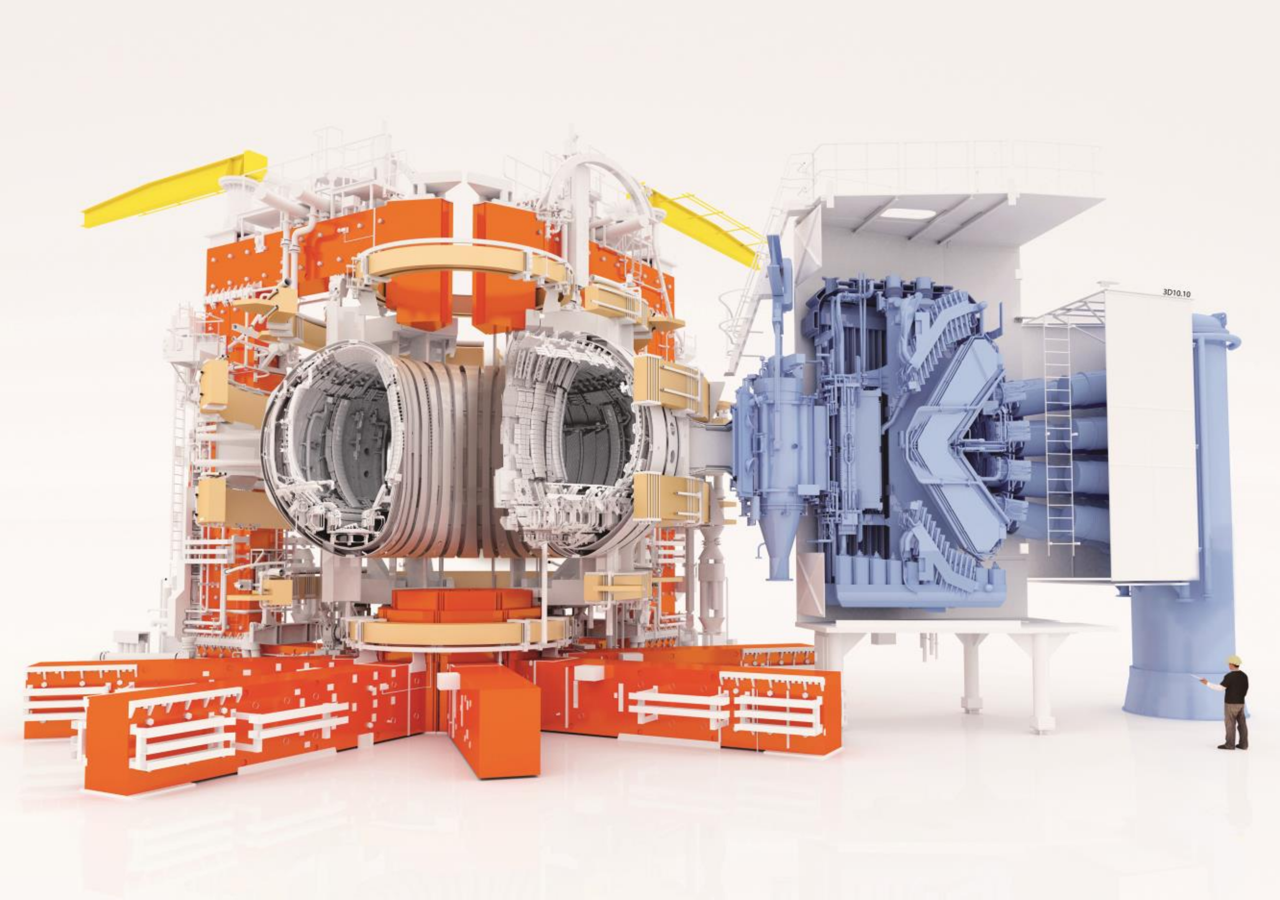
Joint European Torus

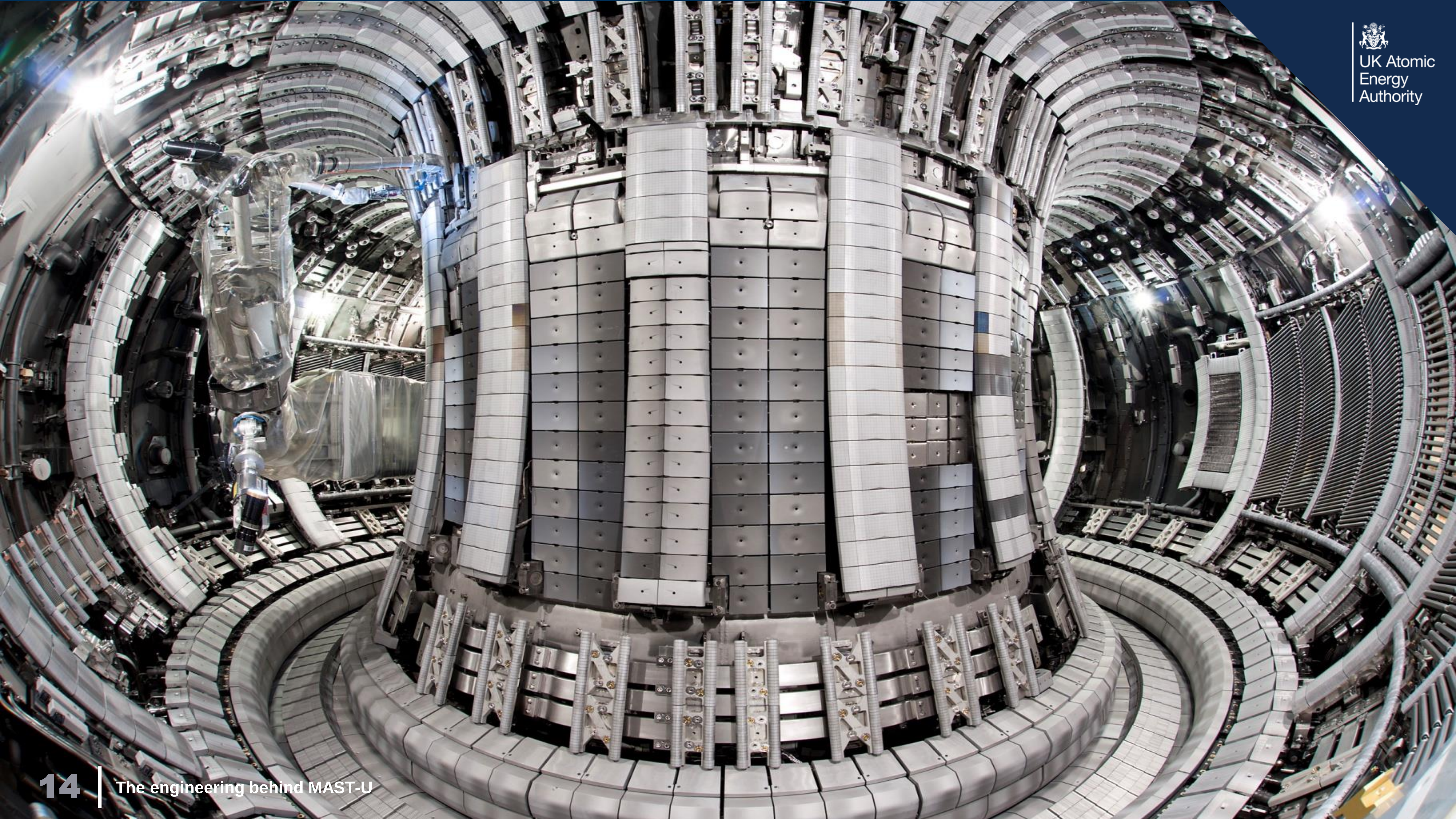
Operated by UKAEA at Culham on behalf of EUROfusion

Largest and most advanced tokamak in the world

The only fusion device which can use Deuterium and Tritium as fuel

Achieved a record breaking 59MJ of power over a 5 second pulse



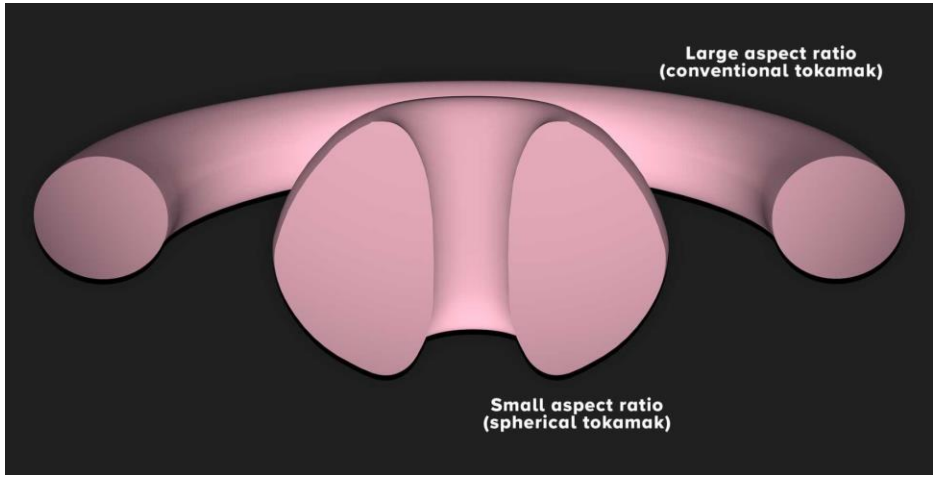


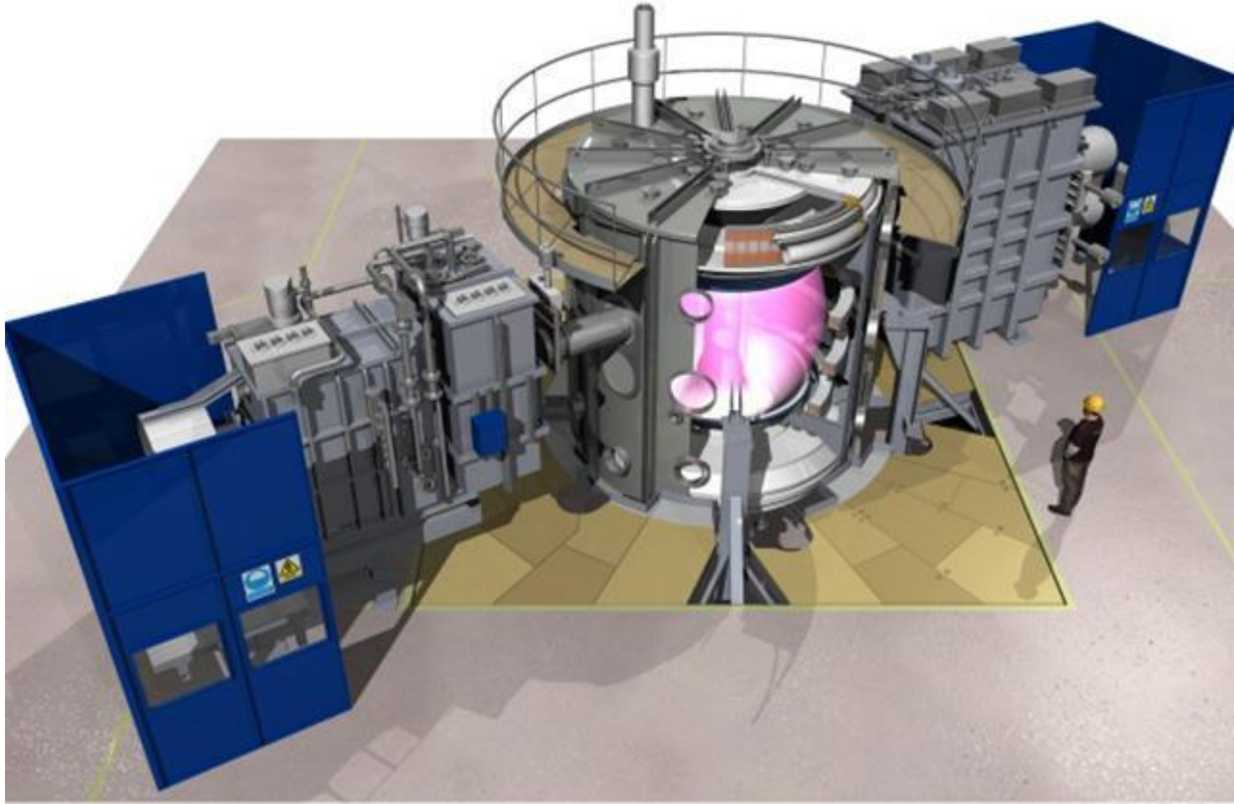
Mega Ampere Spherical Tokamak

A spherically shaped tokamak, as opposed to the torus (donut) shape of JET

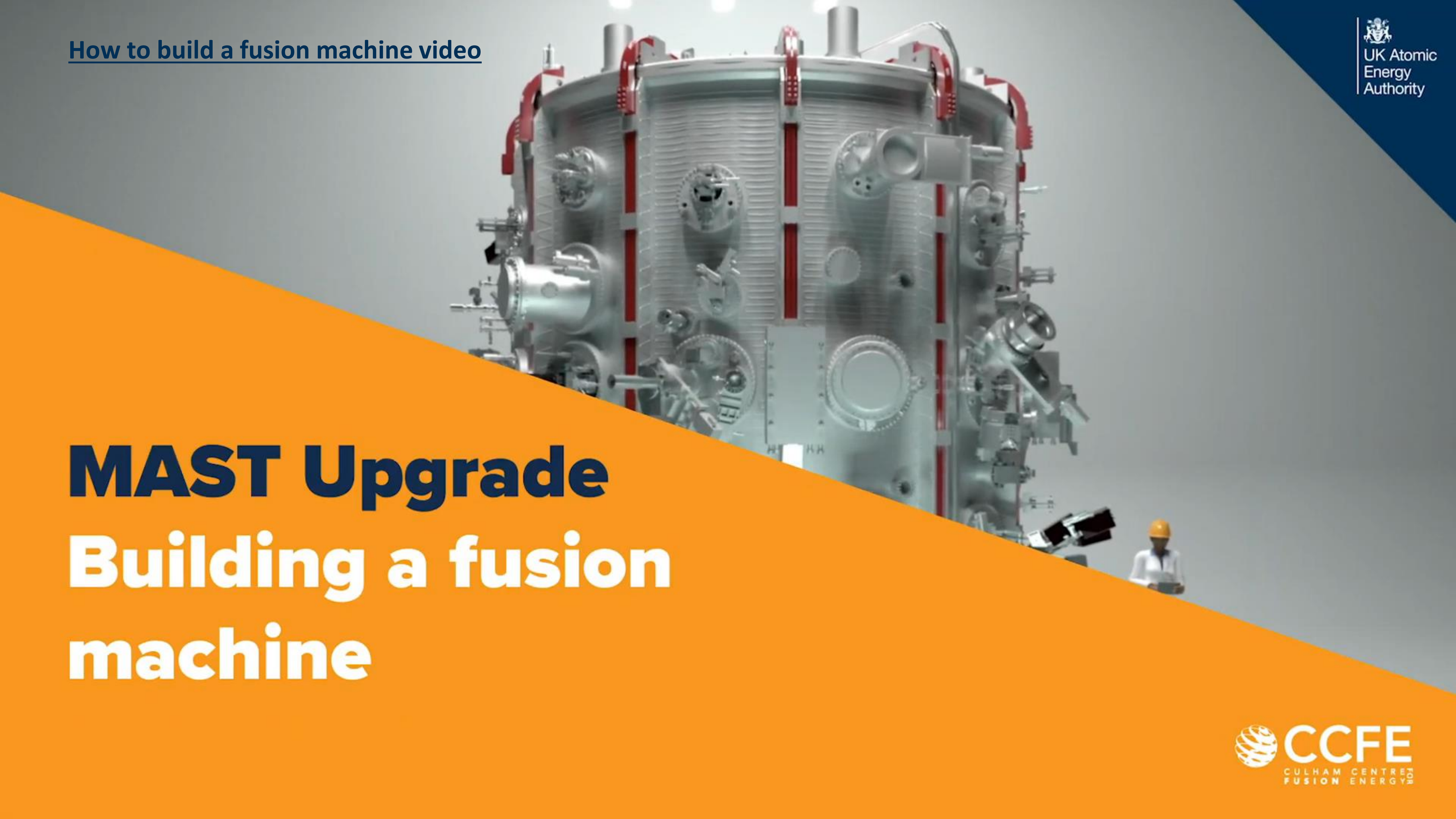
Much more compact than JET

Could lead to smaller, cheaper, more efficient power plants in the future





[How to build a fusion machine video]



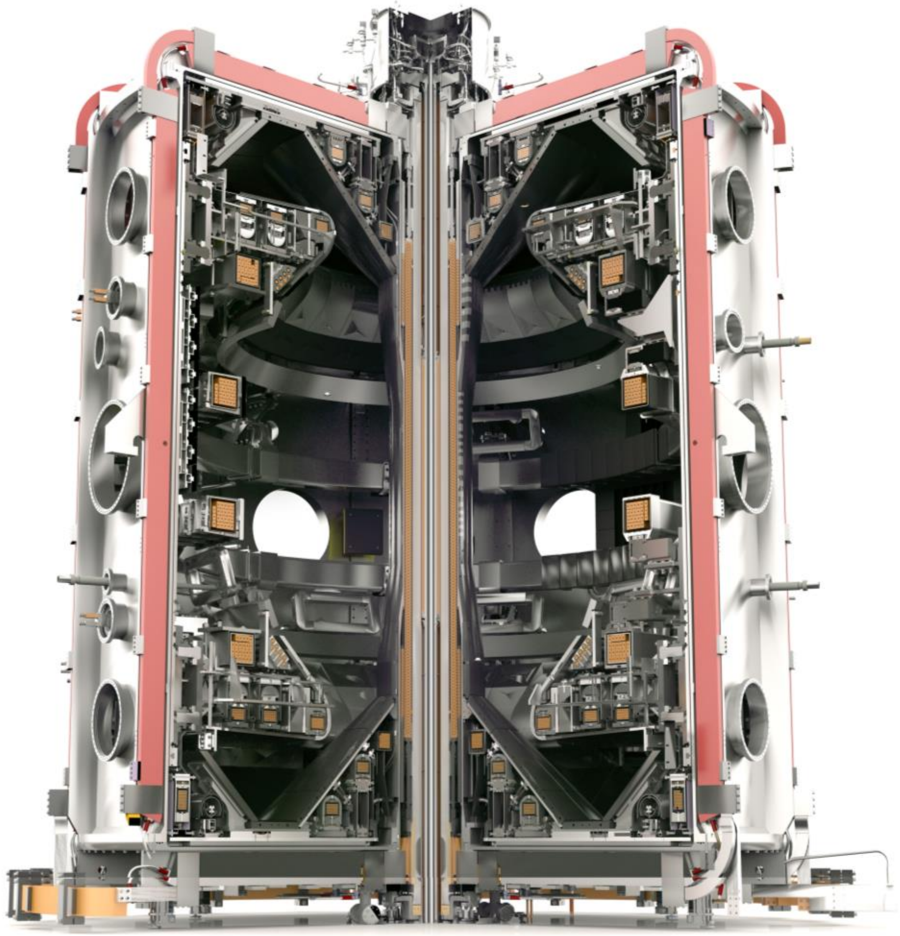
MAST - Upgrade

An upgraded version of the MAST tokamak

Heat from the plasma has to go to an exhaust during any fusion reaction

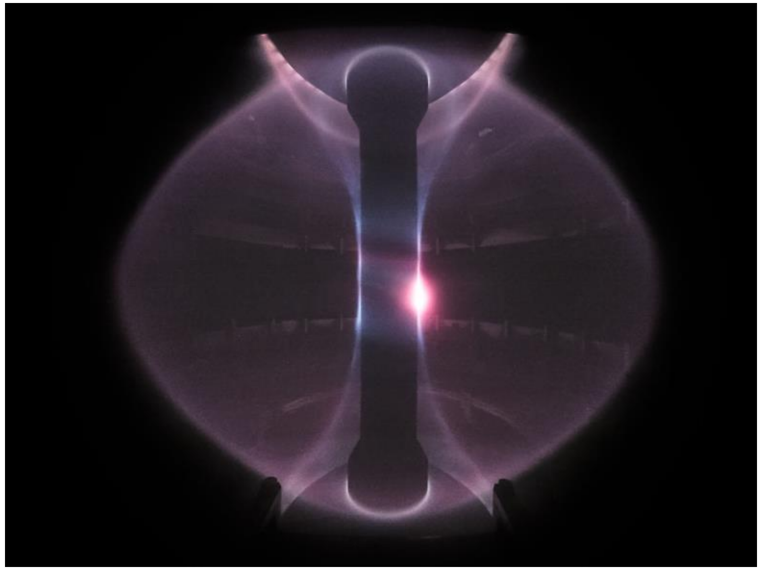
Typically this causes huge temperatures, and the divertor will need regular replacement

MAST-U uses a 'Super X' divertor – plasma travels further and cools more before hitting any components (video)



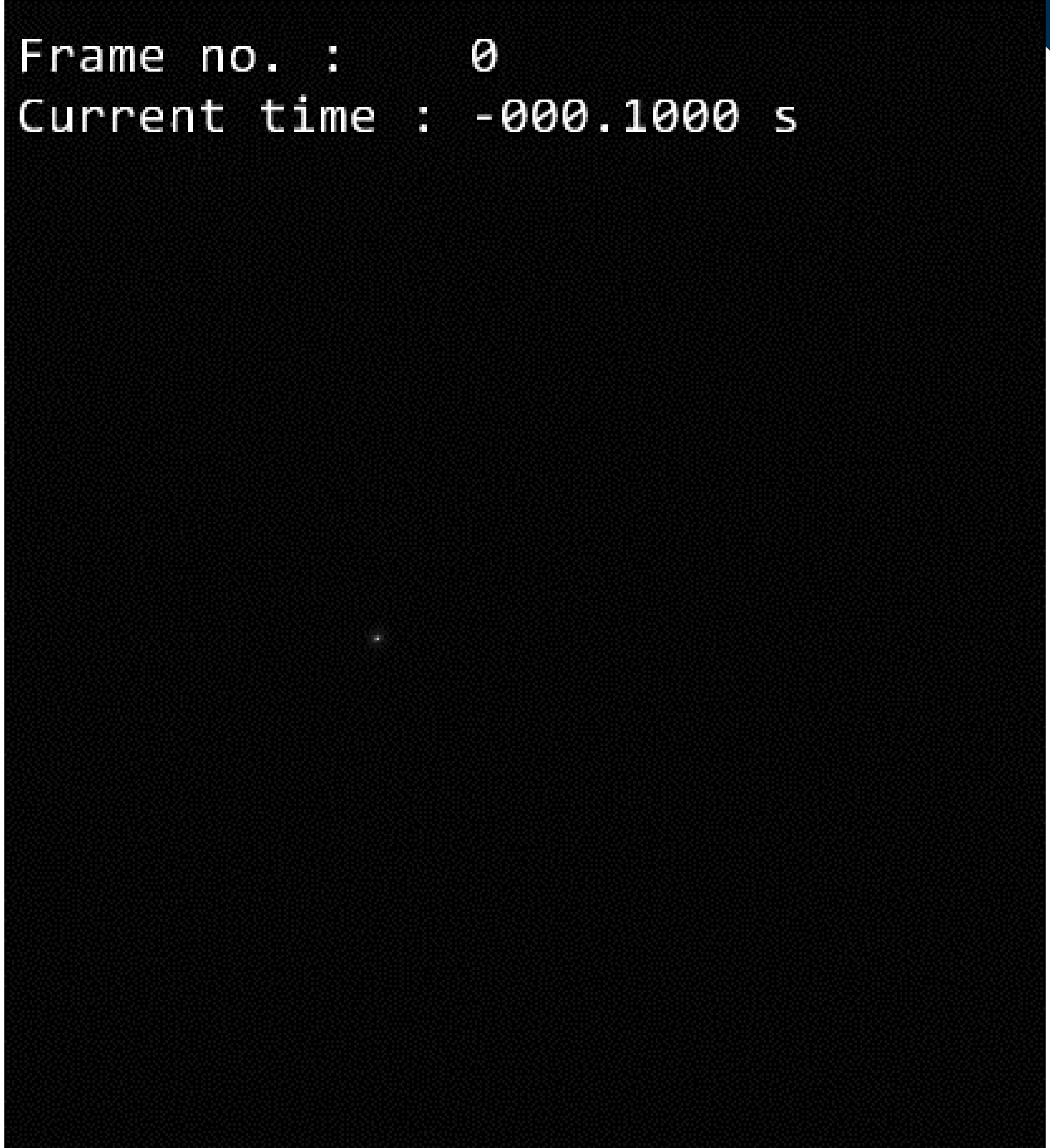
How it works: The Super-X divertor video

Plasma



Plasma in the MAST machine (Pic)

SUPER-X Proven 10x better for heat load!!!



Plasma in the MAST-U machine (video)

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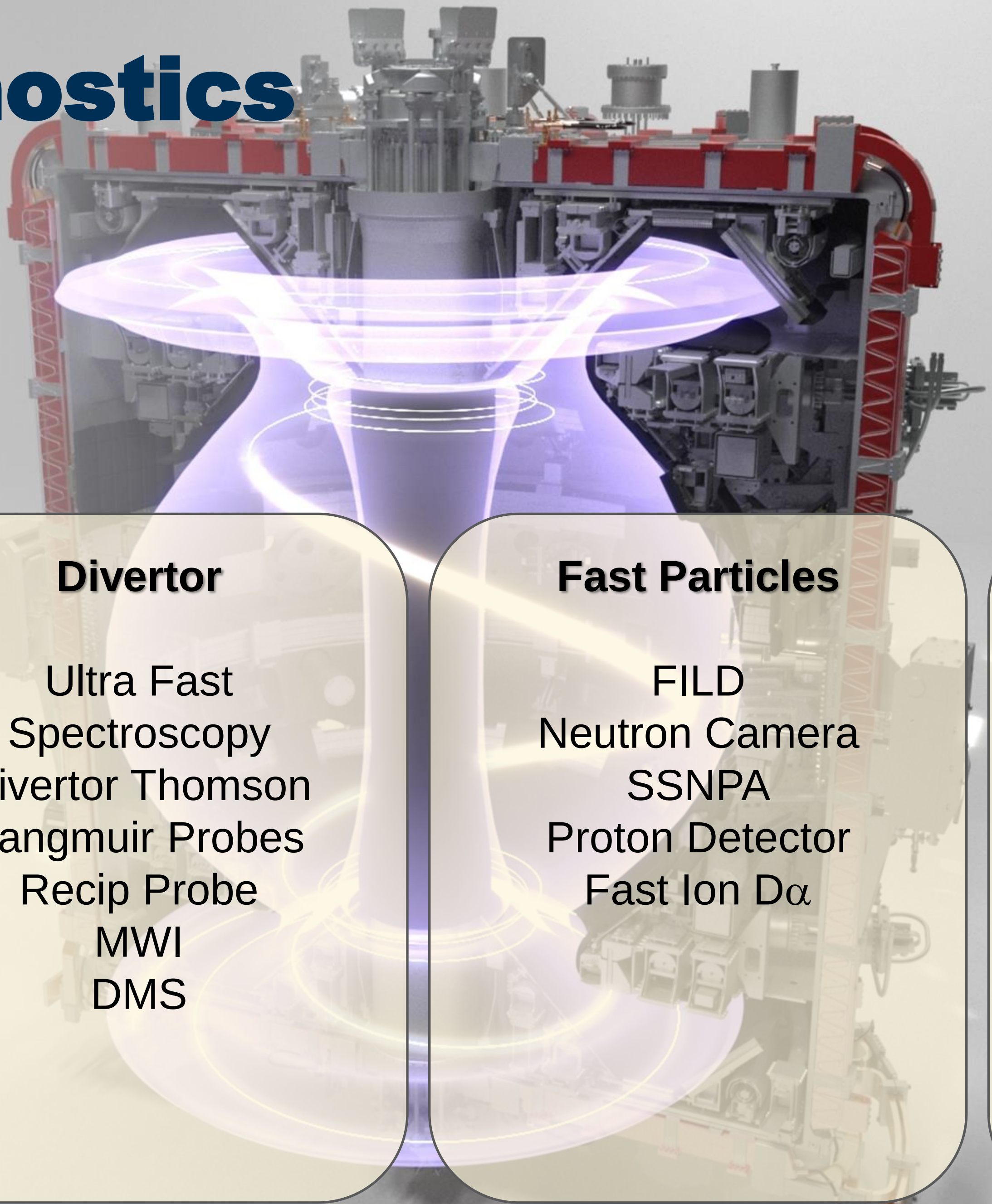
MAST-U Diagnostics



~18 GB per shot

Core Plasma Kinetics

Soft X-Rays
Core Thomson
CXRS
MSE
DBS UCLA
DBS SWIP
Pedestal Code
IR Cameras

Divertor

Ultra Fast Spectroscopy
Divertor Thomson
Langmuir Probes
Recip Probe
MWI
DMS

Fast Particles

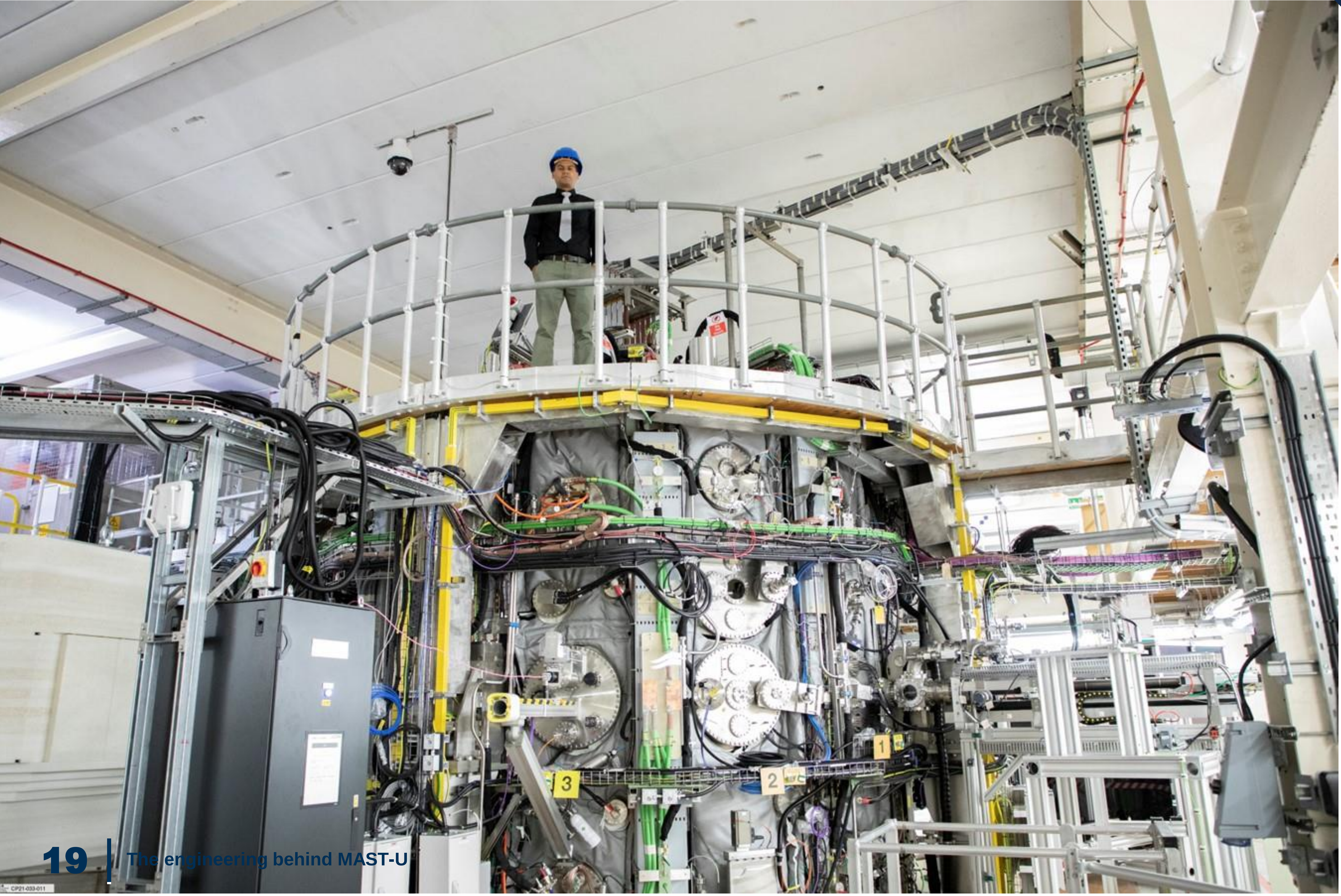
FILD
Neutron Camera
SSNPA
Proton Detector
Fast Ion Dα

And many more…

Magnetics
Homer
Fission Chamber
Fast Ion Gauge
IR Cameras

and more

Total ~40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Context

MAST - Upgrade

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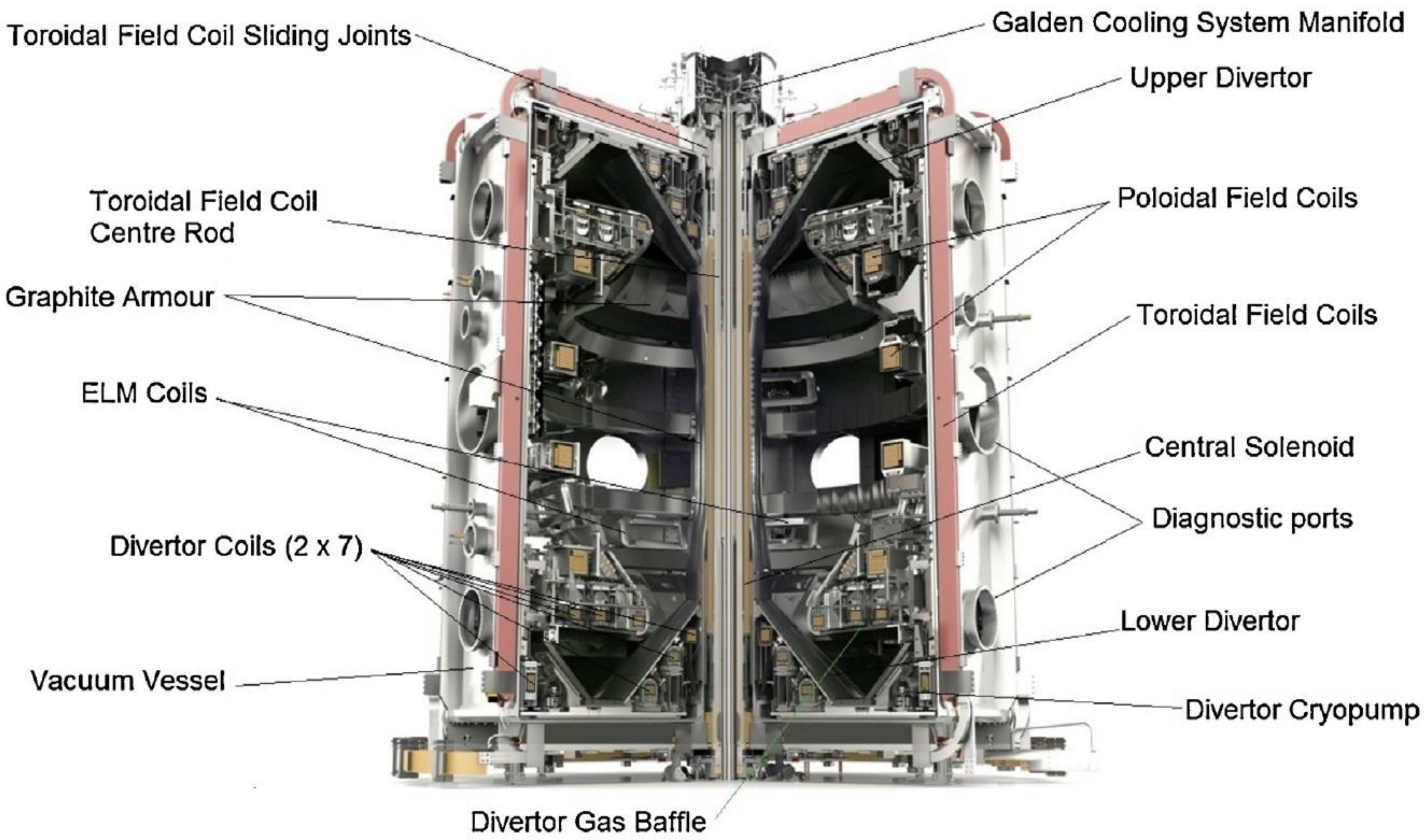
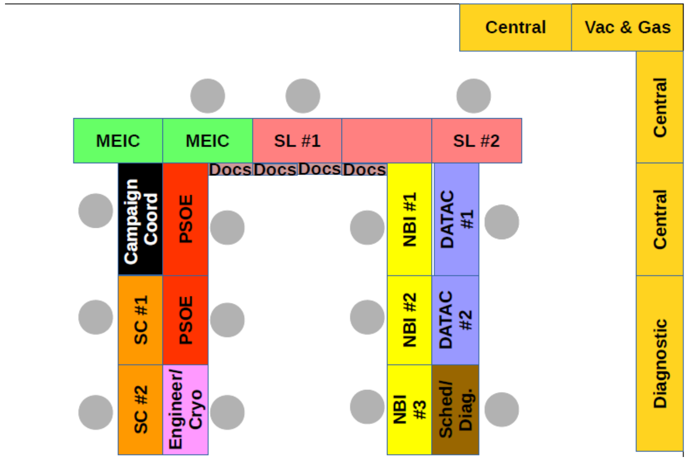
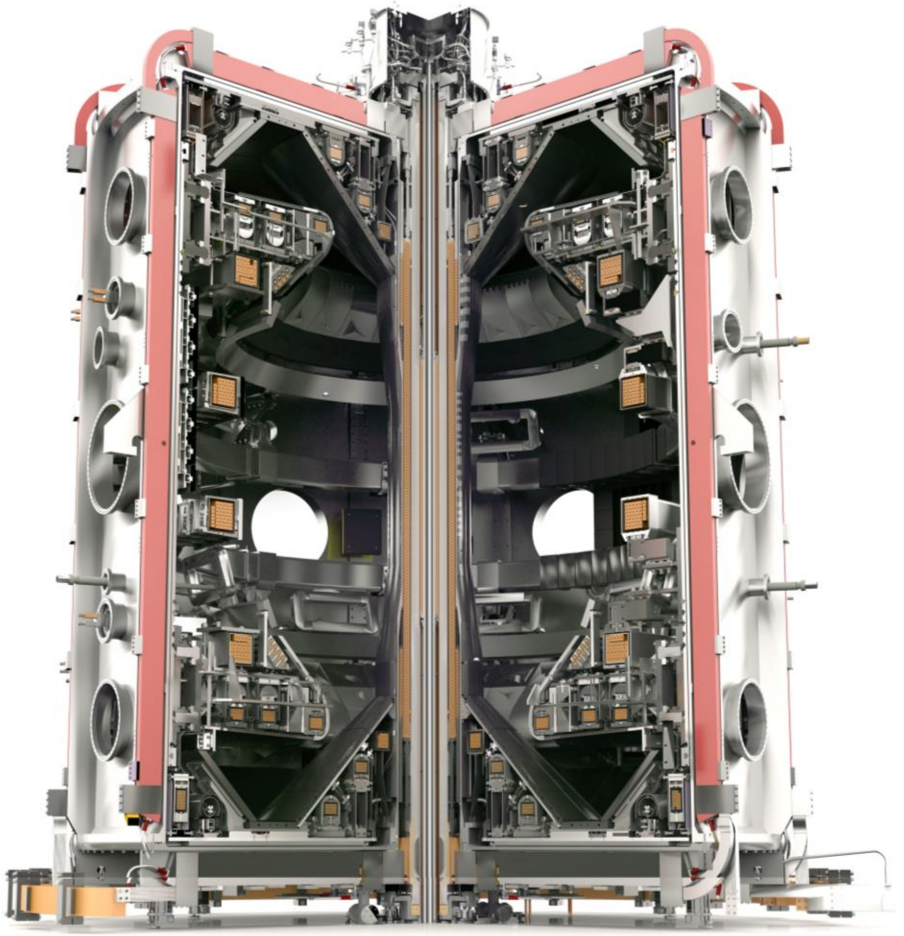


Operating MAST-U

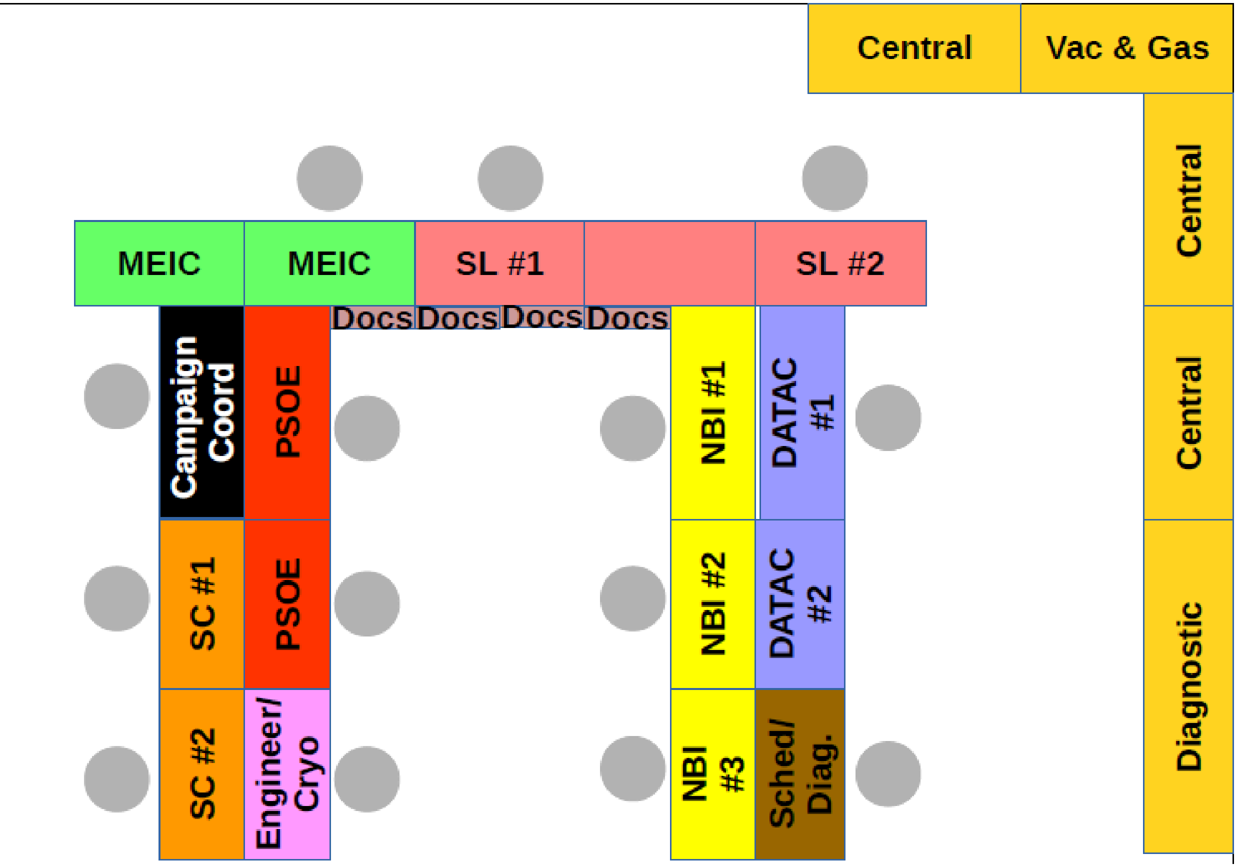
Scientific Research environment [Control Room]





Operating MAST-U

UK Atomic Energy Authority



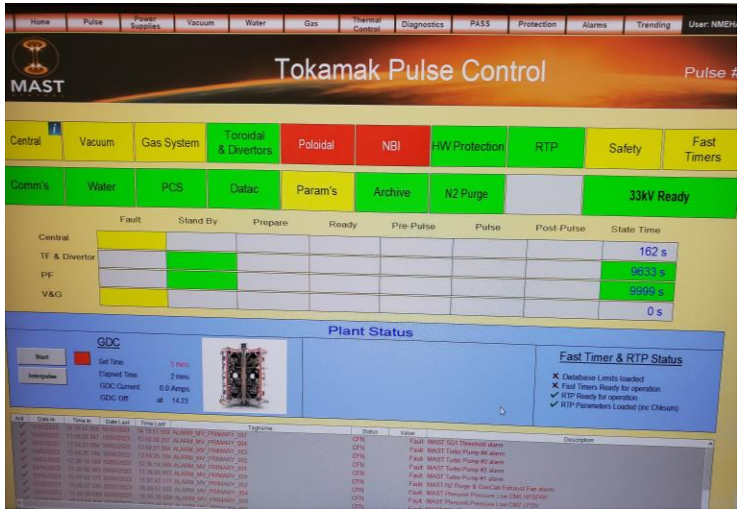
MAST-U Control Room

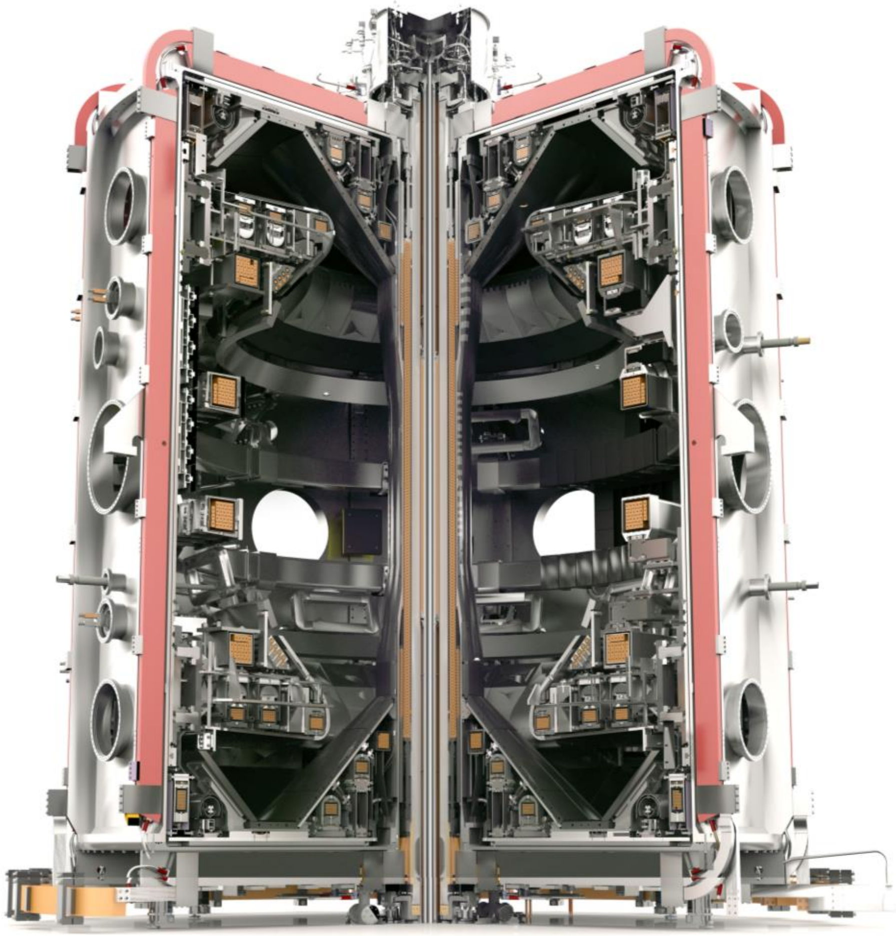
Operating MAST-U

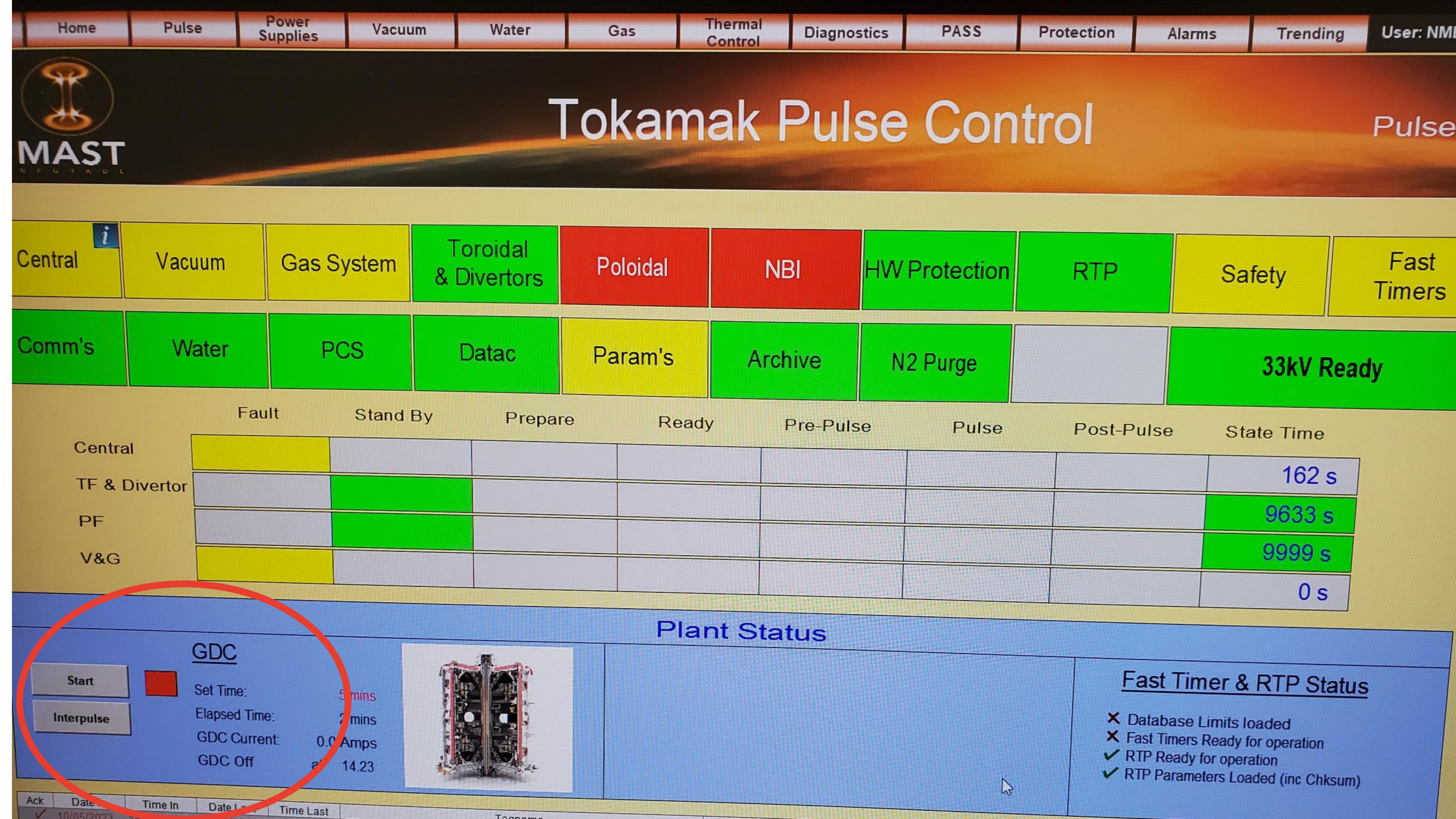
UK Atomic Energy Authority

Scientific Research environment [Control Room]

Role of MAST-U Engineer-in-Charge (CE, ATOH, OM)






Home
Pulse
Power Supplies
Vacuum
Water
Gas
Thermal Control
Diagnostics
PASS
Protection
Alarms
Trending
User: NM
MAST
Tokamak Pulse Control
Pulse
Central
Vacuum
Gas System
Toroidal & Divertors
Poloidal
NBI
HW Protection
RTP
Safety
Fast Timers
Comm's
Water
PCS
Datac
Param's
Archive
N2 Purge
33kV Ready
Fault
Stand By
Prepare
Ready
Pre-Pulse
Pulse
Post-Pulse
State Time
Central
TF & Divertor
PF
V&G
162 s
9633 s
9999 s
0 s
Plant Status
GDC
Start
Interpulse
Set Time:
5 mins
Elapsed Time:
2 mins
GDC Current:
0.0 Amps
GDC Off
14.23
Fast Timer & RTP Status
Database Limits loaded
Fast Timers Ready for operation
RTP Ready for operation
RTP Parameters Loaded (inc Chksum)
Ack
Date
Time In
Time Last

Operating MAST-U

Scientific Research environment [Control Room]

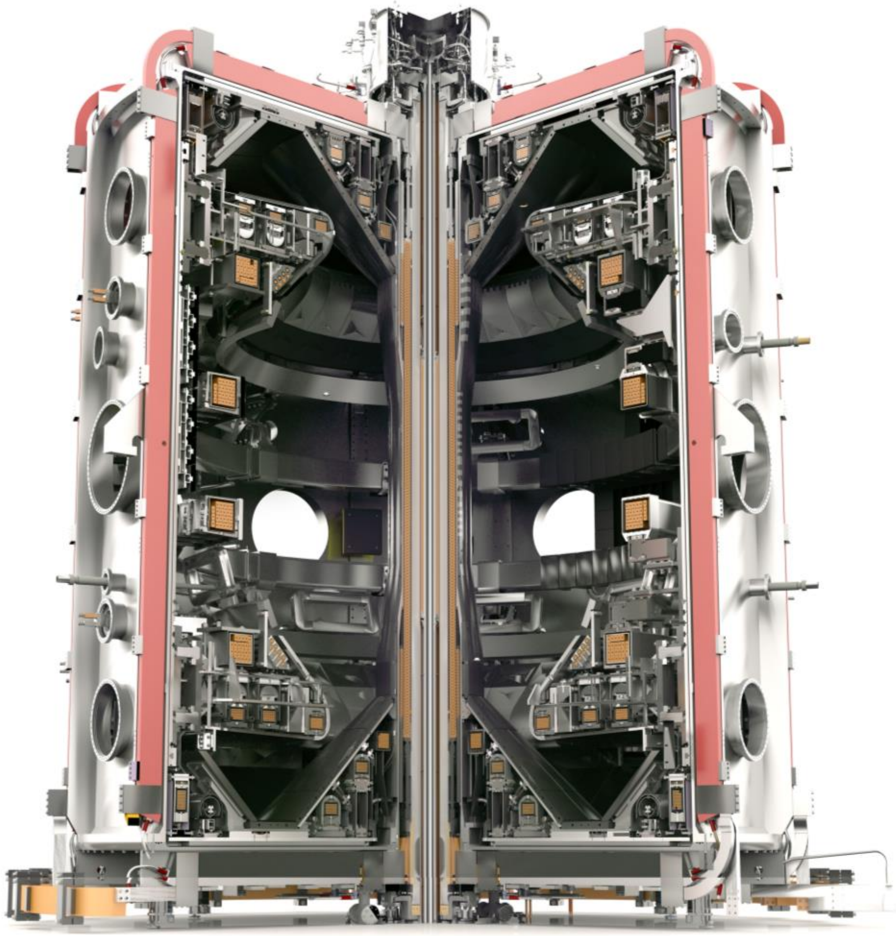
Role of MAST-U Engineer-in-Charge (CE, ATOH, OM)

- Shot frequency ~ 20 mins (w/o JET)
- Coordination & Management procedures

Engineering/Contingency days

Scientific Campaign & Engineering break + Bake

Controlled Area/Access restrictions



Engineering Challenges

Magnetic Coils in close proximity

P1 ramp

$$\boxed{\varepsilon = -N\frac{\Delta\phi_M}{\Delta t}}$$

Faraday's Law

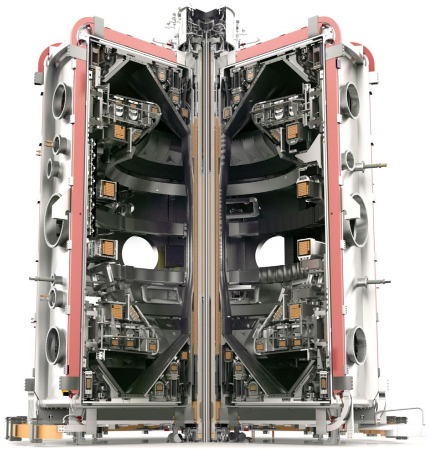
N = number of loops

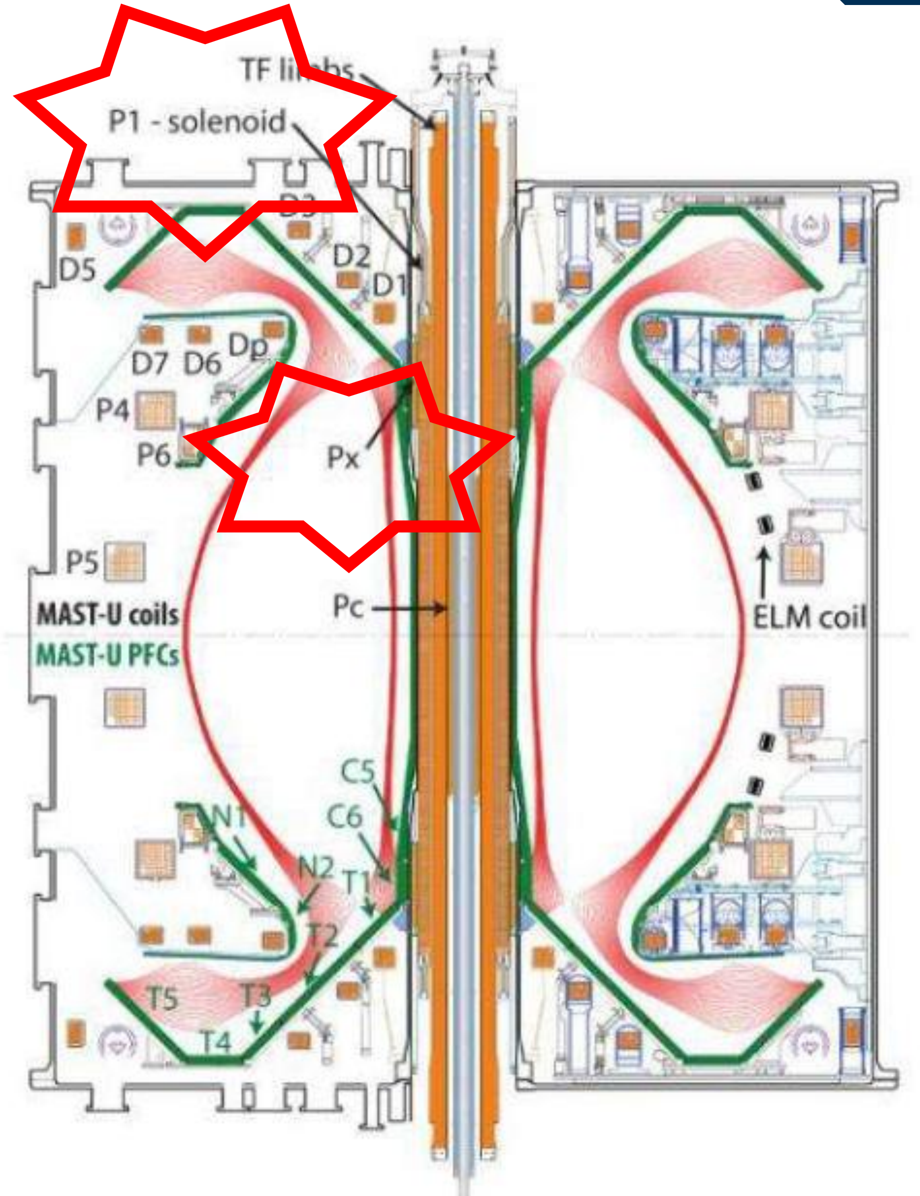
$\Delta\phi_M$ = change in magnetic flux

Δt = change in time

ε = induced voltage (also known as emf)

Induced current in Px





Engineering Challenges

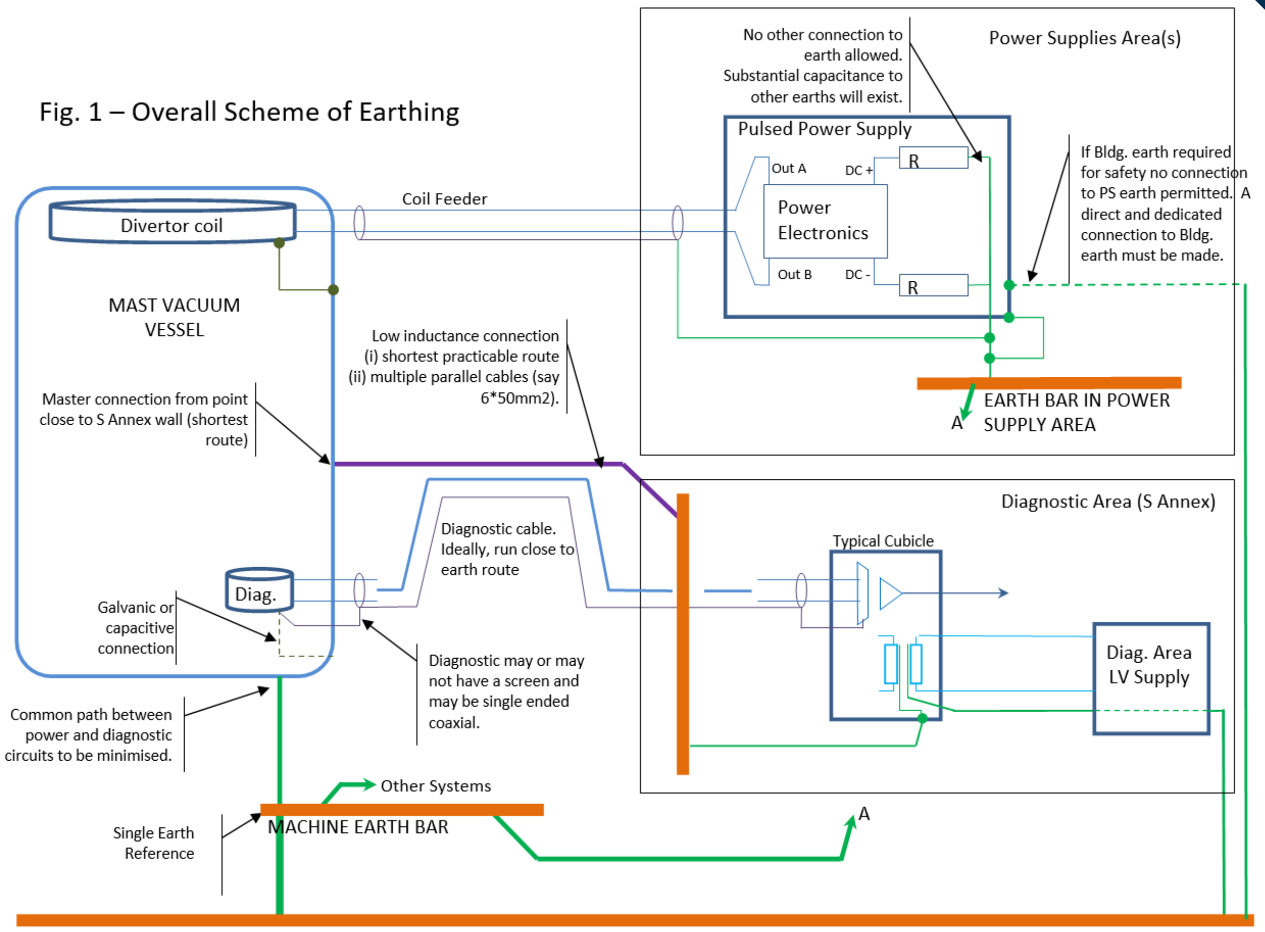
UK Atomic Energy Authority

Clean(er) Earth

Maximise the quality of diagnostic measurements

Earthing strategy

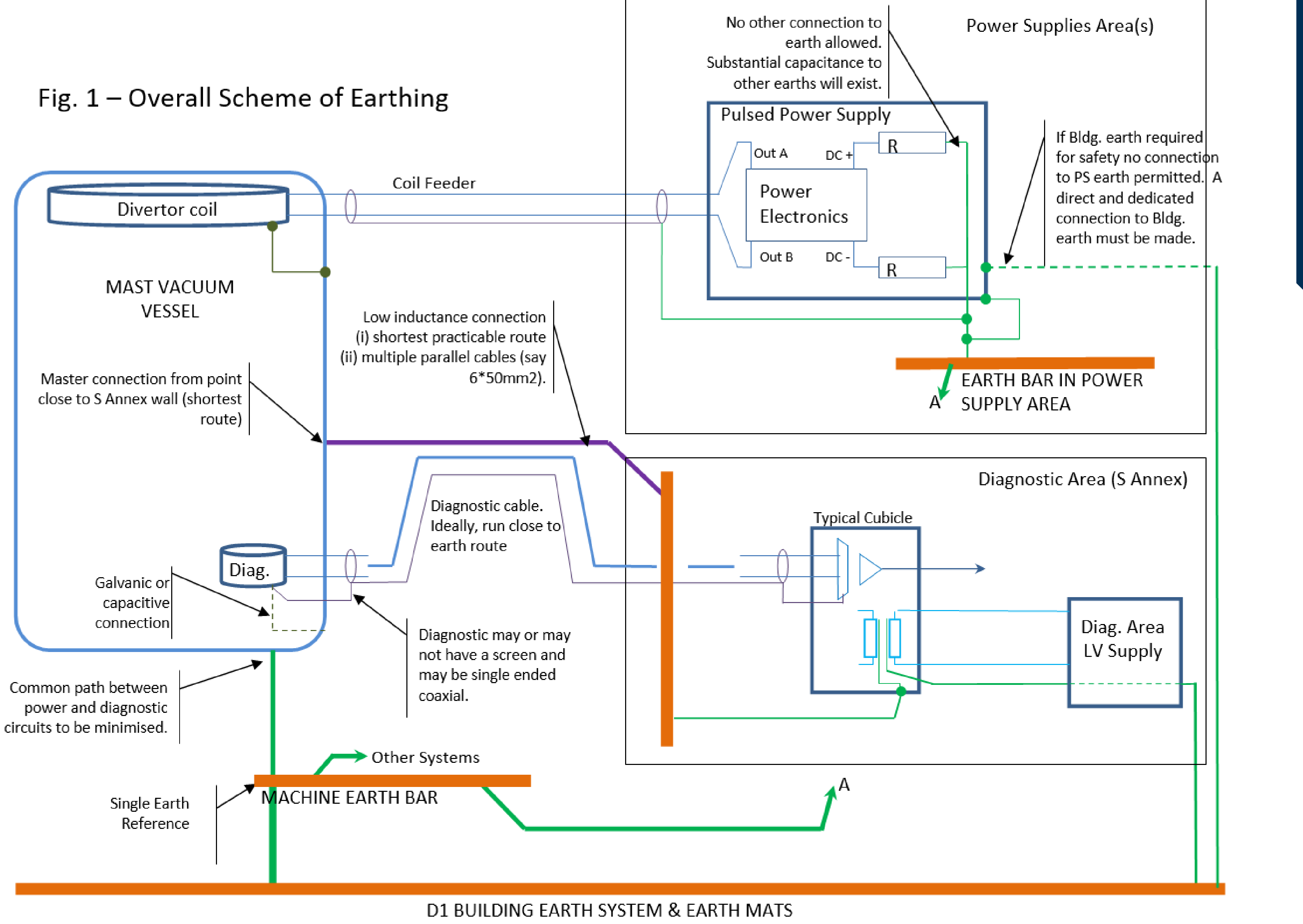
Fig. 1 – Overall Scheme of Earthing



<u>Overall Scheme of Earthing from the Earthing rule book!</u>

Engineering Challenges

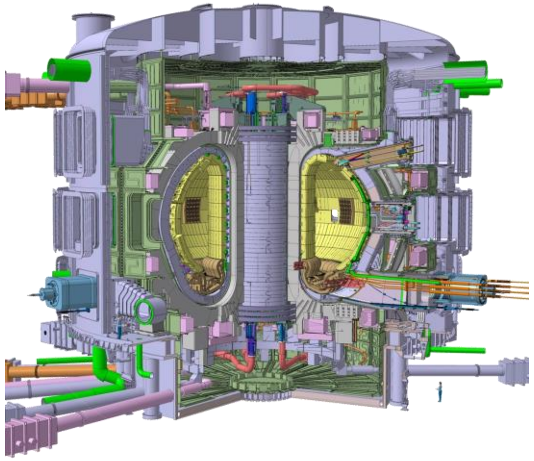
Fig. 1 – Overall Scheme of Earthing

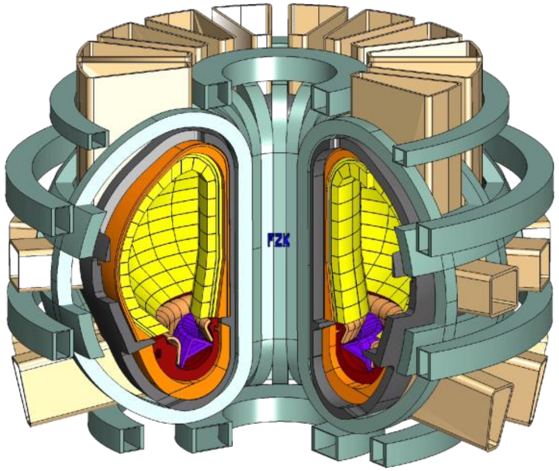


<u>Overall Scheme of Earthing from the Earthing rule book!</u>

Timeline of Fusion Research

UK Atomic Energy Authority





2025

ITER

France

2040

STEP

UK

2050

DEMO

Europe

Fusion is now in the ‘delivery era’

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Fusion needs integrated solutions

UK Atomic Energy Authority

Hot Fuels
JET

Training
Oxfordshire Advanced Skills

Component Testing
Fusion Technology Test Facilities

Remote Handling
Remote Applications in Challenging Environments

Computational Simulations
Computing Division

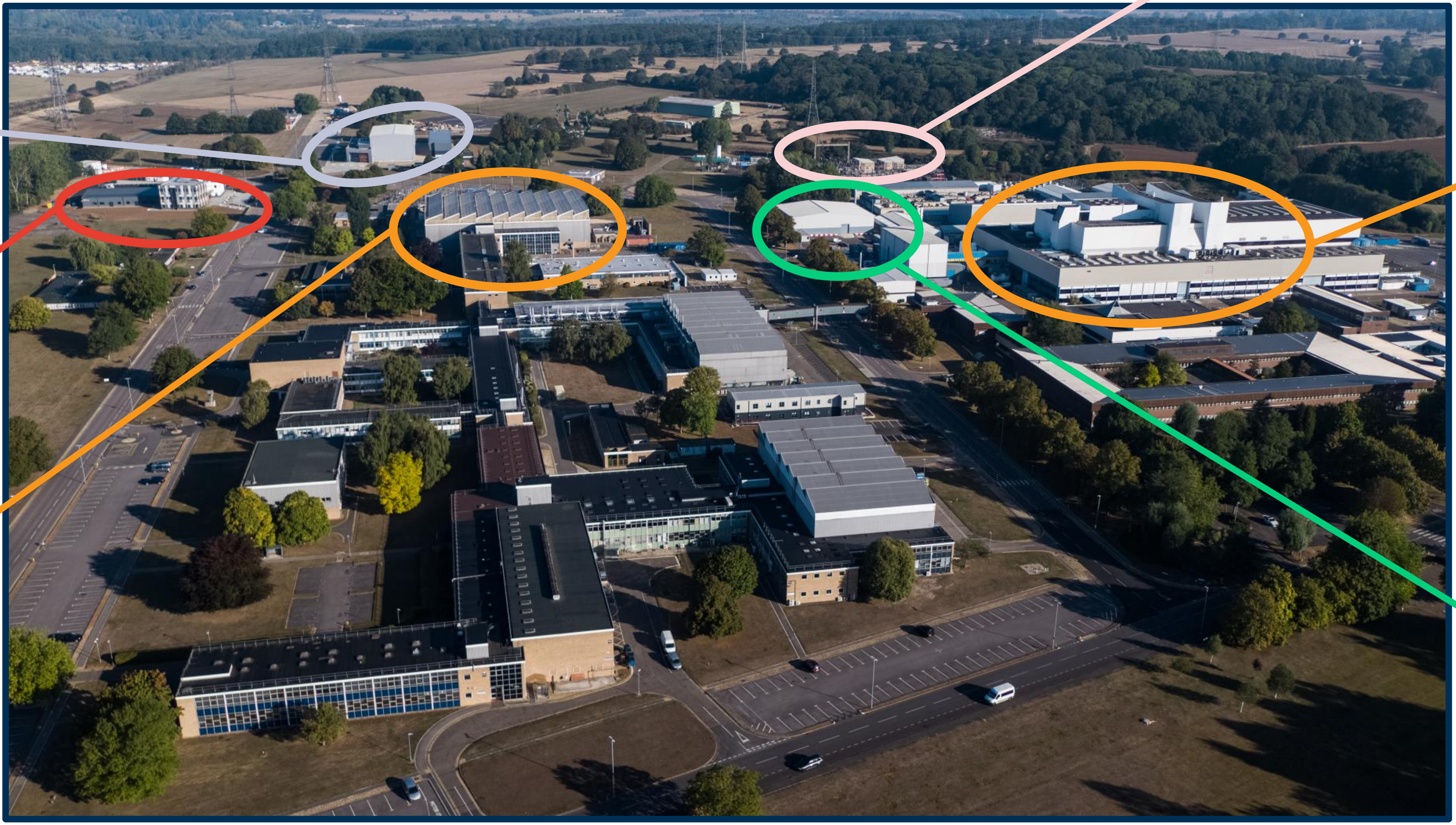
Materials Development
Materials Research Facility

Heat Exhaust
MAST Upgrade

Tritium Fuel Handling
Tritium Advanced Technologies

Engineering
Integrated Engineering

Culham Science Centre



H3AT
TRITIUM ADVANCED TECHNOLOGY

RACE

CAS

JET

MAST
Upgrade

MATERIALS
RESEARCH
FACILITY

UK Atomic
Energy
Authority

Why Fusion?

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Why Fusion?

Sustainable

Fusion produces no CO_2

Fully sustainable energy source

Environmentally responsible

No high level radioactive waste

Waste has a short half life

UK Atomic Energy Authority

Why Fusion?

Environmentally responsible

No high level radioactive waste

Waste has a short half life

Safe

No risk of a runaway reaction

Machine will be shielded

Why Fusion?

Safe

No risk of a runaway reaction

Machine will be shielded

Abundant

Deuterium fuel is in seawater

Tritium produced using Lithium

Why Fusion?

Abundant

Deuterium fuel is in seawater

Tritium produced using Lithium

Near-Limitless

Incredibly fuel efficient

‘Always on’, can be built anywhere

UK Atomic Energy Authority

Why Fusion?

Near-Limitless

Incredibly fuel efficient

'Always on', can be built anywhere

UKAEA’s Belief

UK Atomic Energy Authority

“We believe fusion energy can be an environmentally responsible part of the world’s energy supply in the second half of this century”

Shaping fusion power for the future - Mega Amp Spherical Tokamak (MAST) Upgrade summary video

0:16 onwards

Thank You for listening

Navdeep Mehay