ASC 24

1LOr1E-04

UK Atomic Energy Authority

Stuart Wimbush

STEP: Vision, status, direction and PPP

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Delivering fusion energy – the Spherical Tokamak for Energy Production

IEEE-CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition), Issue No. 57, Oct 2024. Presentation given at ASC 2024, Sept 2024, Salt Lake City, Utah, USA.

Spherical Tokamak for Energy Production

UK Atomic Energy Authority

> **Deliver a UK prototype fusion energy plant, targeting 2040, and a path to commercial viability of fusion.**

STEP Mission Statement

UKAEA fusion pathway

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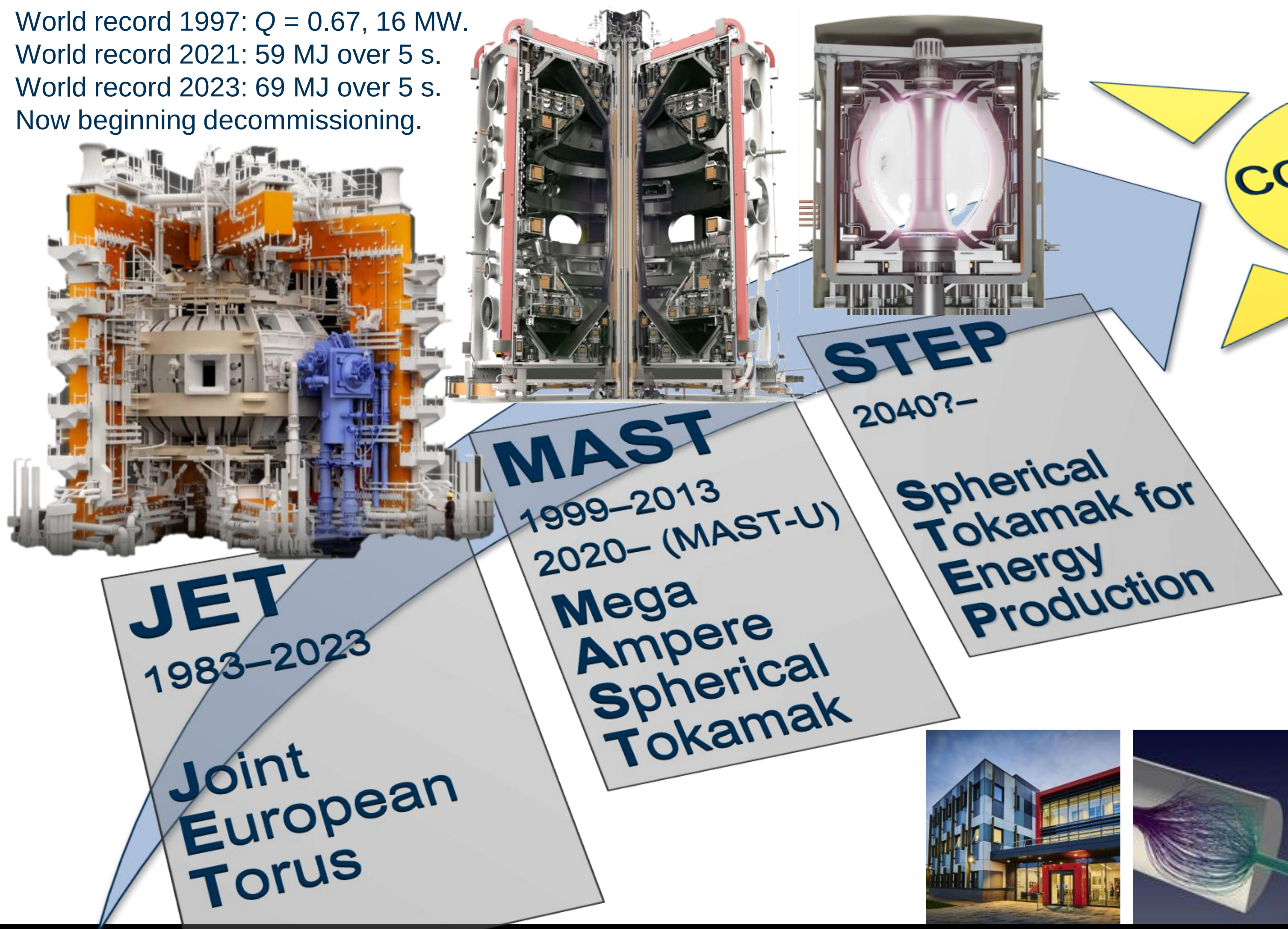
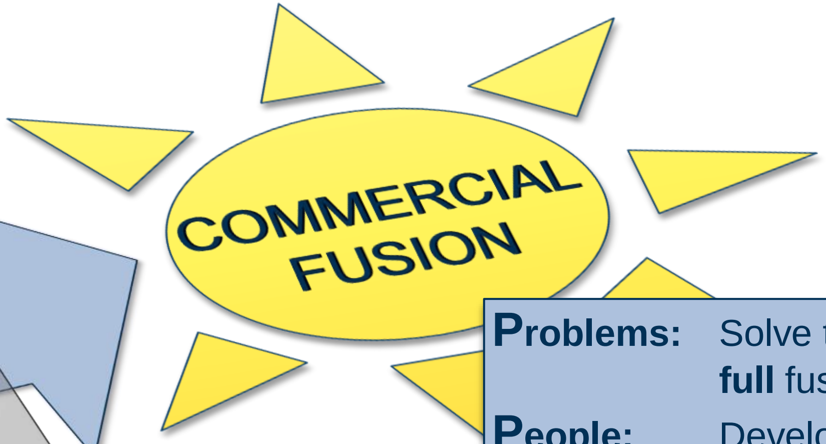
World record 1997: Q = 0.67, 16 MW.
World record 2021: 59 MJ over 5 s.
World record 2023: 69 MJ over 5 s.
Now beginning decommissioning.





Problems:	Solve the challenges across the **full** fusion life-cycle.
People:	Develop skilled, innovative people needed to deliver fusion.
Prosperity:	Drive UK economic growth **and support industry**.
Product:	Enable the design, delivery and operation of power plants **with partners**.
Place:	Create clusters that accelerate fusion and related technologies.

Skills Digital RACE MRF H3AT FTF

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STEP on the global fusion pathway

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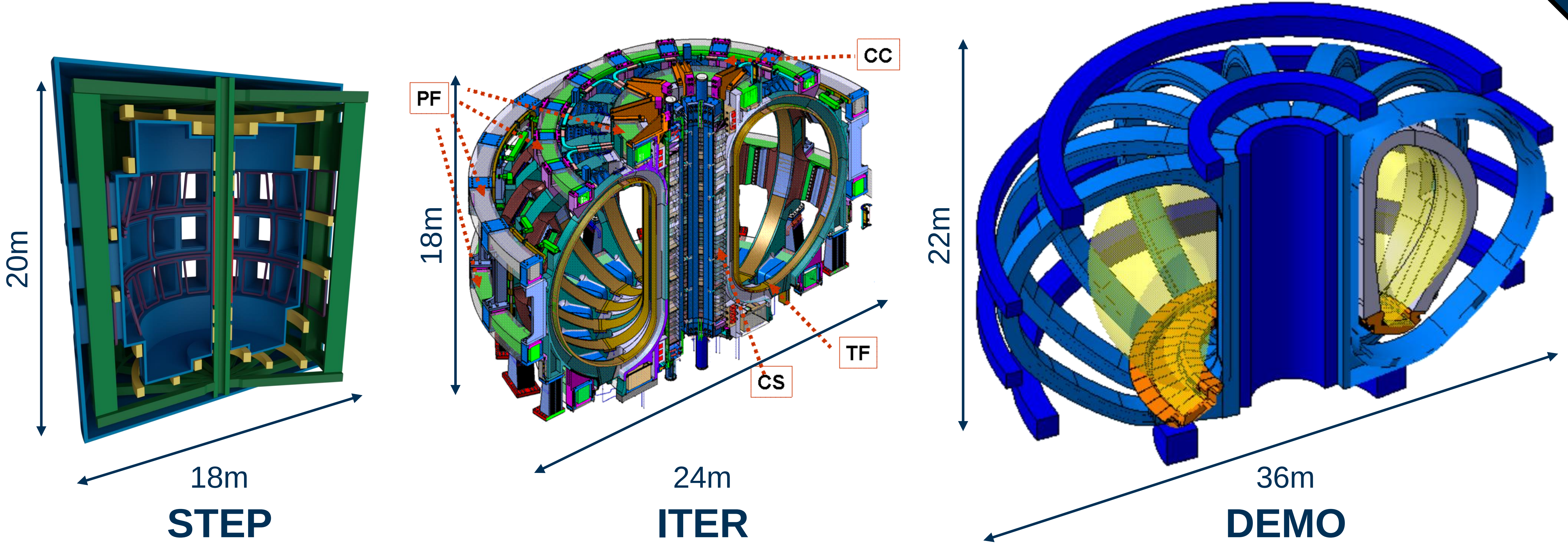
Relative sizes in terms of the magnetic cage:



The functionality of DEMO at a size less than ITER thanks to HTS (and the spherical tokamak).

STEP timeline

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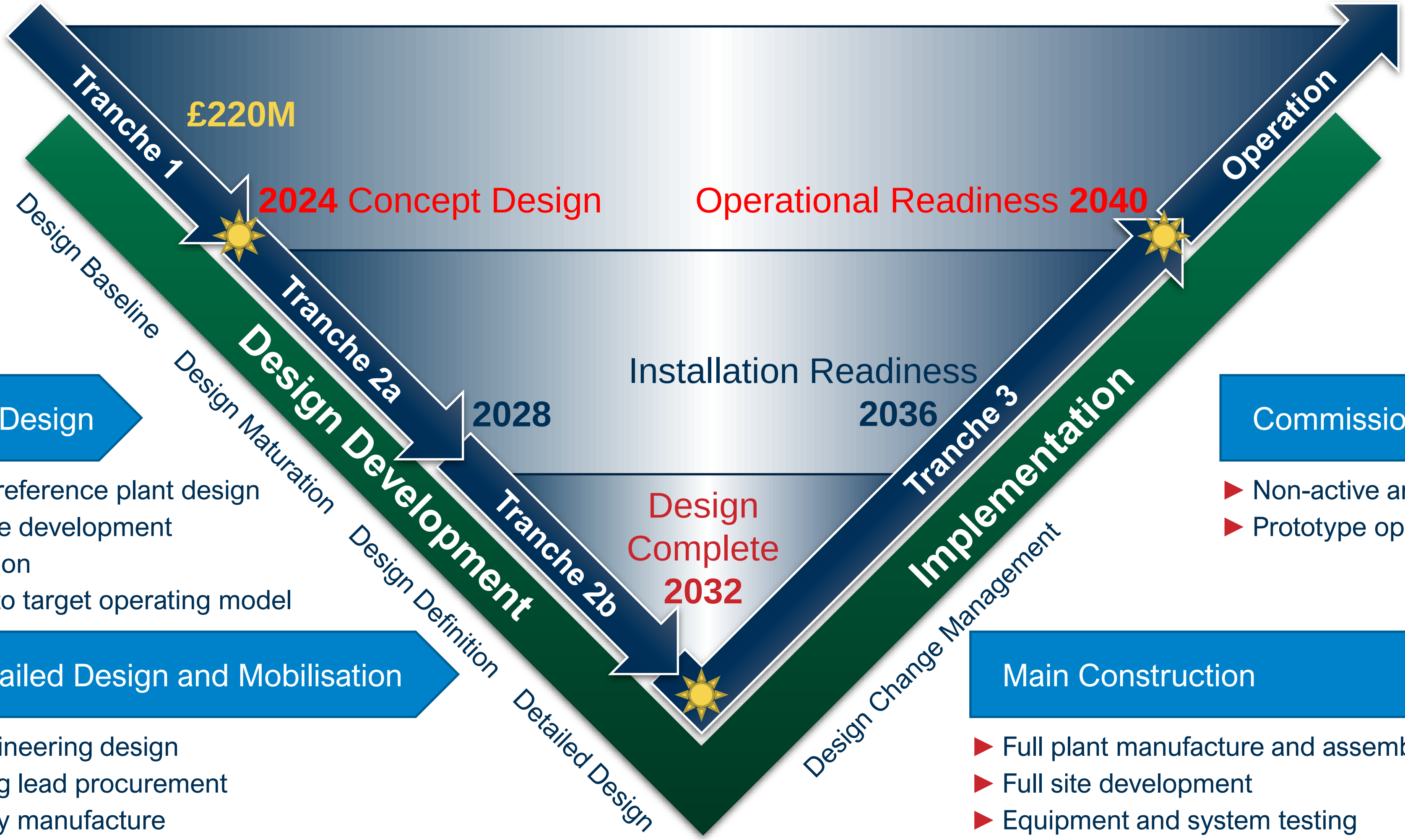

Concept Design

- Concept / reference plant design
- Programme development
- Site selection
- Transition to target operating model

Detailed Design and Mobilisation

- Engineering design
- Long lead procurement
- Early manufacture
- Site development

Commissioning and Operations

- Non-active and active commissioning
- Prototype operations

Main Construction

- Full plant manufacture and assembly
- Full site development
- Equipment and system testing

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STEP machine-defining characteristics

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STEP is being designed as a **prototype power plant**, not a research reactor.

- We have a **whole-plant approach** to design and (de)commissioning: regulation, site, waste handling, …
- It will be **grid-connected**, delivering 100 MW_e net electricity to the national grid (~1 GW fusion power).
- It will have high availability supported by a **realistic maintenance schedule**.
- It will be **fuel self-sufficient**, breeding more tritium than it consumes.

Concerning **magnets**, these high-level requirements have far-reaching implications.

- A need for **magnet (central column) replacement** to mitigate radiation damage.
- A **jointed TF coil** architecture to enable a vertical maintenance strategy.

The overall design process is **plasma-led**, not magnet-led.

Confirmed site of the future STEP Power Plant at West Burton in Nottinghamshire.

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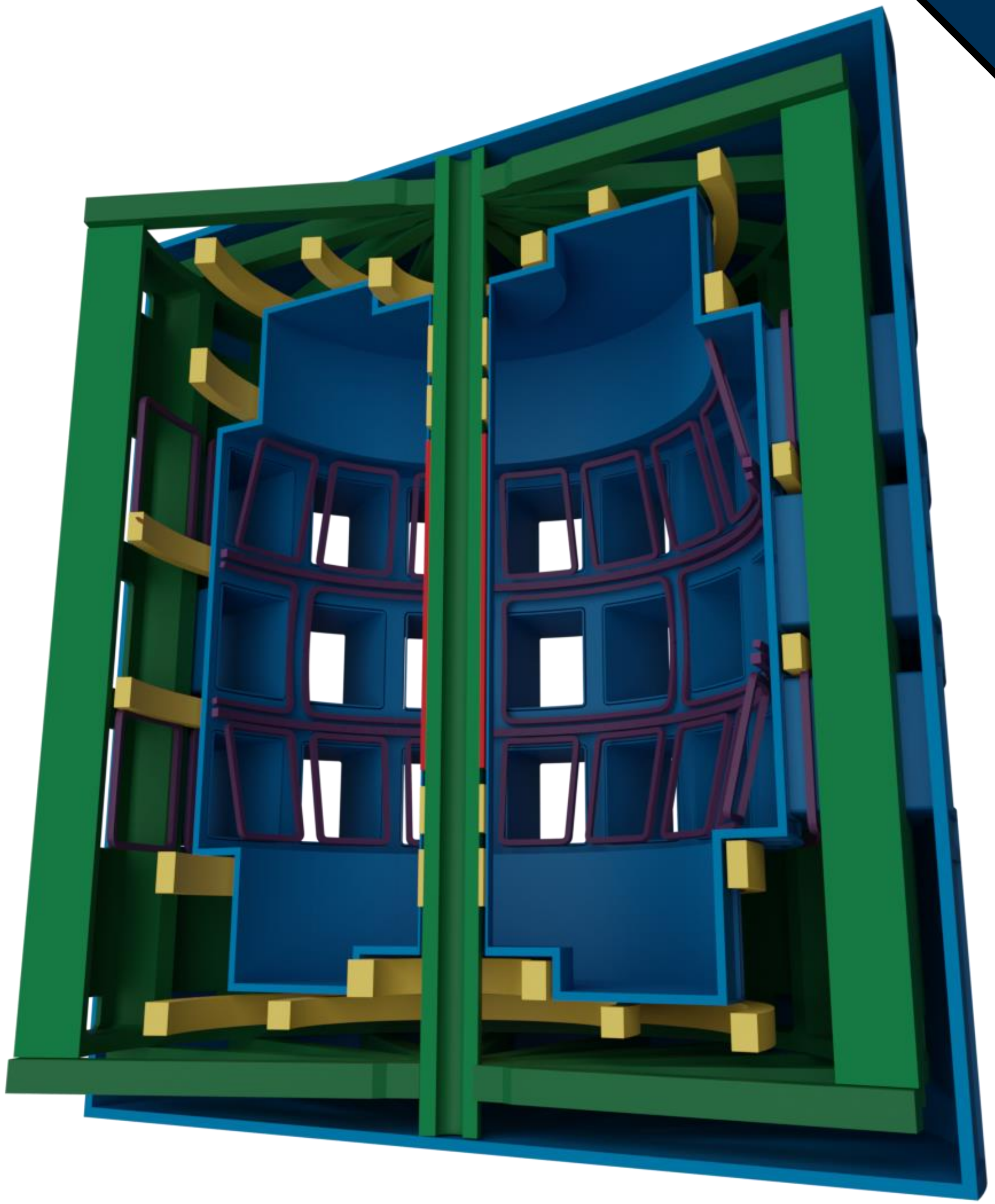
STEP magnet systems

Overview

- Toroidal field (TF) coils
- Poloidal field (PF) coils
- Central solenoid (CS)
- Control coils (CC)
- Thermal shield
- Additional scope
  - ❖ Cryostat vacuum vessel
  - ❖ Inter-coil structures
  - ❖ Cold mass supports



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STEP magnet systems

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Toroidal field (TF) coils

- 16 ‘picture-frame’ shaped TF coils.
  - Approximately 20 m × 10 m each.
- Segmented coils incorporating remountable joints.
  - Enables replacement of central column and vertical access to in-vessel components.
- Vertically stacked HTS tape cable configuration.
  - No twisting, no transposition.
  - ~ 300 tapes per cable, 40 turns, 20 K operation.
- High centre column current density demands.
  - ~ 90 kA operating current.
  - ~ 60 MA centre column current.
  - ~ 20 GJ stored energy.
  - Peak field on the tape ~ 17 T.

3J-ML-Or2A-06 Sam Tippetts
Quench protection analysis and strategy for the STEP TF coils

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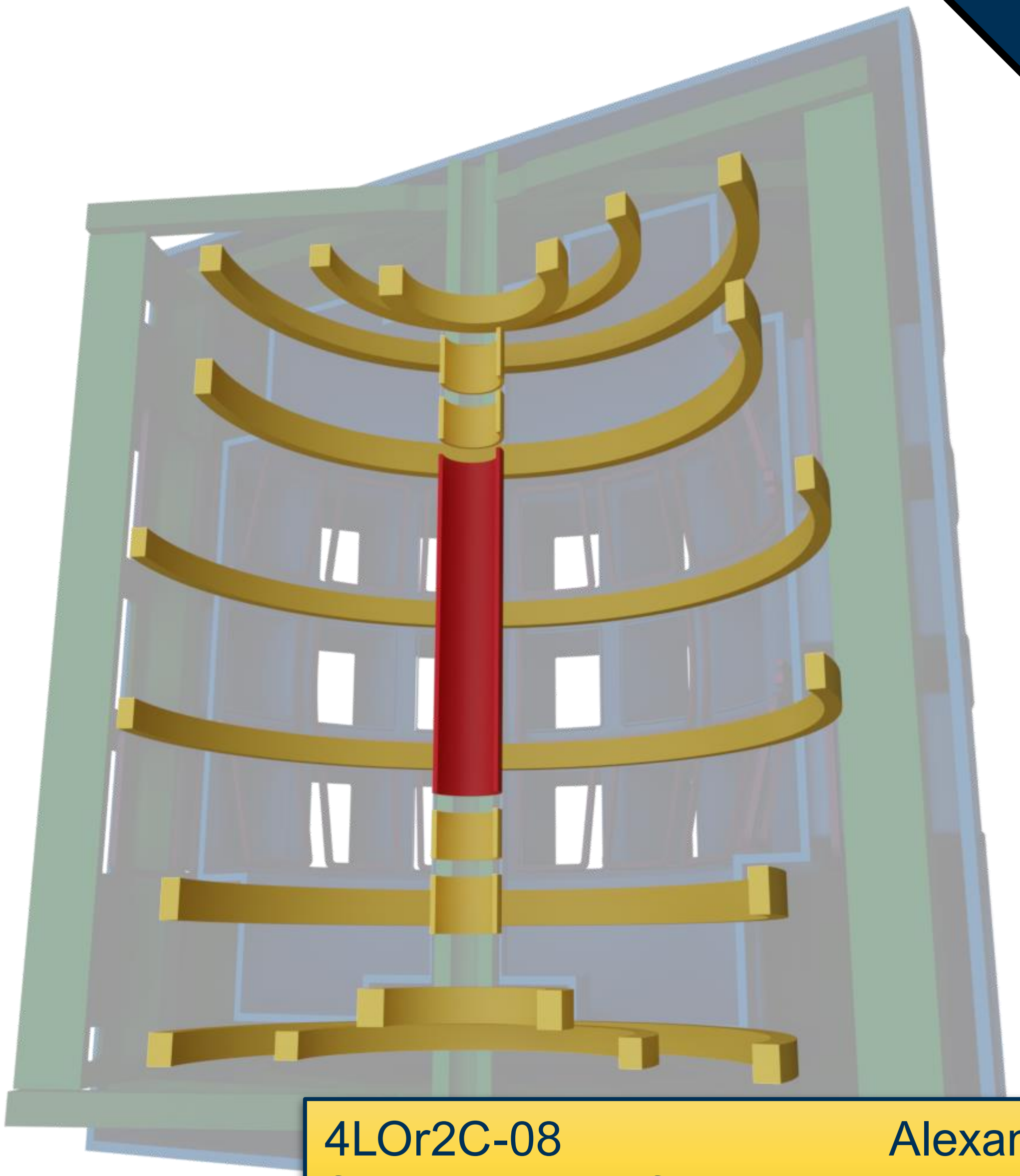
STEP magnet systems

Poloidal field (PF) coils

- 14 circular PF coils (including 4 'shaping' coils).
  - Diameters ranging from ~ 2 m to ~ 17 m.
  - Likely to require on-site manufacture.
- Variable requirements, dc and ac operation.
  - AC loss tolerant designs needed.

Central solenoid (CS)

- Induces current in the plasma.
  - Rapid discharge from peak current to zero.
- Cryocooled resistive (copper) design.
  - Highly constrained spatial allocation.



4LOr2C-08 Alexander Petrov
Solenoidal coils on STEP: challenges and initial solutions

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The programme in terms of risk

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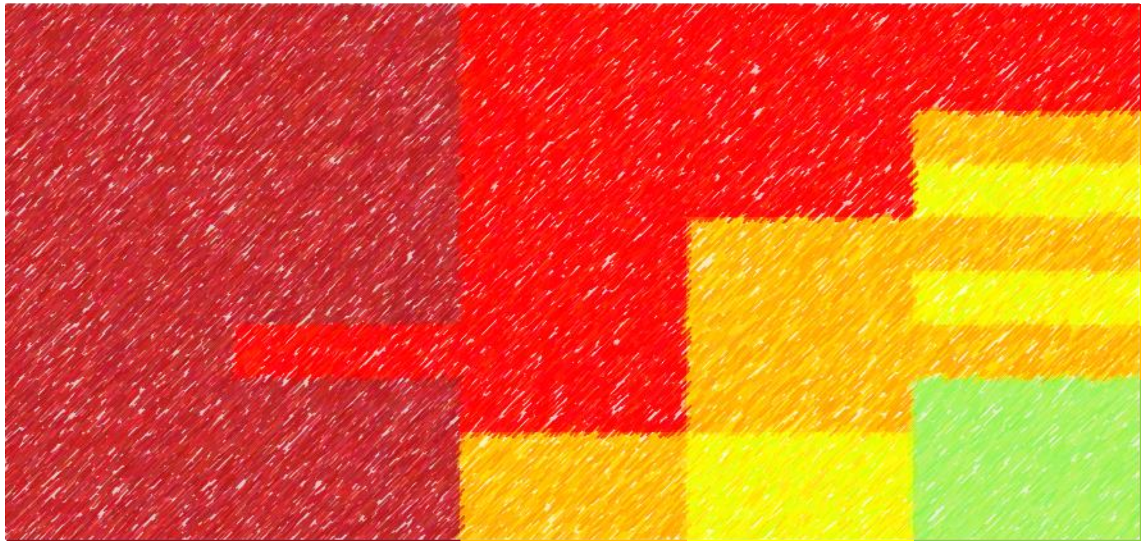
STEP will carry risk throughout the programme in order to move forwards and it will operate at risk.

In terms of public-private partnership, STEP will carry the risk in order to enable industry partners to participate.

From a magnets perspective (top 10):

Challenge — **2020** **2024** **2028** **2032** ··· **2040**

HTS radiation tolerance
Insulation radiation tolerance
High current density HTS cables
Fast ramping HTS magnets
Quench detection and protection
Current lead integration
Inter-coil support structure
HTS supply chain
Insulation manufacturing / assurance
Integrated coil set engineering tools



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Public-private partnership

STEP's goal is a pathway to commercial viability of fusion. We need commercial partners to succeed.

UKAEA has around 2,500 staff.

- **Hinkley Point C:** (an EDF commercial fission reactor presently under construction)
  22,000 workers sourced from 3,600 companies by the end of 2021.
  During construction, 74,000 people are expected to work on the project.

- **Apollo space programme:**
  400,000 people involved.
  Considering scientists and engineers: 15% from NASA, 85% from industry.

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Public-private partnership

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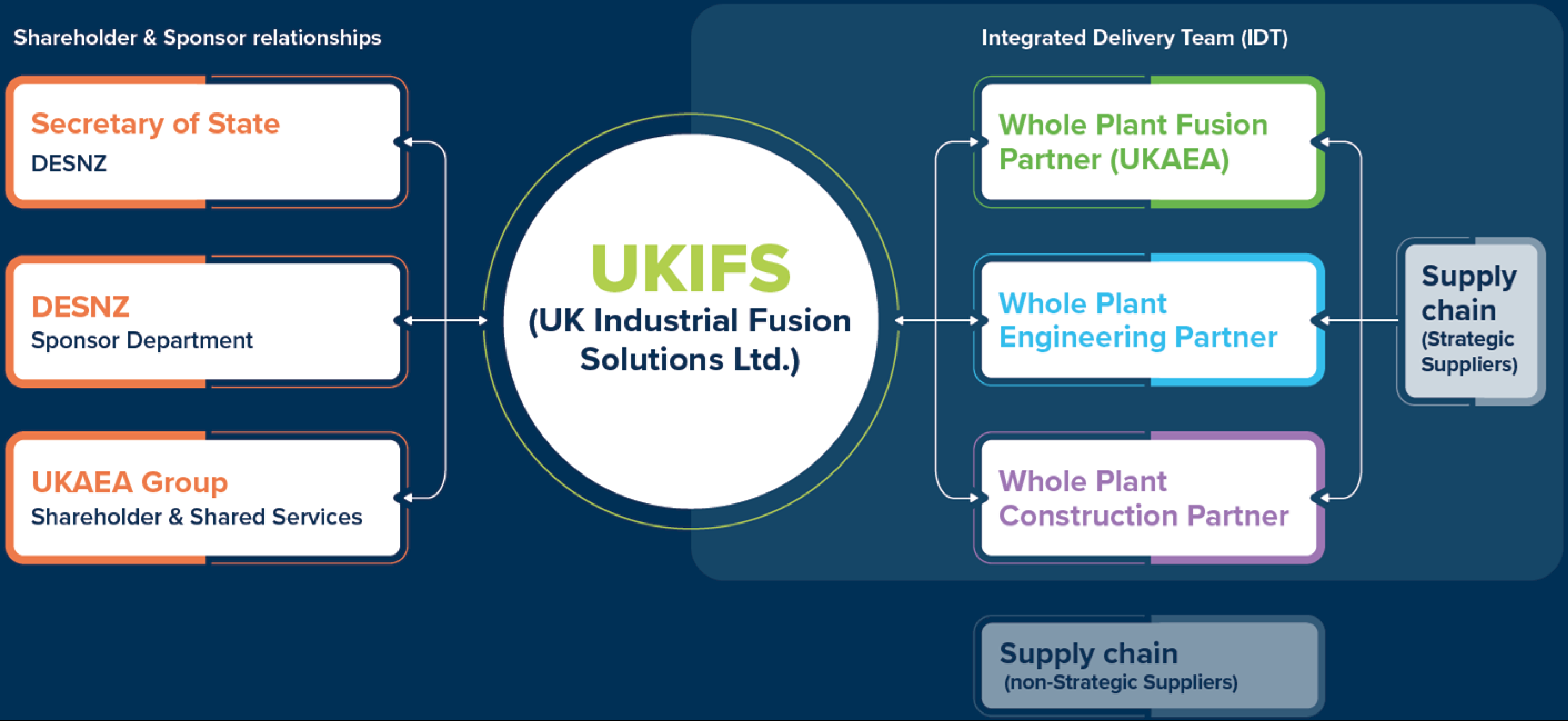

Public-private partnership – programme

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UK Atomic Energy Authority

Department for Energy Security & Net Zero

Department for Levelling Up, Housing & Communities

MIDLANDS ENGINE HM Government

Nottinghamshire County Council

Bassetlaw DISTRICT COUNCIL — North Nottinghamshire —

West Lindsey DISTRICT COUNCIL

Lincolnshire COUNTY COUNCIL

Midlands Connect Transport | Investment | Growth

East Midlands Combined County Authority

EAST MIDLANDS DEVELOPMENT COMPANY

Greater Lincolnshire Local Enterprise Partnership

D2N2 Derby Derbyshire Nottingham Nottinghamshire

The University of Nottingham

ERA ENERGY RESEARCH ACCELERATOR

ARELI DEVELOPMENTS

AMION CONSULTING

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Public-private partnership – magnets

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- Small coils
- Short cables
- Magnet materials

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UKRI Science and Technology Facilities Council
CVŘ Research Centre Řež
HZDR
mi2-factory
NATIONAL COMPOSITES CENTRE

4MOr2B-06 Will Iliffe
STEP's progress understanding REBCO coated conductors in the fusion environment
1MPo1D-02 Simon Chislett-McDonald
Critical current measurements of 4 MeV He+ irradiated REBCO during Co-60 gamma irradiation

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Summary

STEP will build a prototype fusion powerplant in partnership with industry and develop a pathway to commercial deployment of fusion power.

We are pursuing a whole-plant approach from the outset.

The programme structure is organised into a public-private partnership model drawing on a majority of industry involvement. Thought has been given to enabling industry participation at a wide range of levels and across a wide range of sectors.

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STEP

FORWARD TO FUSION