UK Atomic Energy Authority

STEP

Whole Plant Partners engagement

22 February 2023

UK Atomic Energy Authority

Welcome

Sarah Palmer LLM MCIPS

Head of STEP Strategic Supplier Relationships

UK Atomic Energy Authority

The delivery model discussed is subject to approval.

UKAEA reserves the right to:

- Postpone or cancel the planned procurement activity at any stage and at any time.
- Amend, clarify, add to or withdraw all or any part of this document at any time.

Welcome all!

UK Atomic Energy Authority

- Housekeeping
  - No alarms planned
  - Toilets in the lobby and portaloos outside!
- The technical sessions will be recorded but not the 1-2-1s
- We'll send out the slide deck and audio recording after today's session
- Our focus is on technical challenges – providing insight on these
- And finally, anything commercial is outside of today's scope

Agenda for the afternoon

UK Atomic Energy Authority

1.00-6.40pm: Presentations, Q&A and 1-2-1s			
1.00	Welcome	Welcome, introductions and housekeeping	Sarah Palmer
1.10	Programme overview	Our vision for the programme and its delivery	Paul Methven
1.40-4.30pm: Our technical challenges			
1.40	Architect engineer challenge	An overview of the emerging and intricate first of a kind integrated facility design.	Chris Waldon
2.00	New technology challenge	Establishing a supply chain capability for a new consumable core technology.	Jenny Cane
2.20	Scarce technology challenge	Co-designing a supply chain to match the demand.	James Treadgold
2.40	*Refreshments*	*Delegates will be able to sign up for 1-2-1 sessions with the technical teams to further delve into detail.*	
3.20	Data and digital challenge	An exploration of the needs of the programme in terms of digital and data	Martin Aston
3.40	Facility challenge	Progressing the infrastructure development as the plant and regulatory design becomes clear	Mark Kisbey Ascott
4pm	Field assembly and remote maintenance challenge	Meeting the demands for high performance within tight technological, programme and spatial constraints	Roel Verhoeven
4.20	Procurement process	So, what happens next...?	Sarah Palmer
4.30	Close	For those not participating in 1-2-1 sessions the event ends.	
4.40 - 6.40pm: 1-2-1 sessions with the technical teams			
4.40 - 6.40pm	Engineering Partner & Construction Partner Surgeries	20 minute, 1-2-1 sessions with the STEP technical team.	

UK Atomic Energy Authority

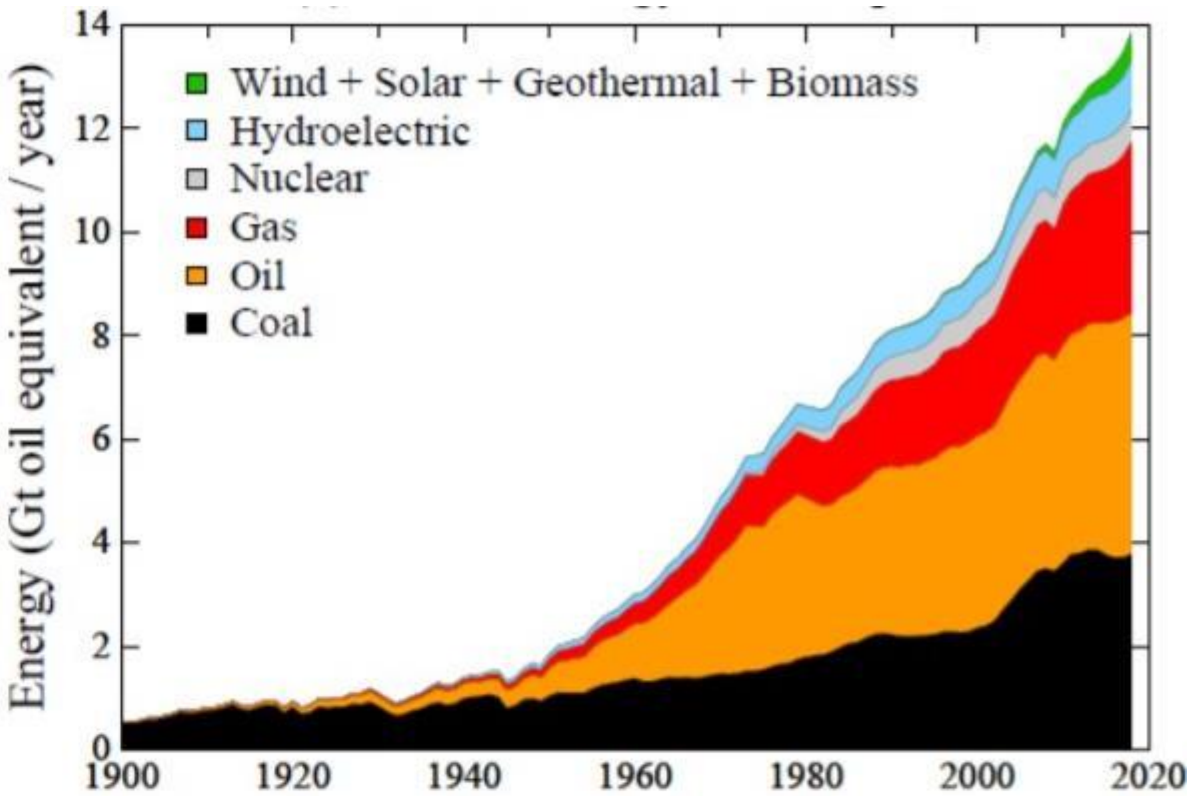
The STEP Programme

Paul Methven CB

STEP Programme Director

Global Crises meets National Opportunity

UK Atomic Energy Authority



Fusion Strategy to STEP Mission

Department for Business, Energy & Industrial Strategy

UK Atomic Energy Authority

1. “For the UK to demonstrate the commercial viability of fusion by building a prototype fusion power plant in the UK that puts energy on the grid

2. For the UK to build a world-leading fusion industry which can export fusion technology around the world in subsequent decades”

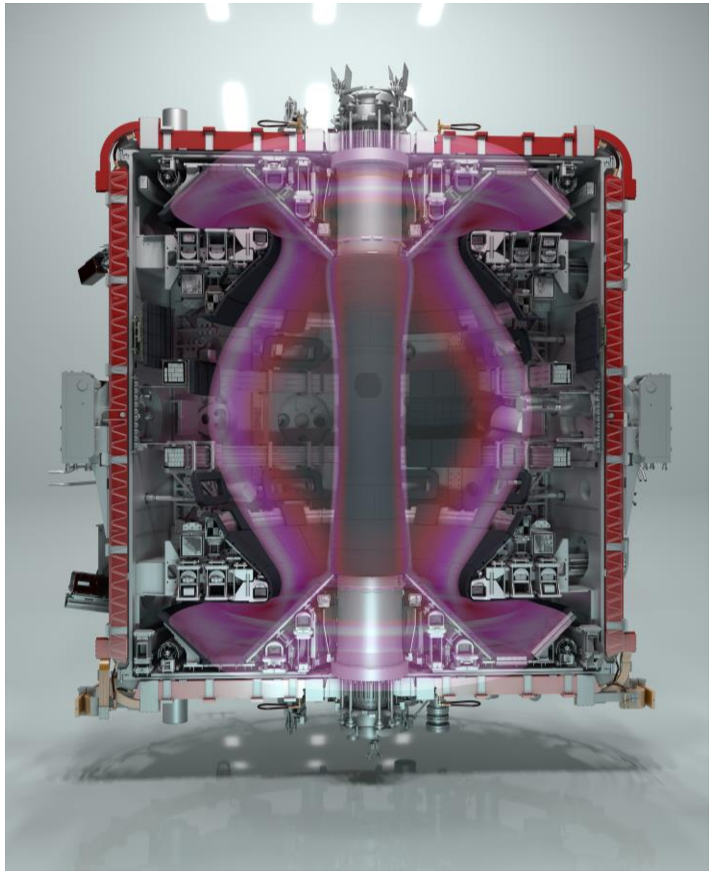
Deliver a UK prototype fusion energy plant, targeting 2040, and a path to commercial viability of fusion.

Towards Fusion Energy

The UK Government’s Fusion Strategy

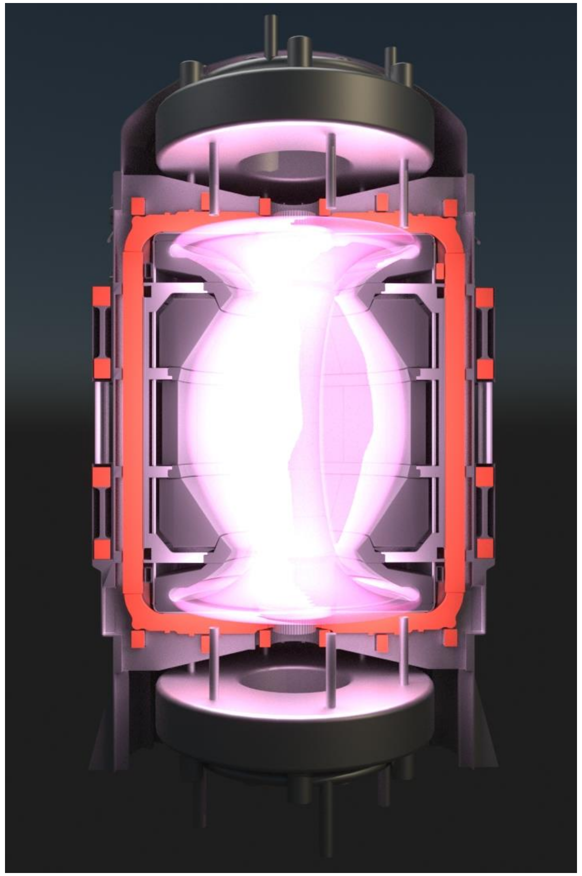
October 2021

Enable Low Cost
The Spherical Tokamak



MAST-U

- Cored apple shape
- More efficient magnetic solution
- Plus better maintenance architecture

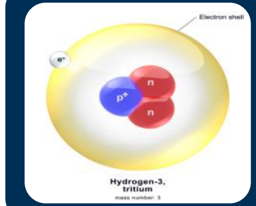


STEP

SPP Measures of Effectiveness

Power

- Confidence in delivering 100MWe net power



Fuel

- Confidence in delivering tritium self sufficiency

Maintainability

- Estimated operating cycle including outage durations, and confidence in those estimates

Development Flexibility

- Ability to capture data
- Ability to support developments for subsequent commercial plant

Safety & Environment

- Confidence that risks can be demonstrated as ALARP
- Delivering with minimum impact

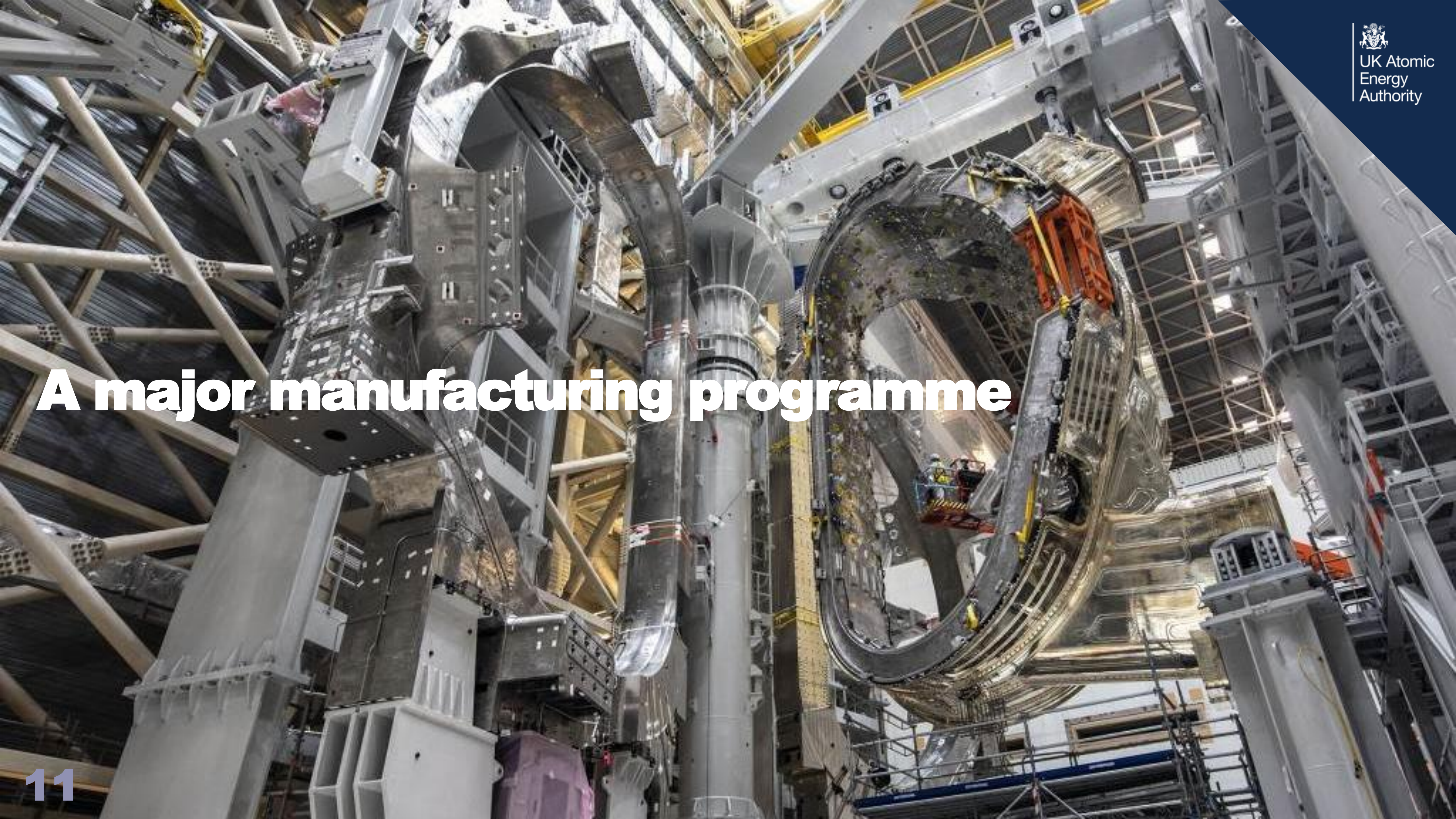
Schedule

- Total Programme Schedule, and confidence in the estimate

Cost

- Total Programme Cost, and confidence in the estimate
- Inferred cost of commercial plant and LCOE (to be developed later)

A major manufacturing programme



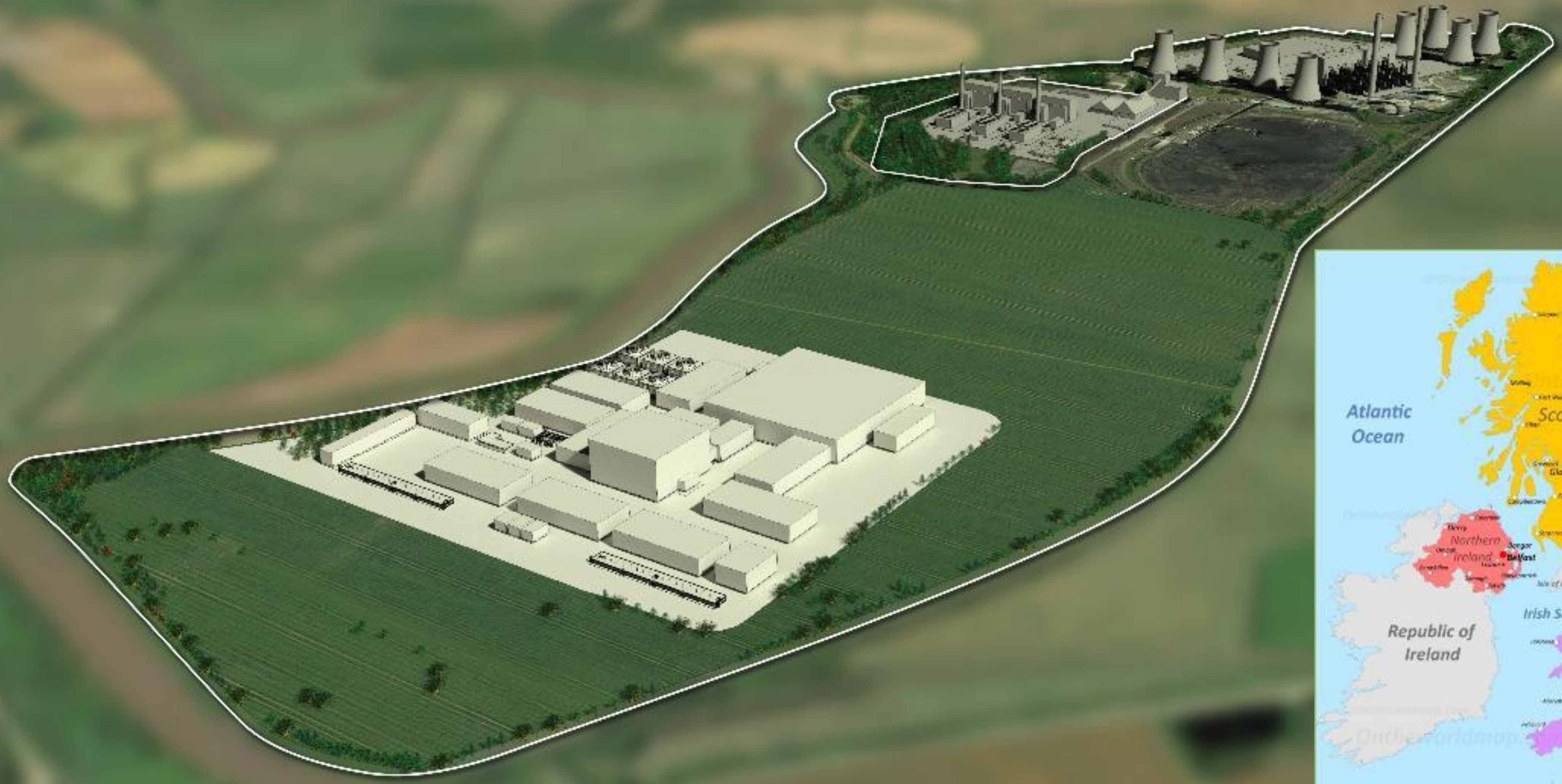
A major infrastructure & re-generation programm

Becoming a major programme

UK Atomic Energy Authority

STEP site – From fossil to fusion

UK Atomic Energy Authority



This is an indicative image of how the STEP prototype plant may look

UK Atomic Energy Authority

STEP high-level schedule

2021 | 2025 | 2030 | 2035 | 2040

Concept (till 3/24)

- 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

Main Construction

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

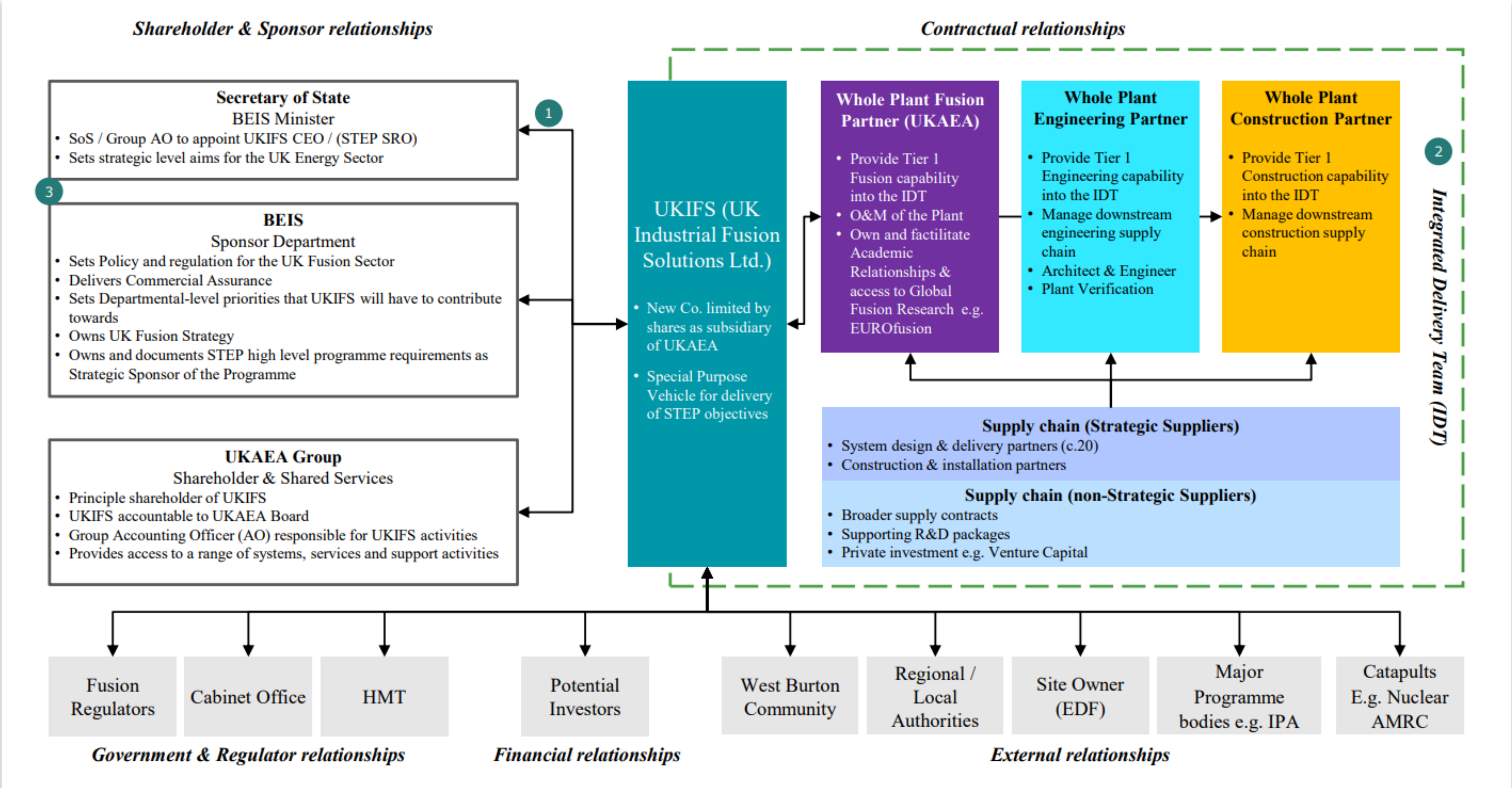
Commissioning and Operations

- Non-active and active commissioning
- Prototype ops

TOM Strategy | Enterprise Model

In draft – will change

UKIFS operates in an **increasingly complex stakeholder ecosystem**. The model below sets out **key entities that interface with UKIFS** during the delivery of STEP.

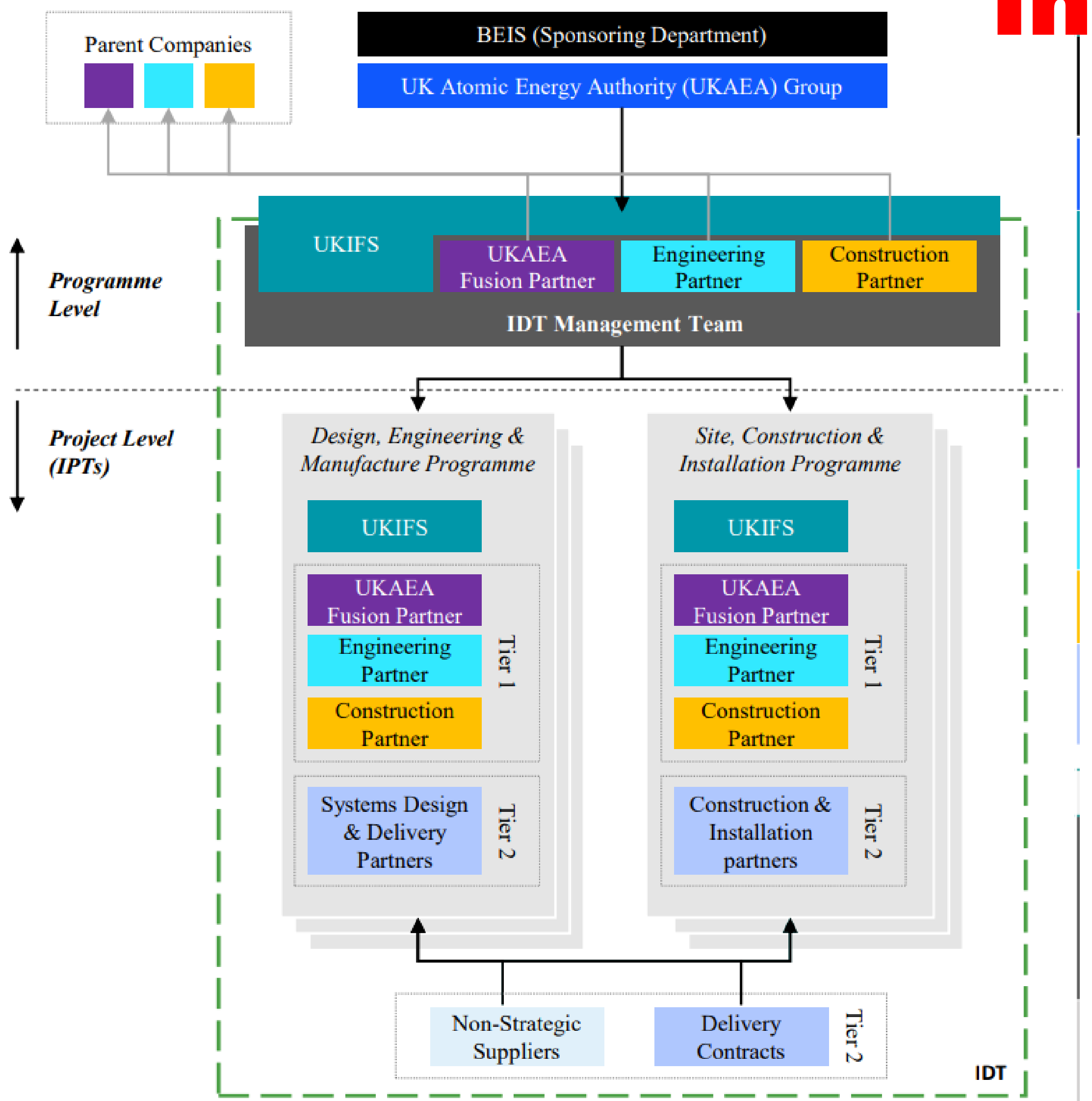


Model notes:

1. Connections between UKIFS and all other entities do **not** represent governance / reporting lines, rather they represent working interfaces.
2. The **IDT** refers to the 3 partner organisations (Engineering, Construction and Fusion / UKAEA) who will work under a multi-party collaboration agreement. It also includes some strategic & non-strategic suppliers.
3. TBC how BEIS / DESNZ roles interface with UKEA

In draft - will change

UK Atomic Energy Authority



- **Build the collective capability** to deliver a world first prototype fusion plant, leaving a legacy industrial capability to take forward commercial fusion:
  - Build capability at the system level (the key level in the future supply chain from which critical fusion systems will be designed, manufactured, exported)
  - Build capability at the plant / integrator level
- Bring **public and private sector together** to build that capability, upskilling industry in the process:
  - Public sector provides the deep fusion concept design experience in the early stages, and operating experience in mid to later stages
  - Private sector provides high quality engineering, manufacturing and complex infrastructure, learns how to apply that to the fusion task
- **Source industry partners** that:
  - can bring the right spectrum of capabilities across a complex engineering programme lifecycle, that will develop fusion capability through STEP, and that will stay in fusion
  - Lead and co-ordinate those capabilities to deliver the programme on behalf of Gov via the new single purpose body, UKIFS
- **Operate UKIFS efficiently**:
  - Leverage the capabilities of industry
  - Develop the programme with full participation of industry, but UKIFS decides on the key points
  - Staff UKIFS efficiently with:
    - Core staff – in reserved roles such as many senior exec, finance and many commercial posts
    - Secondees from the partners where appropriate

Architect Engineer

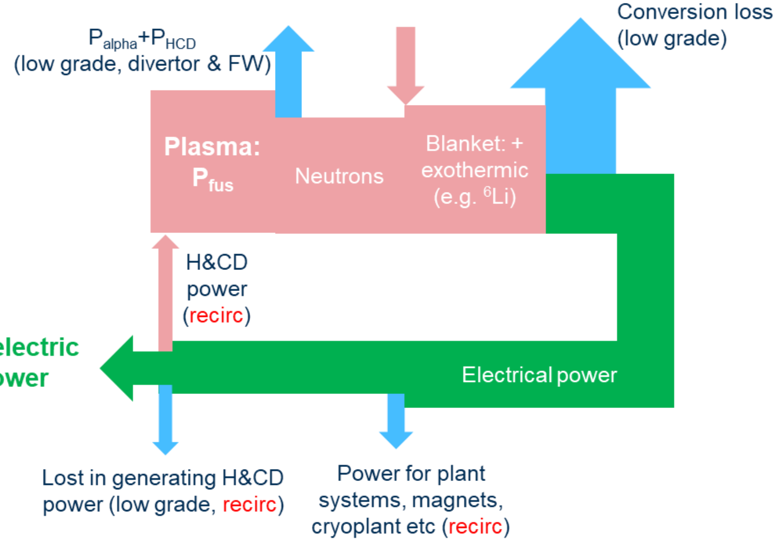
Chris Waldon FREng, FRSA, CEng FIMechE

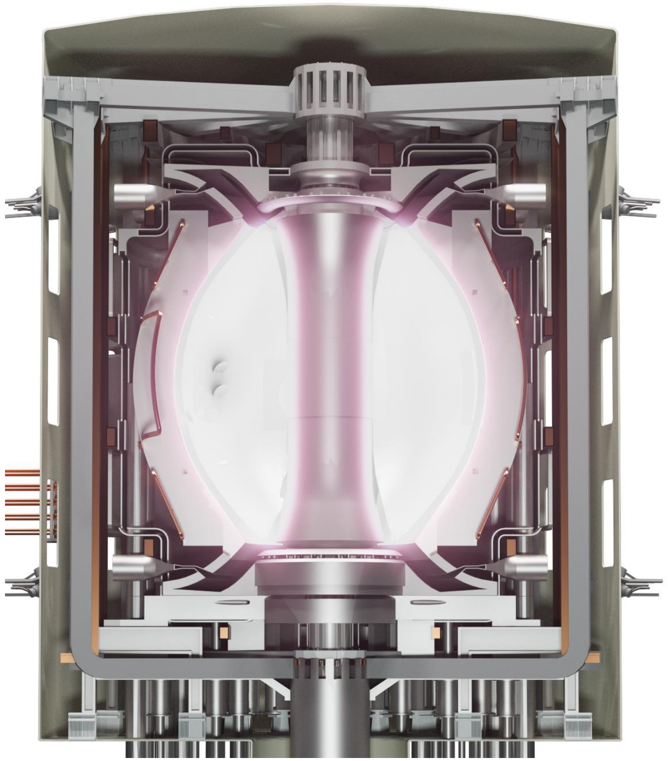
STEP Deputy Director

Why a Spherical Tokamak?

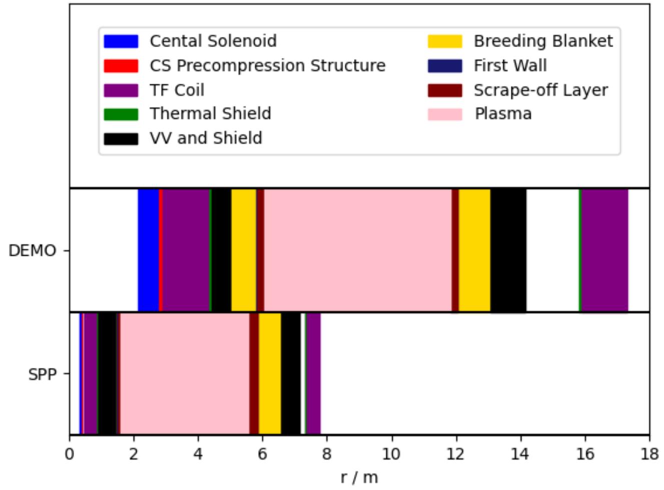
UK Atomic Energy Authority

$Q_{Engineering}$ & High bootstrap fraction

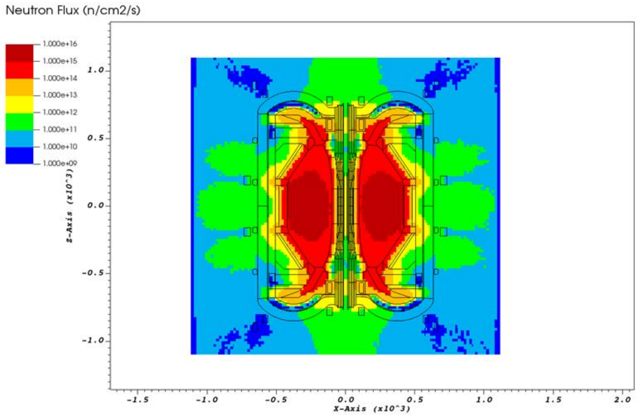




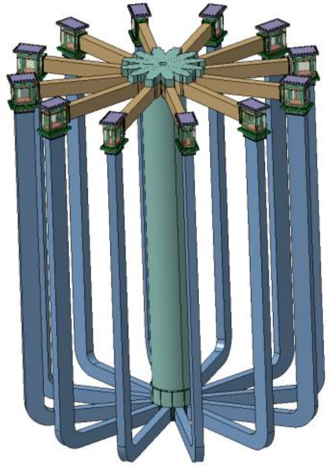
Reduced radial build (& Cost)



Technology proximity to CR



Accessibility & Maintenance

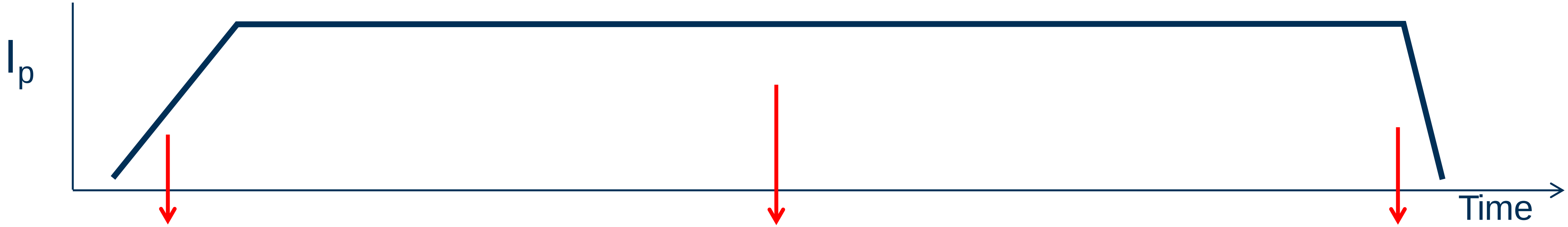


Concept provides stimulus and focus on integrated solutions

The Trade Space

STEP resolves a highly complex trade space by making informed compromises that balance operational performance with safety, risk, cost and programme schedule

Integration in time



Ramp-up	Flat-top	Ramp down
➢ Exhaust solution different ➢ Power from grid	➢ Control, self-organisation, power ➢ Exhaust integration	➢ Avoid disruption ➢ Exhaust solution different

Over a pulse: start-up, burn phase, ramp down, pulse length, control

Over neutron dose: material and component performance change

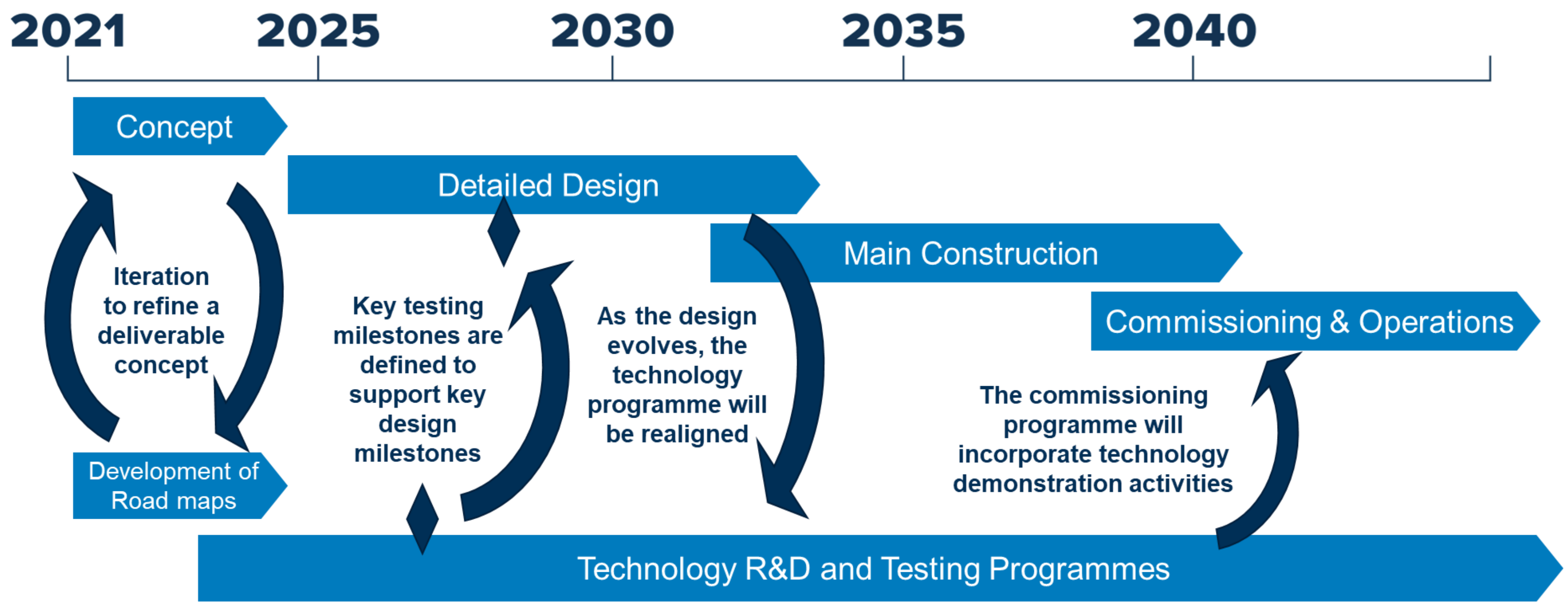
Over design and build: coherent integrated concept

Over operational programme: plasma scenario & control development; operational phases

Pre-CDA → CDA → EDA → Construction → Commission → Operation phases

The Programme

A detailed programme is being developed to deliver net power demonstration in the early 2040's, which includes provision for enacting the technology development outlined in each roadmap.



Design and Technology streams will be run in parallel, with each planned around the success of the other.

Milestones and gate reviews will be used to maintain alignment and adjustments will be made to incorporate favourable and unfavourable results in both directions.

Evolution of T1 approach

Safety & Environment
- Confidence that risks can be demonstrated as ALARP
- Delivering with minimum impact

Power
- Confidence in delivering 100MWe net power

Fuel
- Confidence in delivering tritium self sufficiency

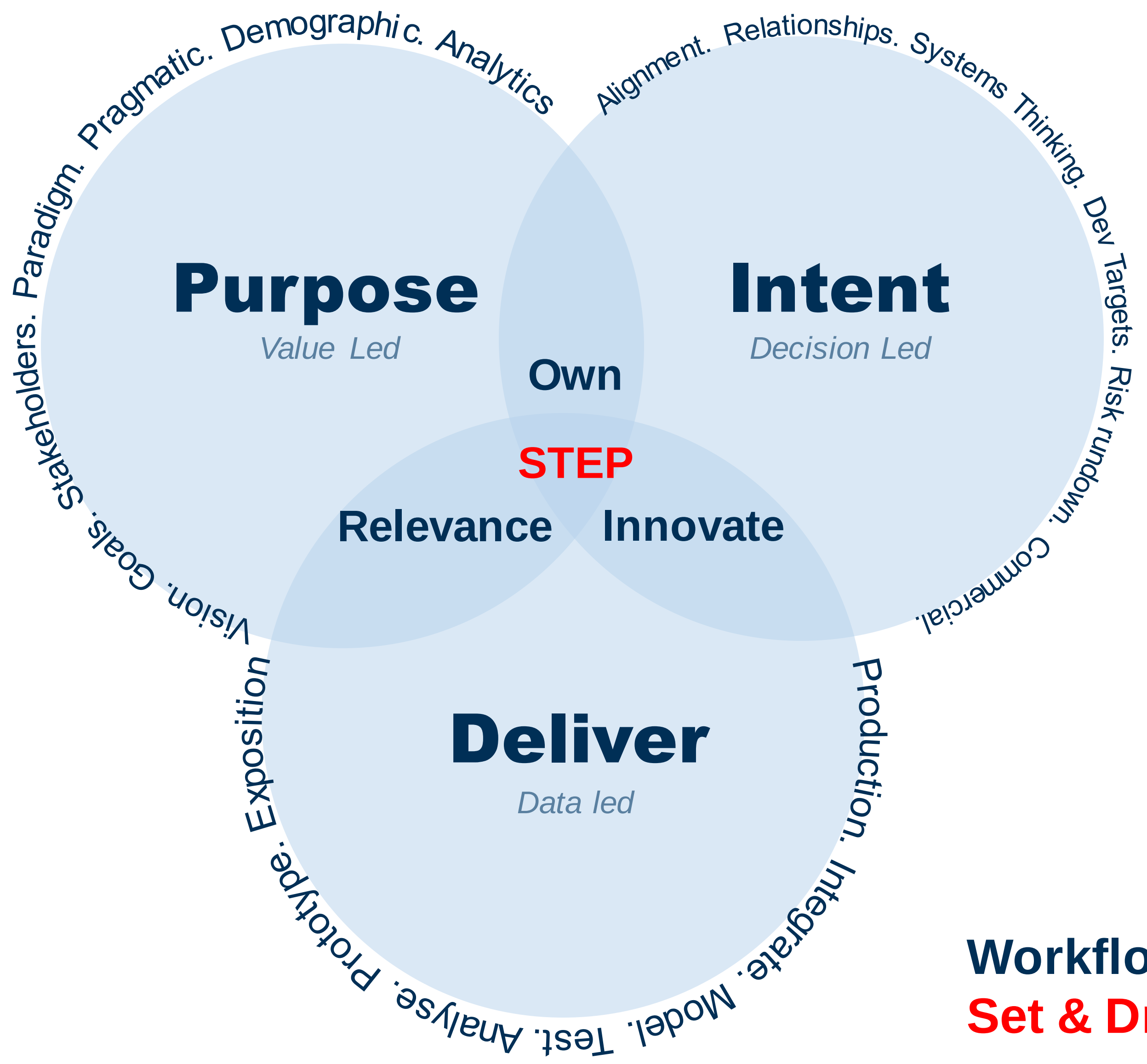
Cost
- Total Programme Cost, and confidence in the estimate
- Inferred cost of commercial plant and LCOE (to be developed later)

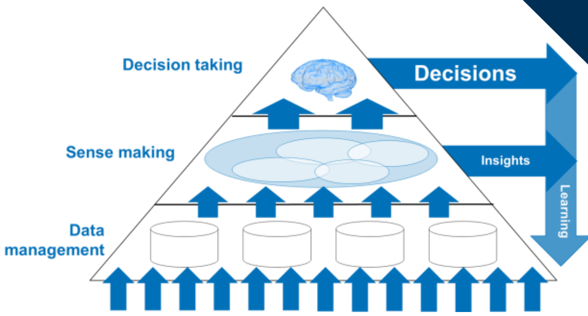
Maintainability
- Estimated operating cycle including outage durations, and confidence in those estimates

Schedule
- Total Programme Schedule, and confidence in the estimate

Development Flexibility
- Ability to capture data
- Ability to support developments for subsequent commercial plant

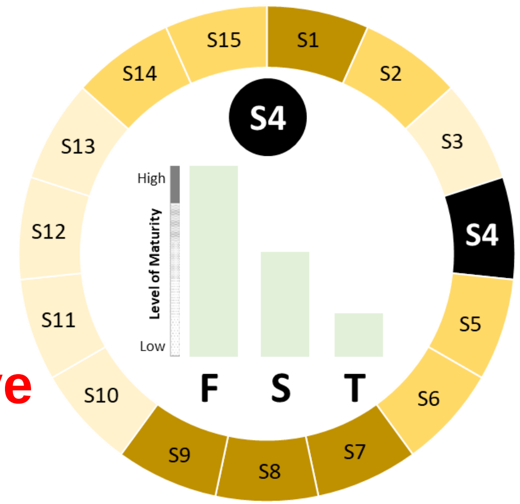
Performance, Cost, Time
Acceptance





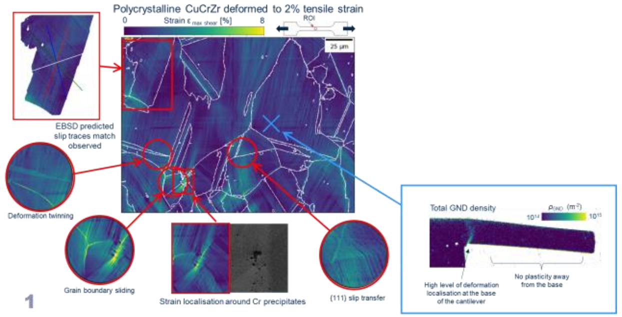
Emergence
Adaptation

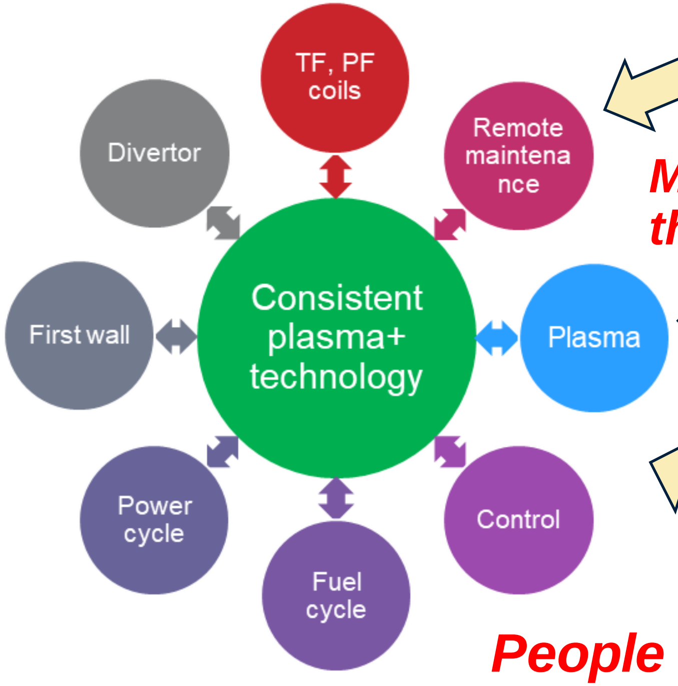
Workflow
Set & Drive



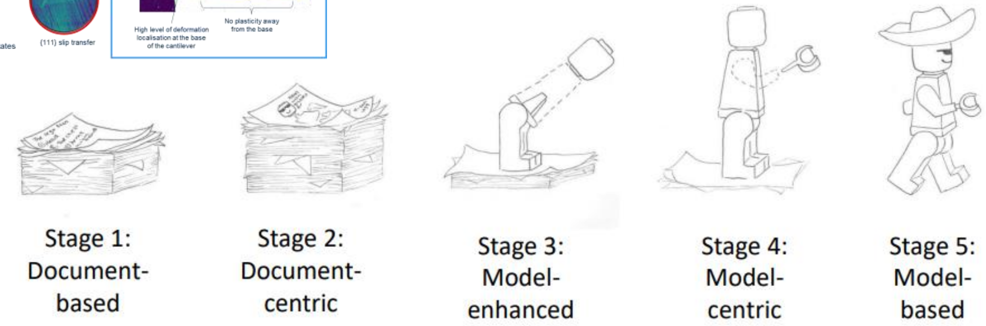
Capability for emergent behaviour

Theory development

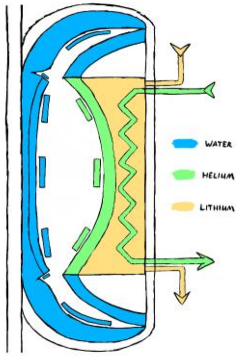


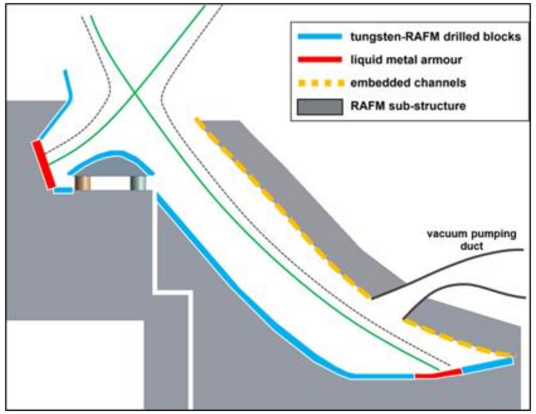


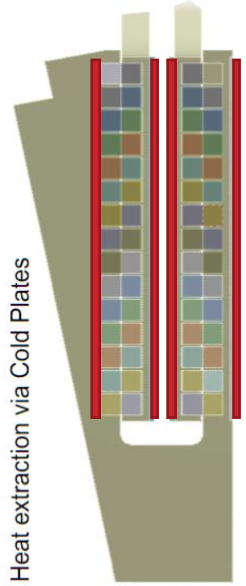
Model based delivery, Digital thread & Connected workflow



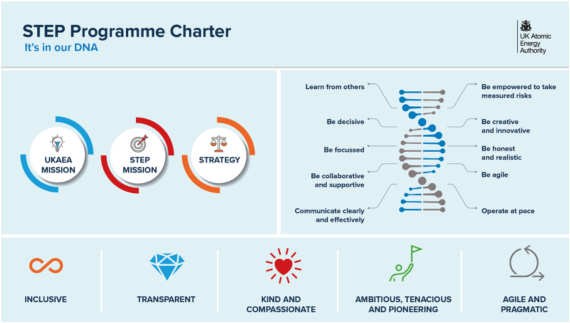
Multidisciplinary & Value driven







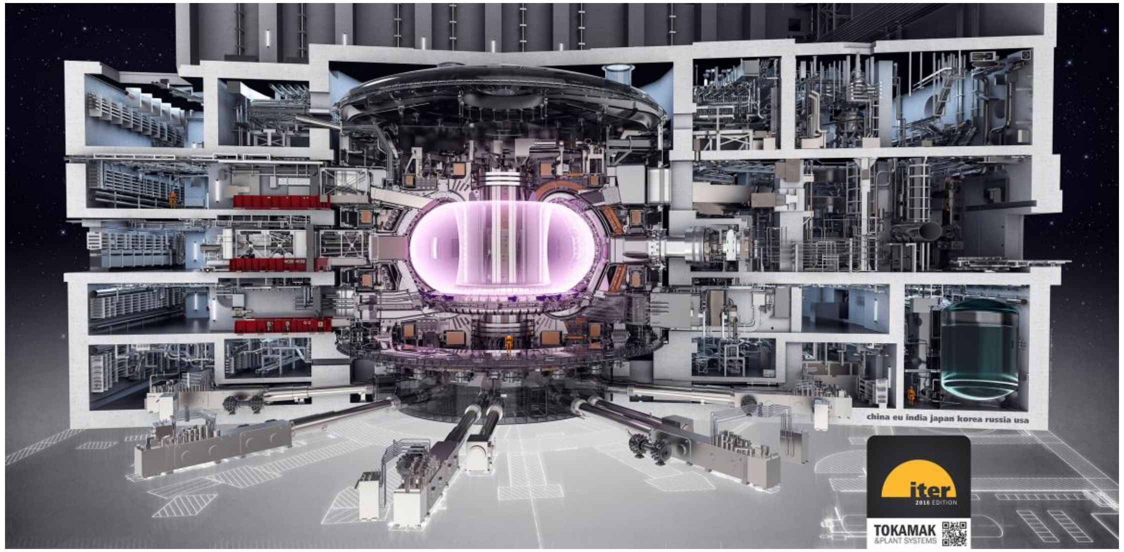
People & Culture

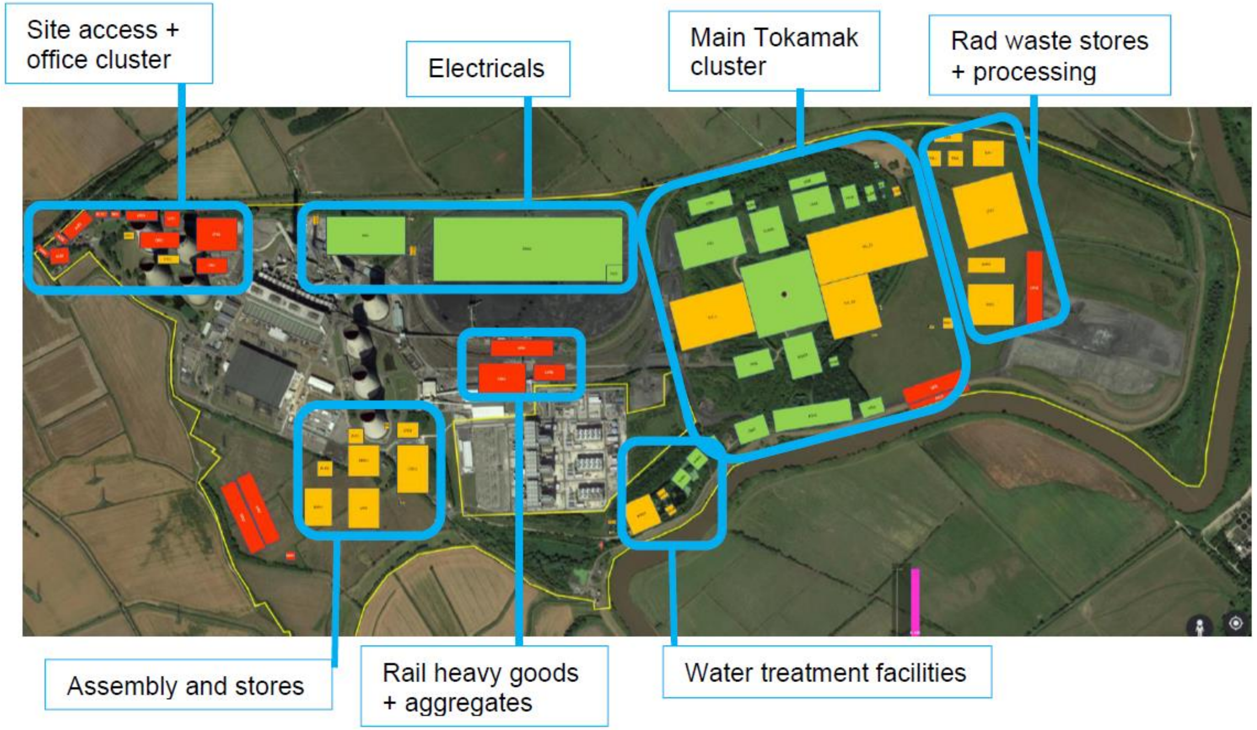


Site Complexity

Large Complex collection of systems

Tokamak is complicated enough on its own, but we need to integrate all other facilities too.





Note: layout is illustrative only and not agreed as the proposed site layout.

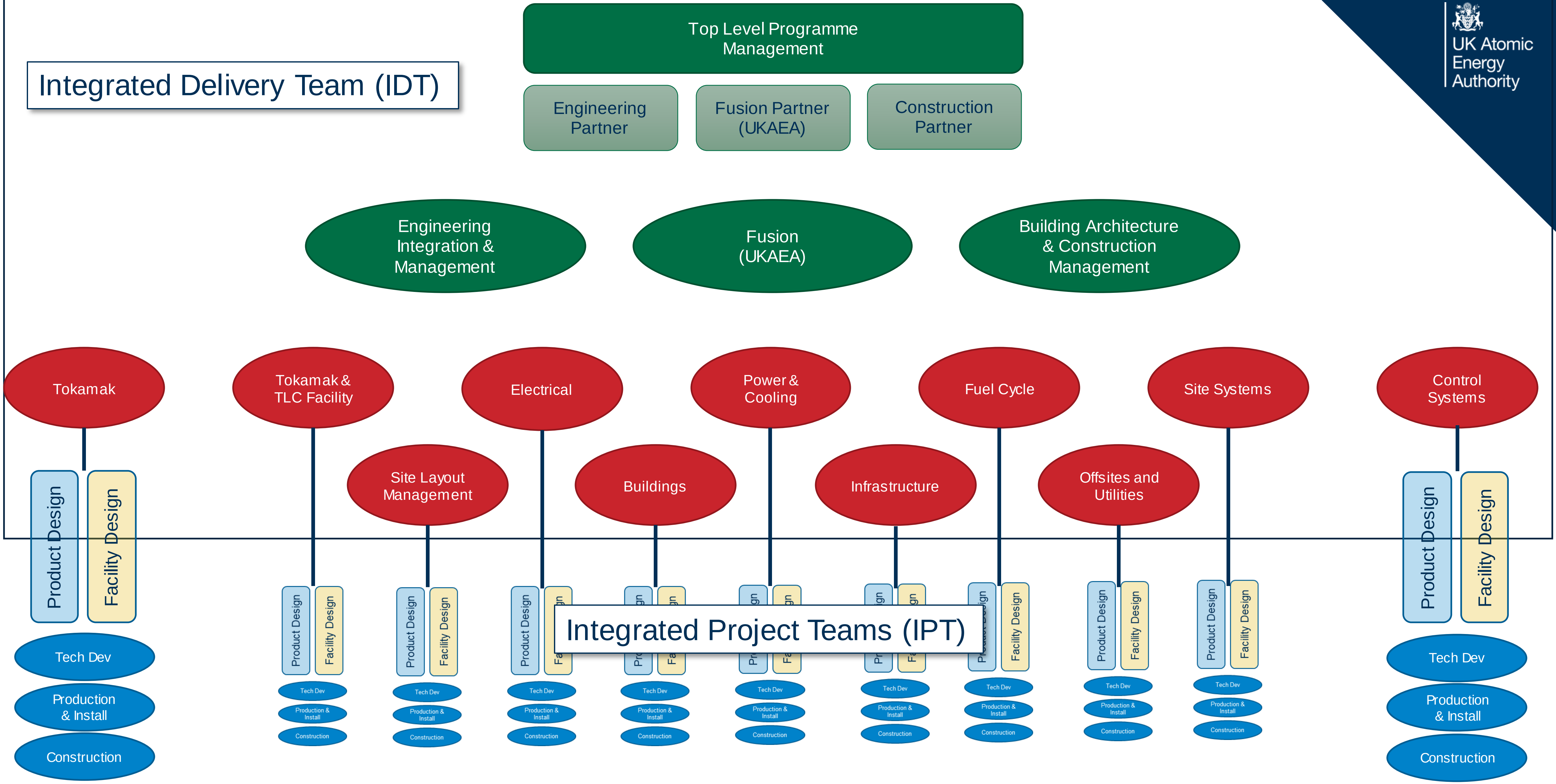
How Will STEP Tackle the Key Challenges?

UK Atomic Energy Authority

The STEP design has matured sufficiently to identify the strategic technologies that must be implemented. Detailed planning has commenced.

Plasma Scenario Development Advanced modelling and targeted experimental campaigns will be used to refine and qualify the plasma performance	**Tritium Breeding and Extraction** A lithium breeder will be developed to provide highly efficient fuel production, with an advanced extraction system to enable on-load fuel processing	**Plasma Facing Components** Robust armour and highly efficient cooling systems will be developed to protect key tokamak structures and systems
Materials Where existing materials are not suitable, specialist materials will be developed to survive harsh radiation, chemical, stress, magnetic and thermal environments of the tokamak, whilst balancing the waste legacy	**Remountable Magnet Joints** Joints in the Toroidal Field Coils will be developed to enable replacement of limited lifetime parts of the magnetic system and to significantly ease access for maintenance	**Thermal Cycles** Emergent supercritical carbon dioxide thermal cycle technology will be developed for STEP, as this provides a unique means of achieving efficiency, flexibility and auxiliary heating requirements.
Magnets High current density and energy efficient High Temperature Superconducting magnetic coils will be developed at scale	**Microwave Heating** Existing lab-scale Microwave Heating technology will be refined and scaled to industrial levels to enable steady state heating of STEP	**Tokamak Control** Radiation tolerant sensors and actuators will be developed to work with ground breaking algorithms to control the tokamak
Remote Maintenance Robotics to enable rapid intervention and efficient outages will be developed to keep humans from harm's way	**Vacuum Pumping** Existing vacuum pumping technology will be refined for steady state operation in tritium and radiation environments	**Processing Facilities** Efficient facilities to support the tokamak logistics and operations will be developed to enable

But they're inter-related!



UK Atomic Energy Authority

- Manages Projects to completion

Scope of the Integrated Delivery Team

UK Atomic Energy Authority

Provide 'client' role for long term development direction for the delivery of STEP Prototype Plant

Industrial Fusion Solutions

Client Role for Final Performance Specification
Corporate services
Long Term fusion plant design strategy

Fusion specialist support

Fusion Partner (UKAEA)

Primary Capabilities

IDT Management – Collab Agreement
Plasma Design Authority
Very low TRL Fusion Tech Development
Fusion Specialist Analysis Capabilities
Tokamak Performance
Fusion Expertise
Fusion operational experience
Specialist Testing Facilities

Design and Delivery of an integrated Plant to meet Performance expectations

Engineering Partner

Primary Capabilities

DT Management – Collab Agreement
Plant design & Information management
Plant engineering integration
Tokamak and supporting systems design
Technology development management
Manufacturing development
Manufacturing Production management
IQ/OQ/PQ Qualification Protocols

Design and Delivery of the West Burton site and all facilities, integrated with the Plant

Construction Partner

Primary Capabilities

IDT Management – Collab Agreement
ALL Building and services design
Site infrastructure
DCO Planning and Application
Site Development and Preparation
Site Assembly and Installation
Construction Planning
Site Construction Management & Delivery

What we are looking for…

- Experience of Large Plant integration (design, manufacturing, development)
  - Low technology maturity
  - Complex multi discipline, System of Systems, Concurrent design maturation
  - High hazard environment
  - Large scale (multi year, multi £bn)
  - Innovation to reduce cost and Schedule
- Able to work collaboratively with partners in joint leadership positions
- Able to establishment and sustain new specialist partnerships
- Able to manage complex production/construction supply chains/suppliers
- Development of people and capabilities to sustain a long term programme
- Core Integration Skills

New technology
Blanket – heat extraction & tritium production

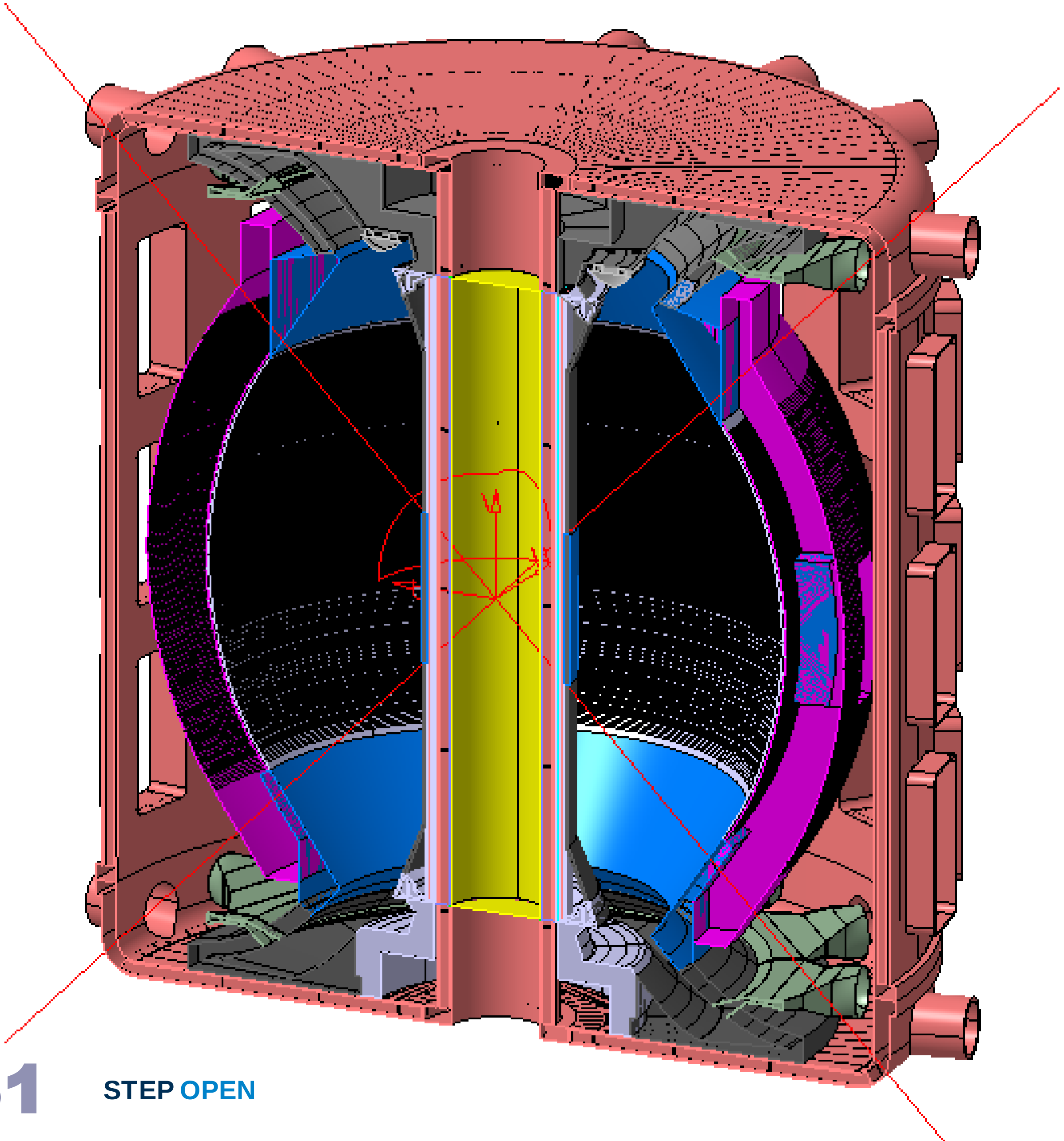
Dr Jenny Cane CEng FIMechE

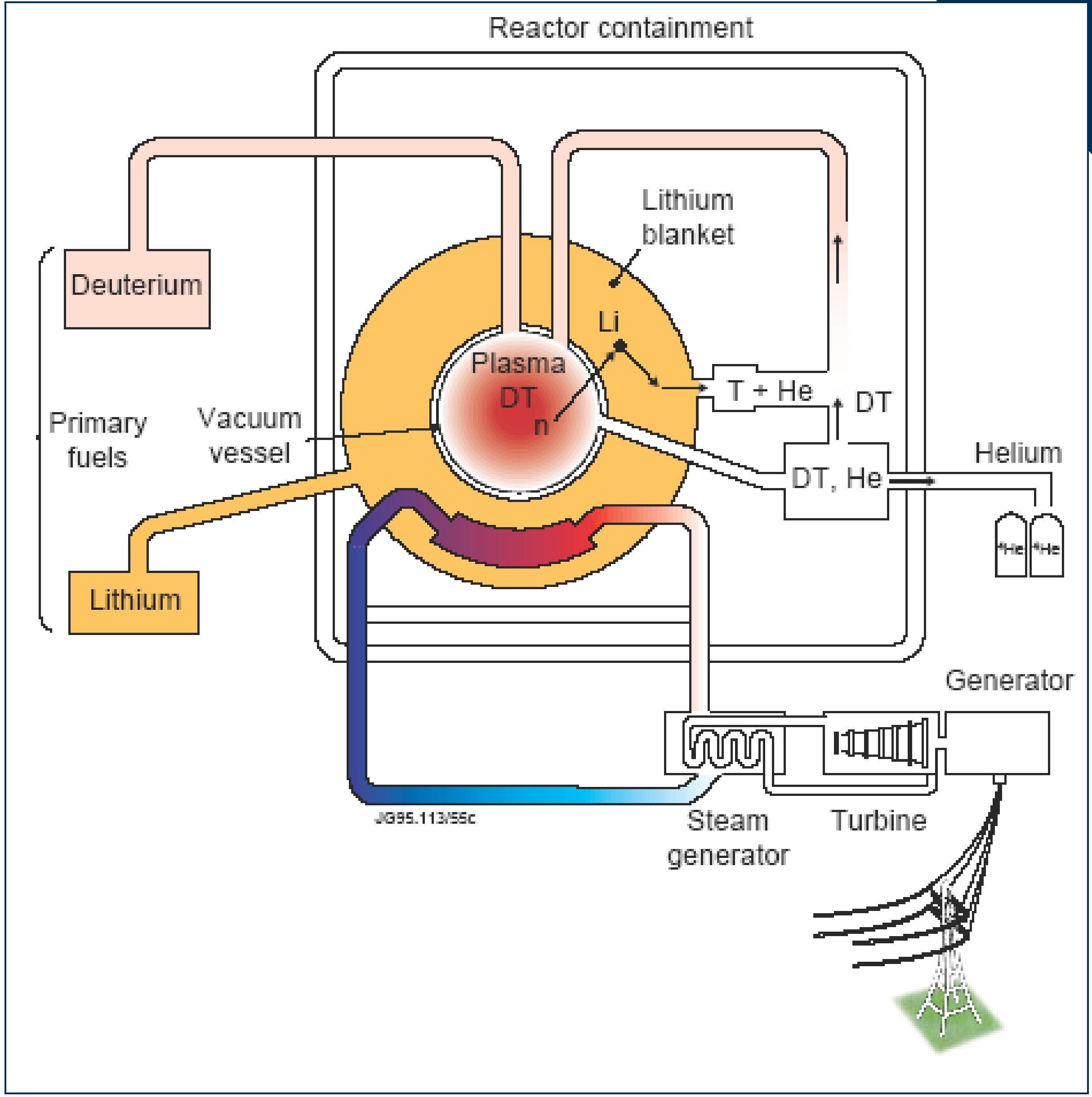
Product Lead – In-Vessel Components

UK Atomic Energy Authority

The STEP Breeder Blanket Challenge

UK Atomic Energy Authority



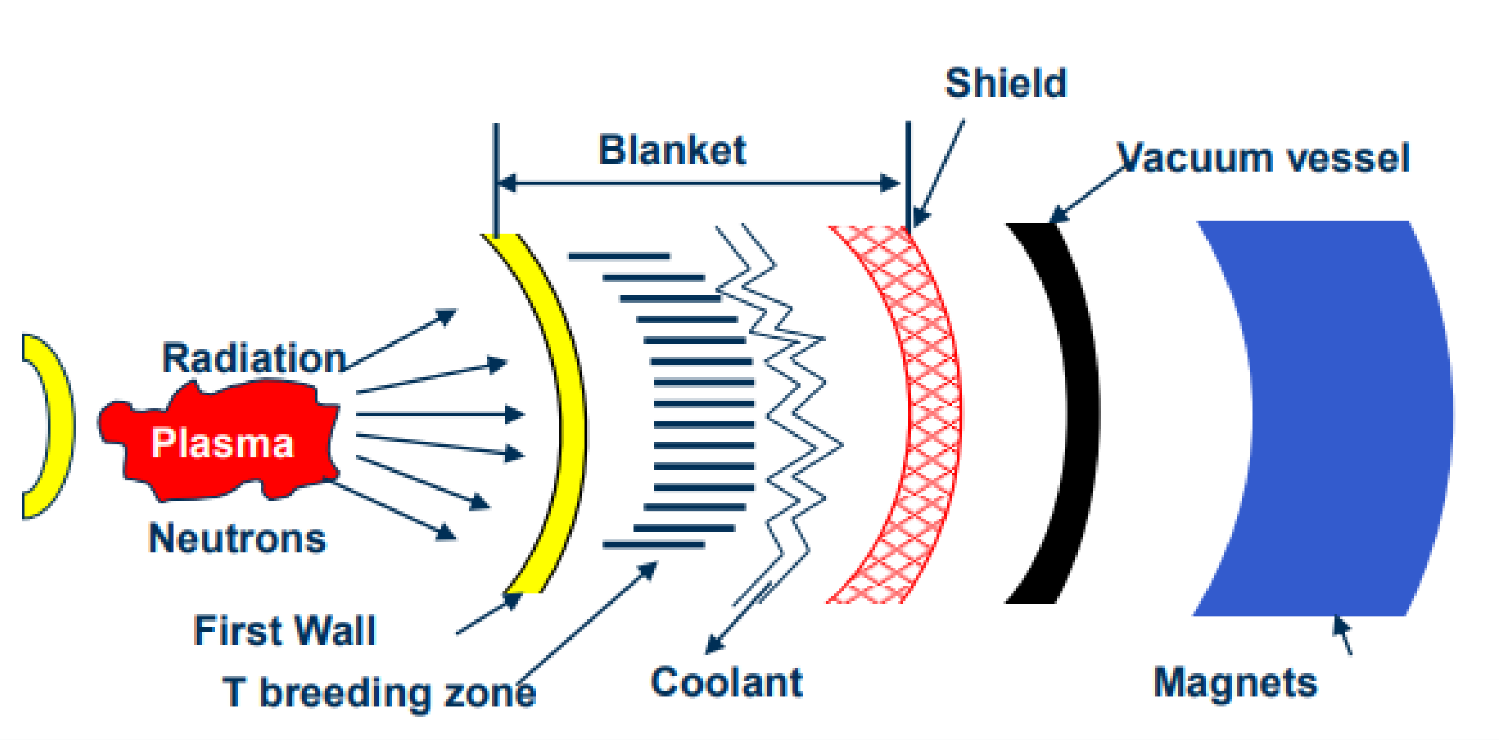


The STEP Breeder Blanket Challenge

UK Atomic Energy Authority

The role of the breeder blanket

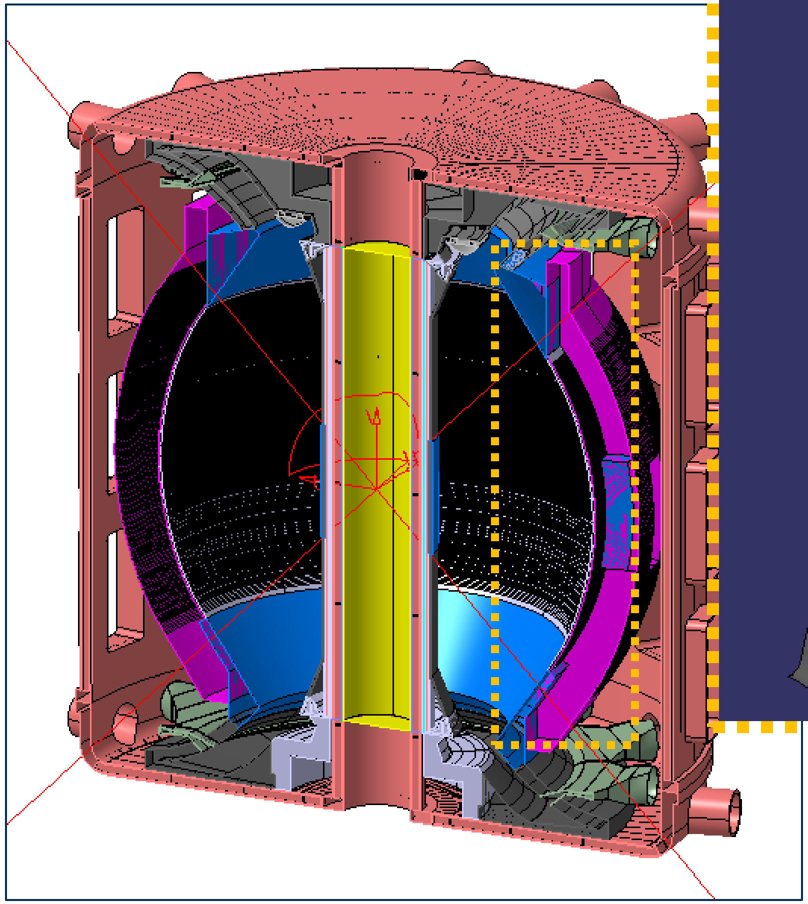
- Generate heat
- Breed tritium
- Absorb neutrons

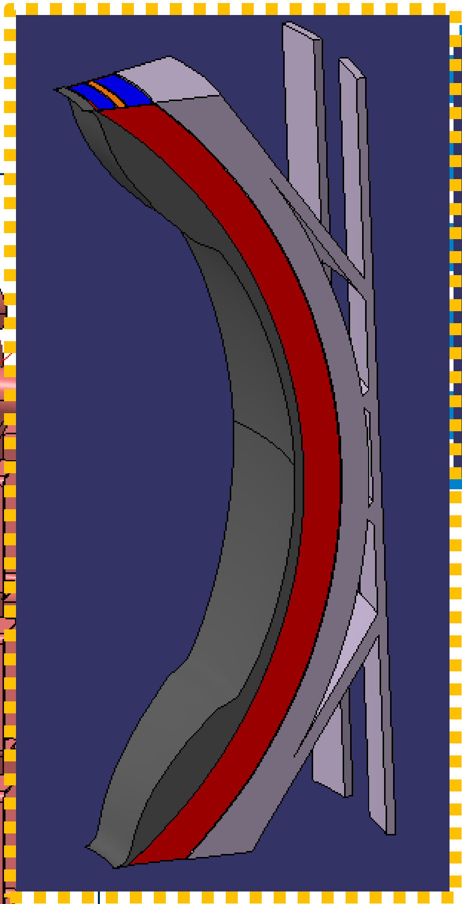


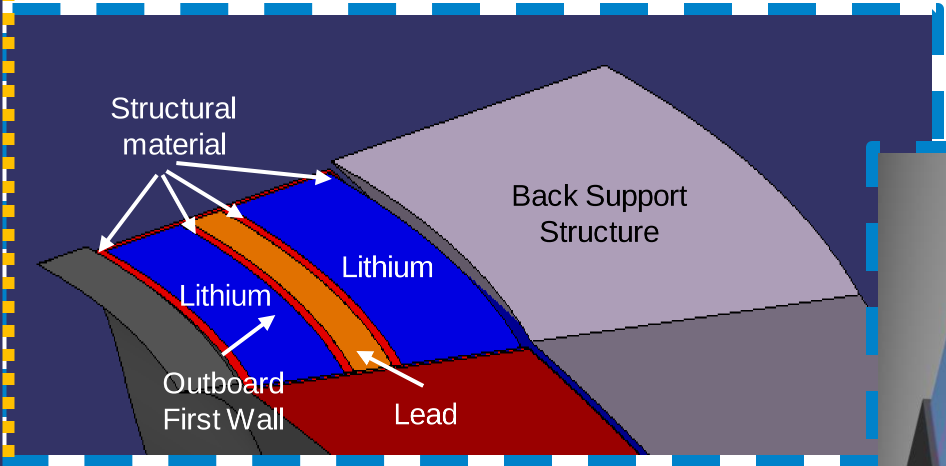
- Tritium breeder blankets are essential for (DT) fusion.
- No breeder blankets have been made or tested.
- Breeder blankets are predicted to represent a significant % of fusion plant total costs.
- Breeder blankets are expected to be replaced several time during the life of a powerplant
- There is no international leader in breeding blankets

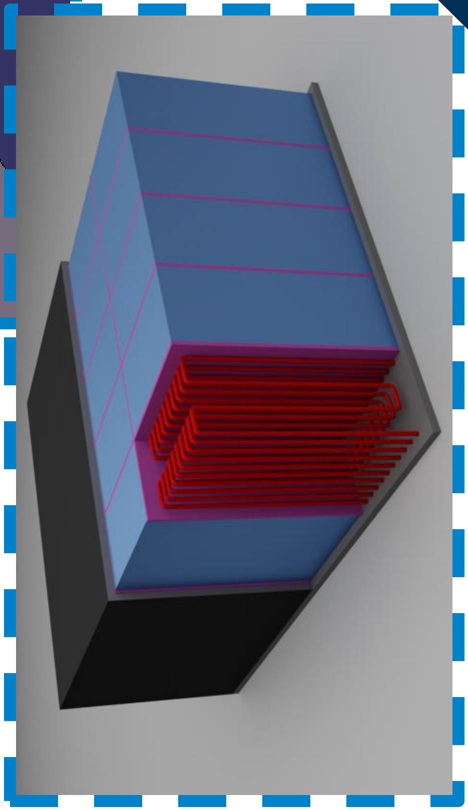
The STEP Breeder Blanket Challenge

UK Atomic Energy Authority









Approximate quantities of materials:

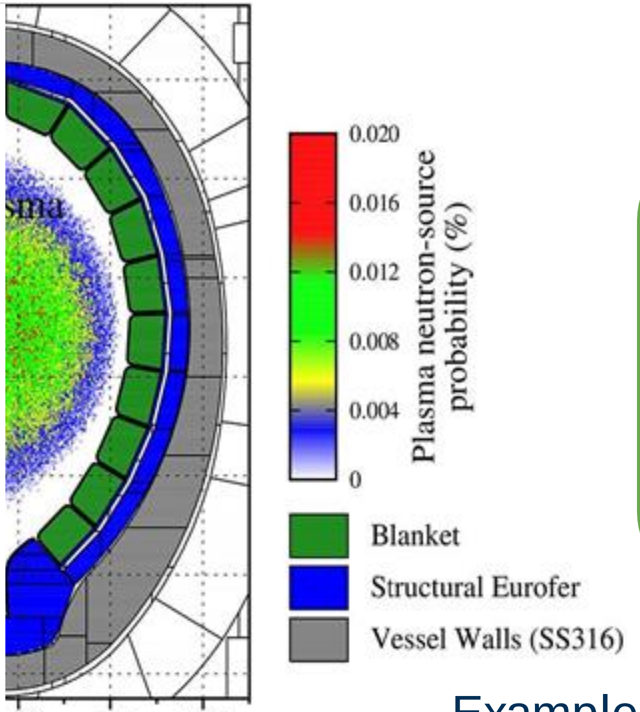
- 200 tonnes liquid 20-40% enriched lithium
- 1000 tonnes structural material

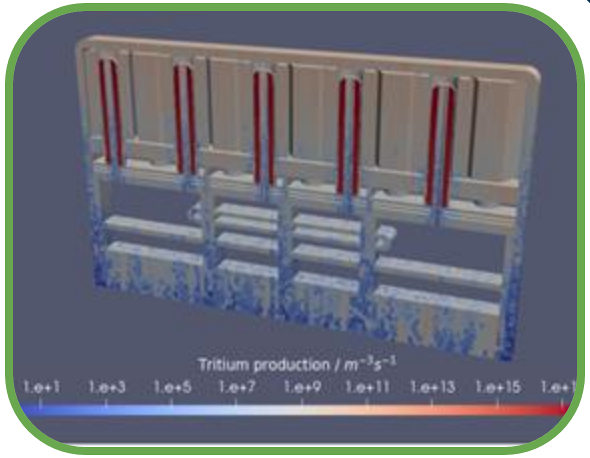
The STEP Breeder Blanket Challenge

UK Atomic Energy Authority

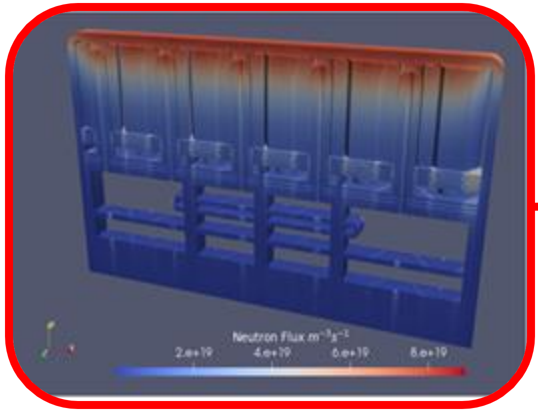
Complex multi-physics, integrated design

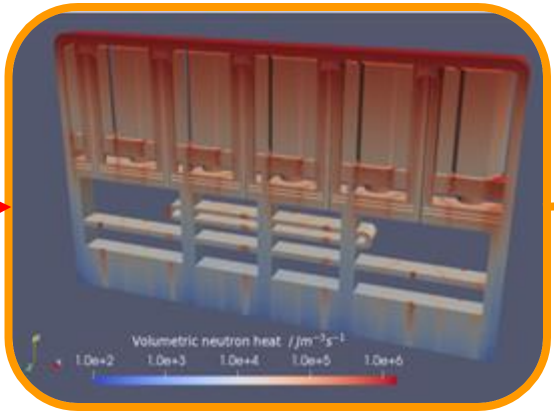
- High irradiation levels
- Pure liquid Lithium at 600ºC
- Several Tesla magnetic field
- High Tritium breeding rate and recovery
- Design code development
- Failure protection design

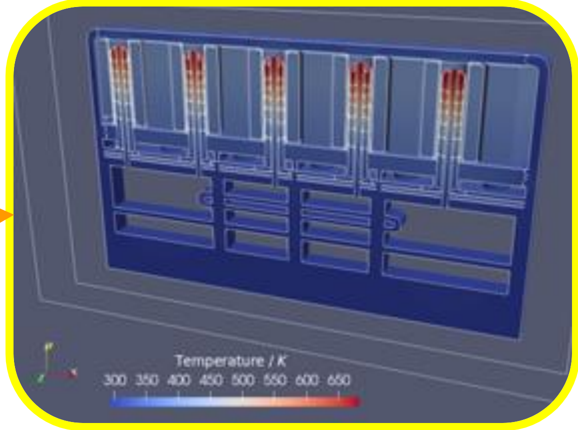




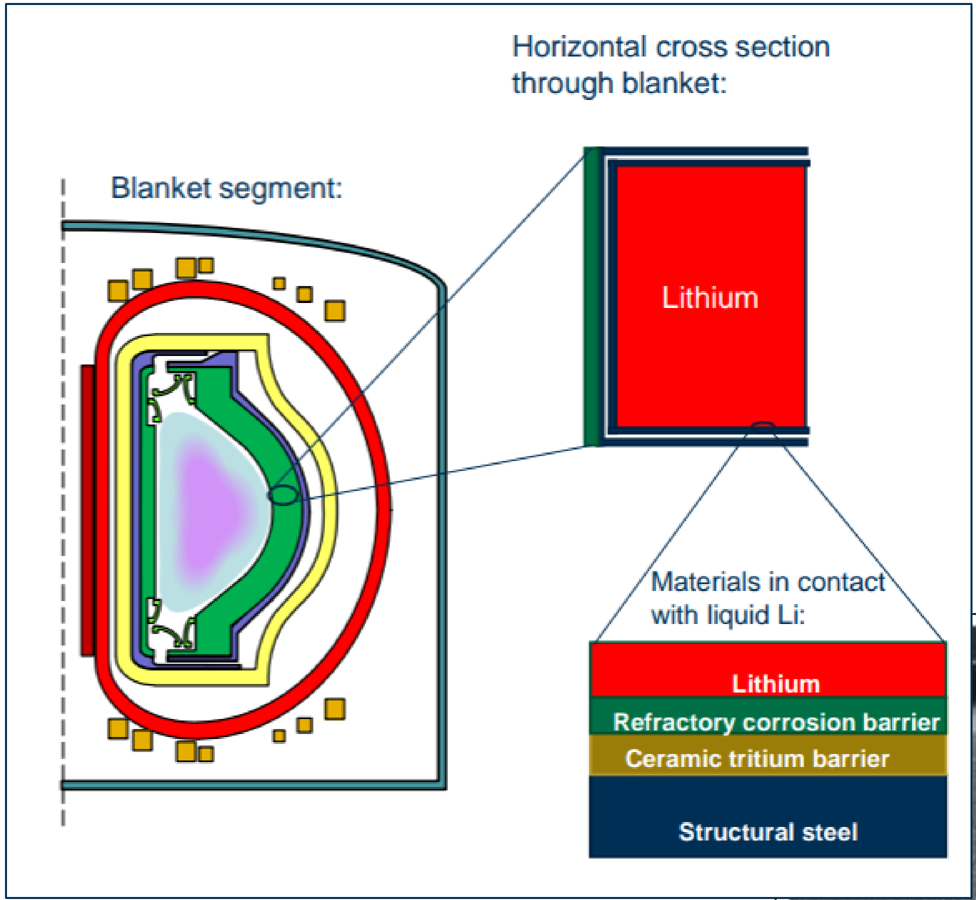
Example neutronics, structural and thermohydraulic coupled analysis





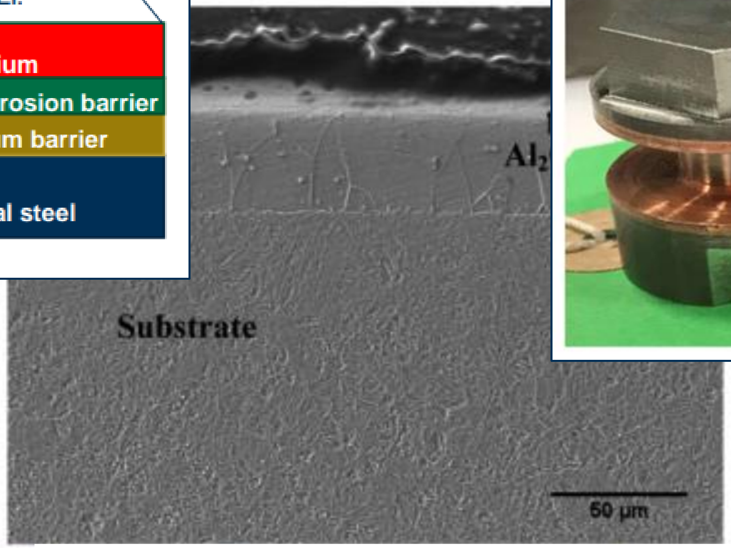


The STEP Breeder Blanket Challenge

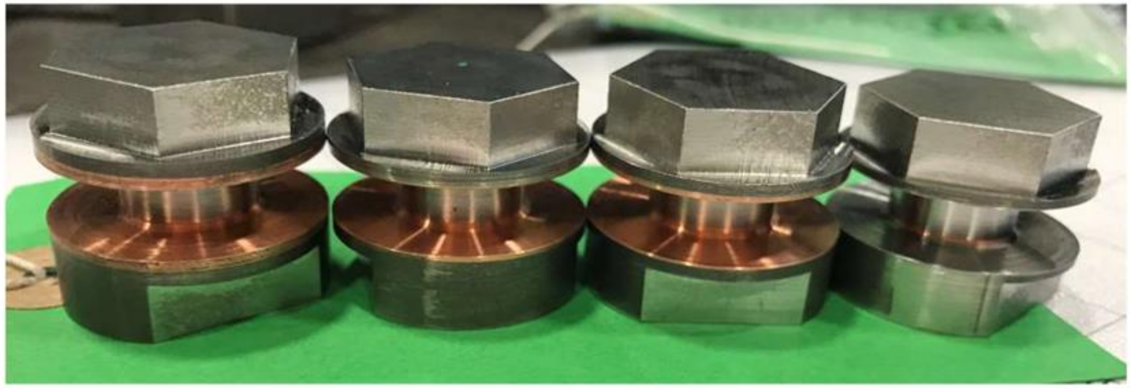


Technology development

- High temperature, low activation advanced structural material development & supply
- Corrosion, tritium & electrical barrier development
- Joining and manufacture



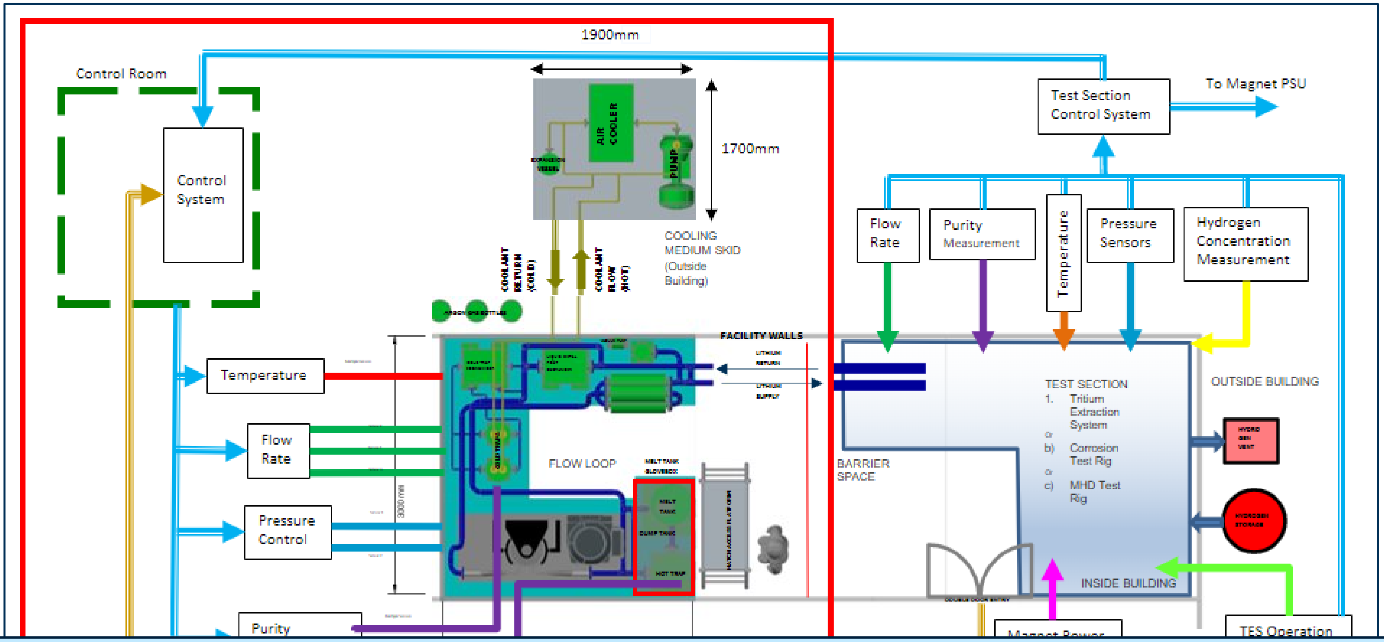
26: Example corrosion barrier trial



Example joining trial test pieces

The STEP Breeder Blanket Challenge

UK Atomic Energy Authority



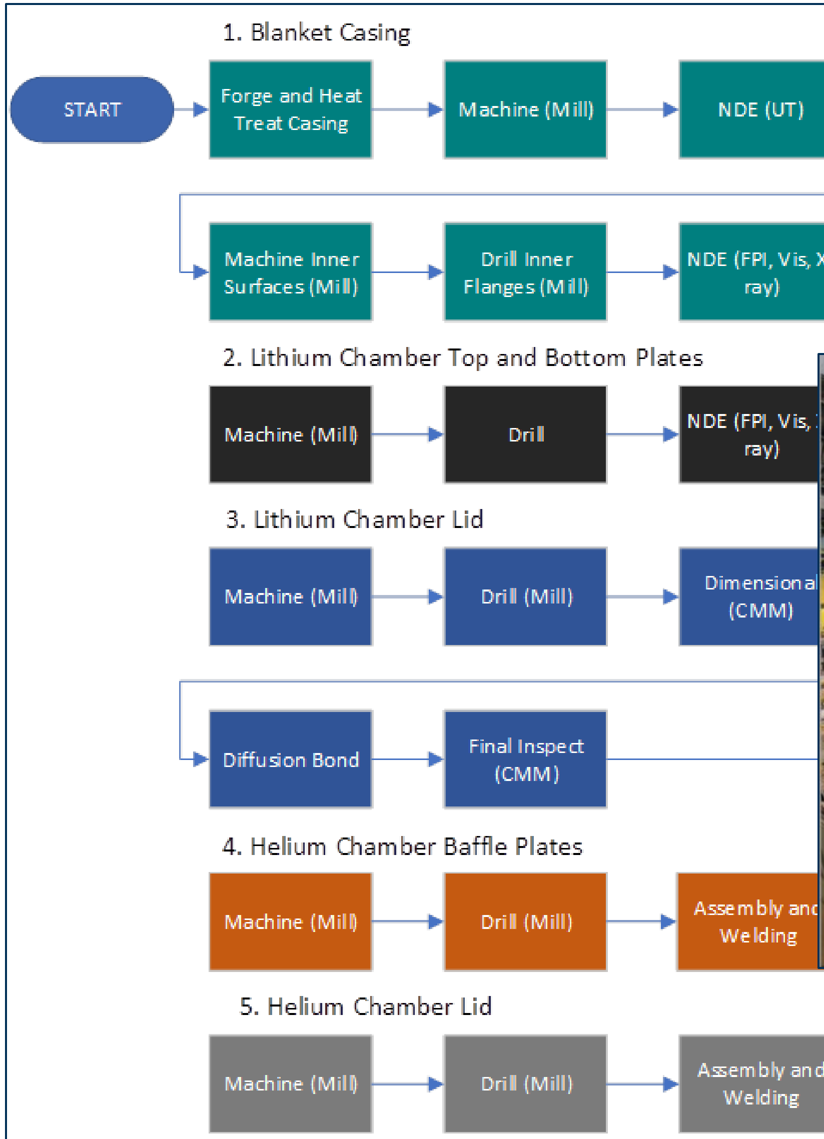
UKAEA Lithium flow loop design proposal

UKAEA CHIMERA large scale prototype blanket thermohydraulic and structural prototype test facility

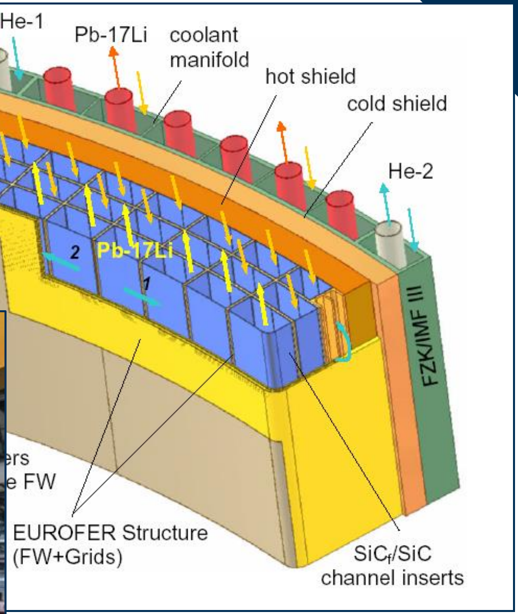
Validation facility creation

- Tritium breeding testing
- Thermohydraulic and structural tests in high magnetic field
- High temperature lithium corrosion and thermofluid testing
- Irradiated materials properties testing

The STEP Breeder Blanket Challenge



Initial breeder blanket manufacturing overview



Example breeder blanket module construction

ITER poloidal coil manufacturing facility

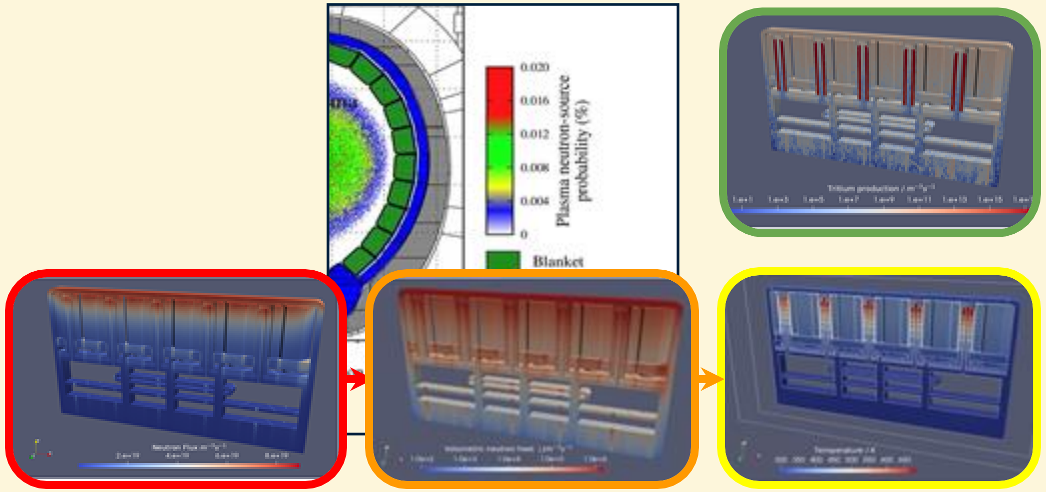
Large scale, complex manufacture

- Raw material supply chain
- High tolerance, large scale, complex manufacture

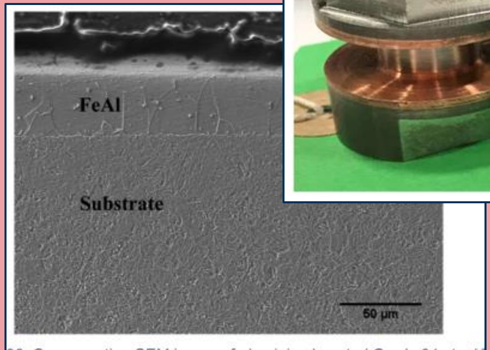
The STEP Breeder Blanket Challenge

UK Atomic Energy Authority

Complex multi-physics, integrated design

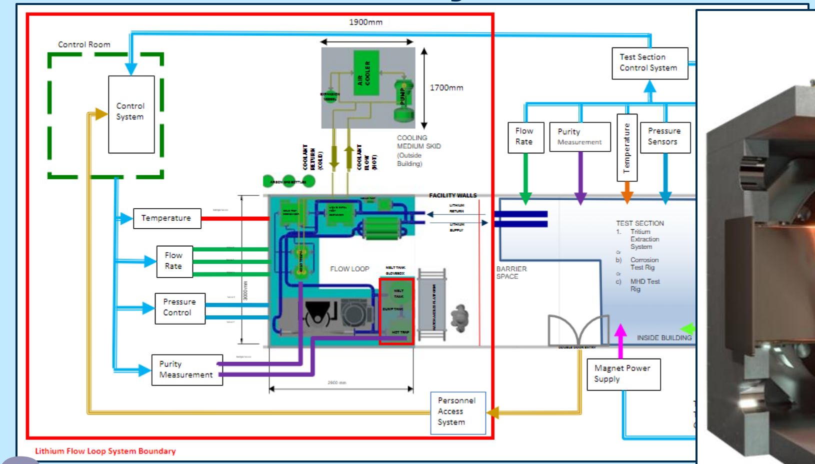


Technology development

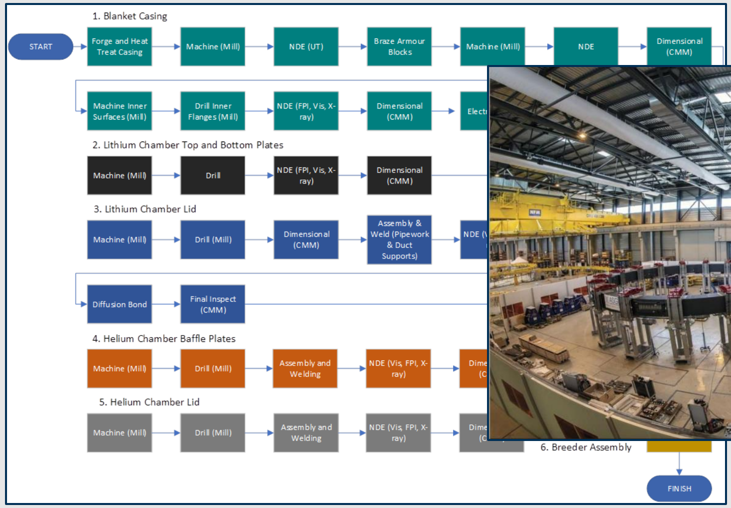


26: Cross-section SEM image of aluminised coated Grade 91 steel

Validation facility creation



Large scale, complex manufacture



Co-designing a supply chain for scarce technology

James Treadgold CEng, FIMechE

Confinement Systems Project Manager

Content

UK Atomic Energy Authority

Description of the Challenge

Magnetic Confinement

STEP Magnets

Existing market

Scale of task

Case Study – ITER

Where does this apply on STEP

The Challenges of Scarce Technology and Co-designing a Supply Chain

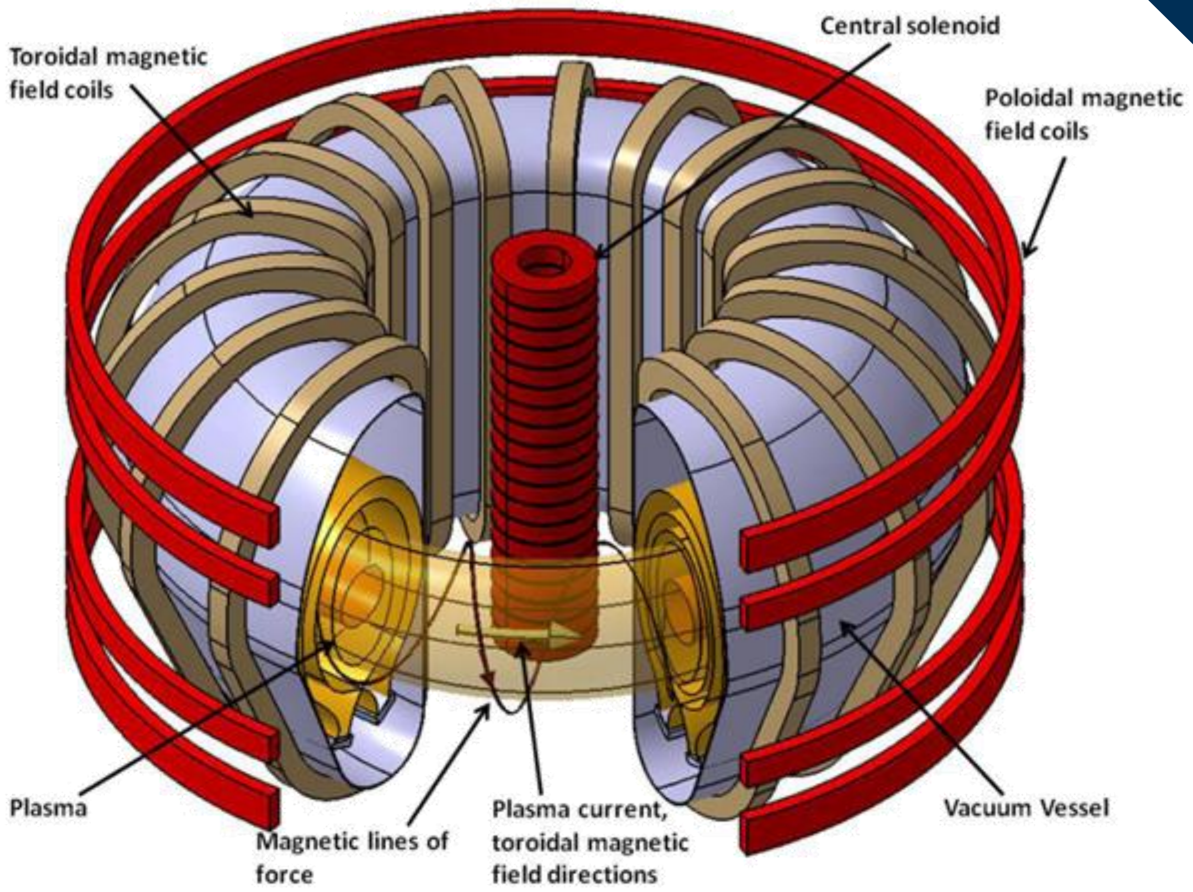
- STEP concept design includes materials and technologies that are low Technology Readiness Level (TRL)
- Volumes currently available from commercial providers low if any
- In some cases no commercial provider – lab R&D only
- Supply chain does not yet exist to meet STEP demand

Magnetic Confinement

UK Atomic Energy Authority

STEP uses high field magnets to confine the plasma (like JET, ITER, DEMO)

JET	ITER	STEP
Copper conductor	Low Temperature Superconductor (LTS)	High Temperature Superconductor (HTS)
Water cooled	4.5 K	20 K



STEP Magnets

UK Atomic Energy Authority

Figuratively:

TF ~20m high by 8m wide

PF ~18m diameter

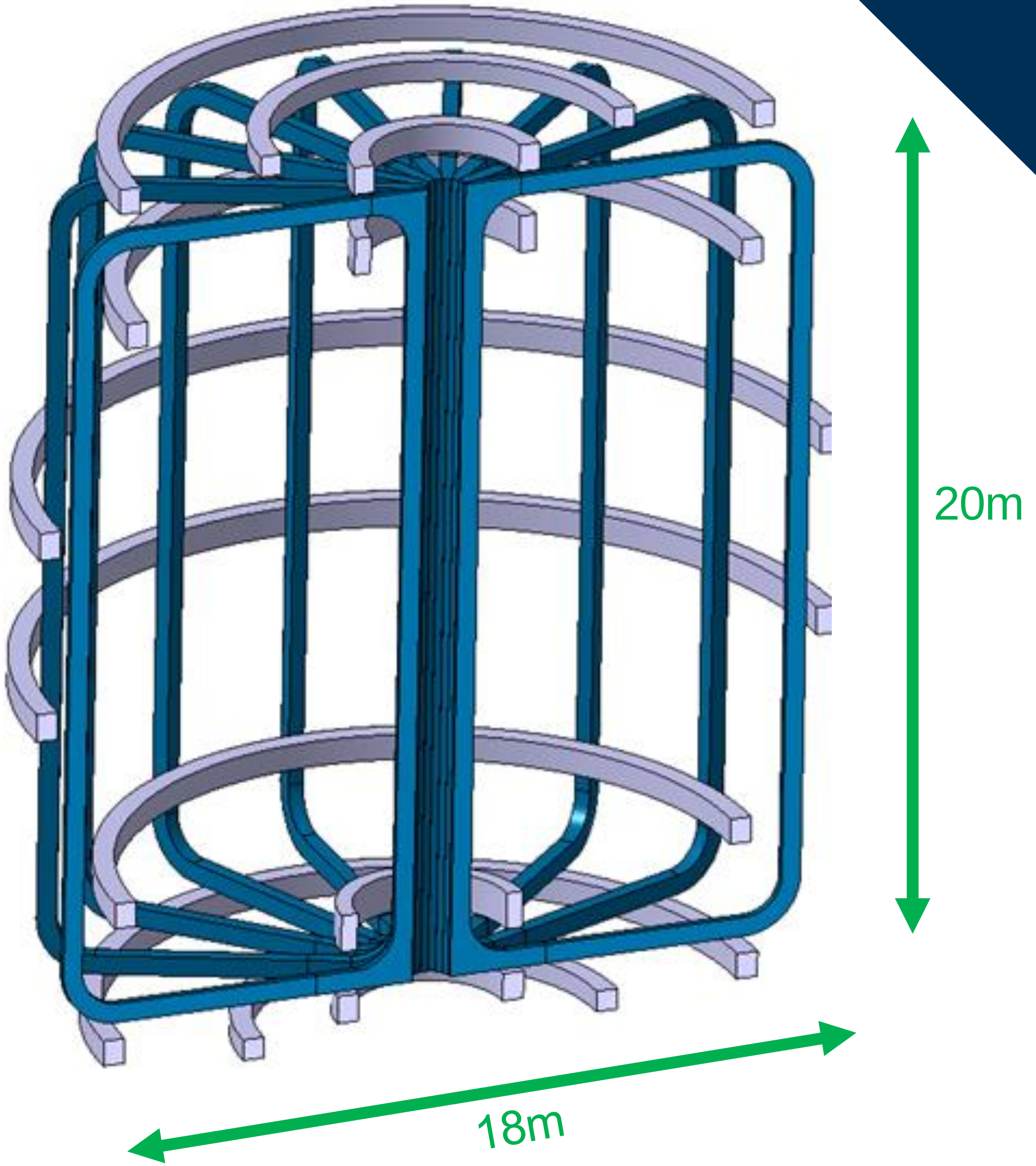
CS ~8m high by 1.5m radius

Conductor – High Temperature Superconductor (HTS) REBCO (Rare-earth barium copper oxide)

30,000 km required

Note: other fusion devices are also choosing HTS => on-going future demand

- TE – ST80, E1
- CFS – SPARC, ARC



Existing markets

UK Atomic Energy Authority

HTS Tape

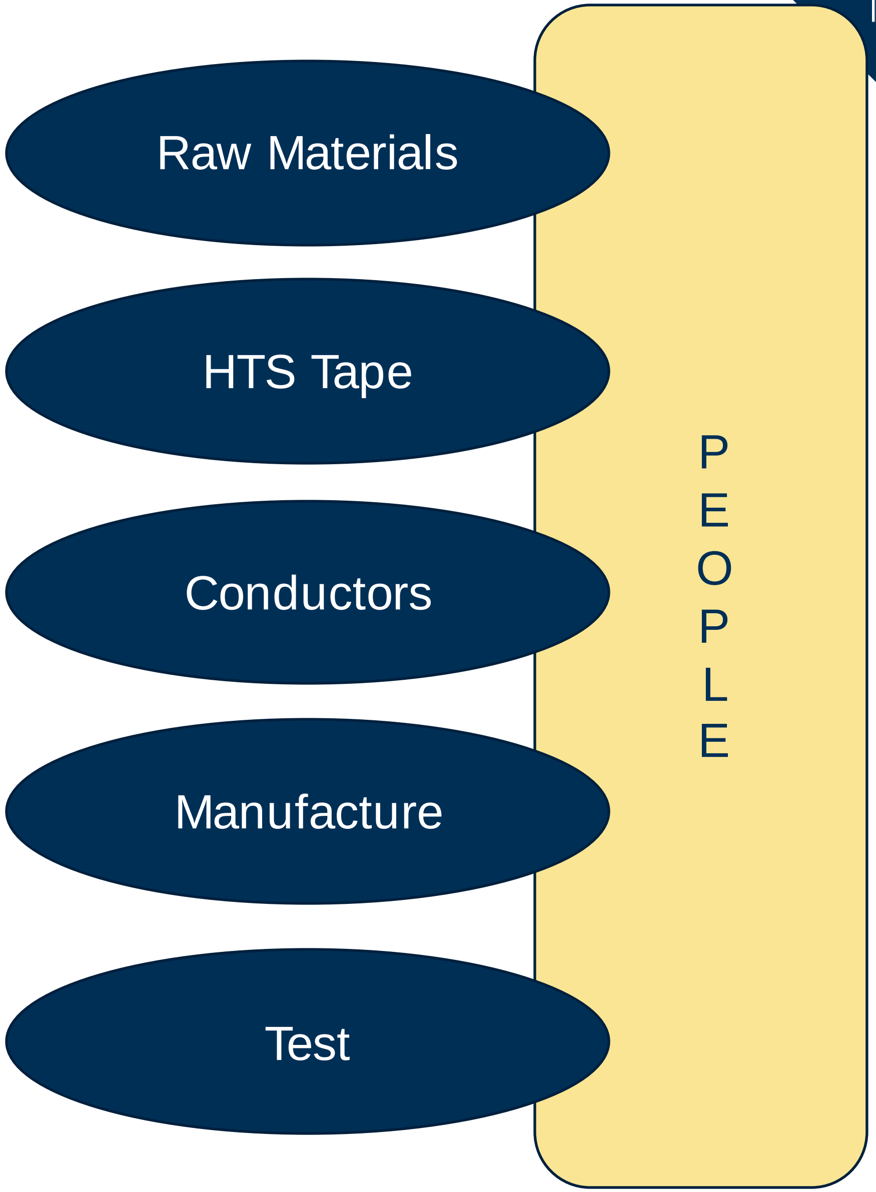
- 10 suppliers
- Small volumes produced ~1000 km/yr
- Can produce more but no current market demand
- Rate limiting factor?
    - Raw material supply
    - Trained operatives
    - Production facilities
    - QA & testing

Coil Manufacture

- HTS magnets at “lab” scale
- Large LTS magnets have been commercially manufactured but select – e.g. ITER factory for their PF coils.
- Winding machines, resin vacuum impregnation equipment available – although bespoke

The task

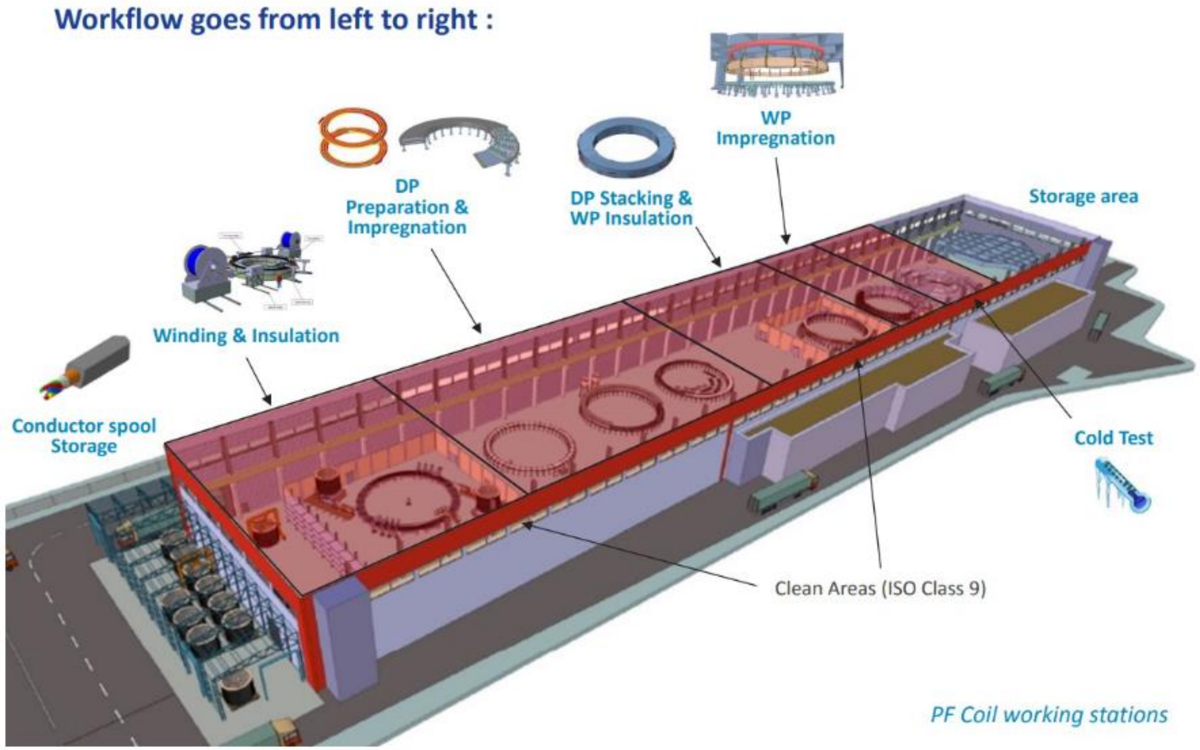
- Build HTS supply chain – stimulate suppliers to scale up production
- Develop coil winding techniques and equipment
- Build factories for coil manufacture
- Build test facilities or secure significant access to existing
- Train people to operate factories, wind coils, test coils, etc



Case Study - ITER

- There was an established commercial supply chain for LTS wire (NbTi) from body scanner, NMR markets
- Stimulated Nb_3Sn market through early orders for significant quantities to drive improvement of manufacturing techniques and scale up
- Used single specification across multiple suppliers
- On-site factory for PF coils
- TF by partners
- CS through industry

This took ~25 years - STEP timeline significantly shorter - challenging but doable!



Where does this apply on STEP?

UK Atomic Energy Authority

Low TRL and minimal supply chains

- Fuel cycle – lithium enrichment, lithium extraction
- In Vessel Components – first wall materials, breeder blankets
- Magnets – HTS tape, magnet manufacture

Known technologies with manufacturing volume challenges

- Stainless steel – for vessels, structures, pipework
- Gyrotrons – volume of manufacture

Summary

UK Atomic Energy Authority

- STEP needs to:
  - Mature TRL
  - Upscale or create supply chains

- Challenging:
- Timeline
- Volumes

- Achievable

UK Atomic Energy Authority

Tea and cake time

Please sign up for any 1-2-1 sessions at the reception desk

UK Atomic Energy Authority

Data management and digital challenge

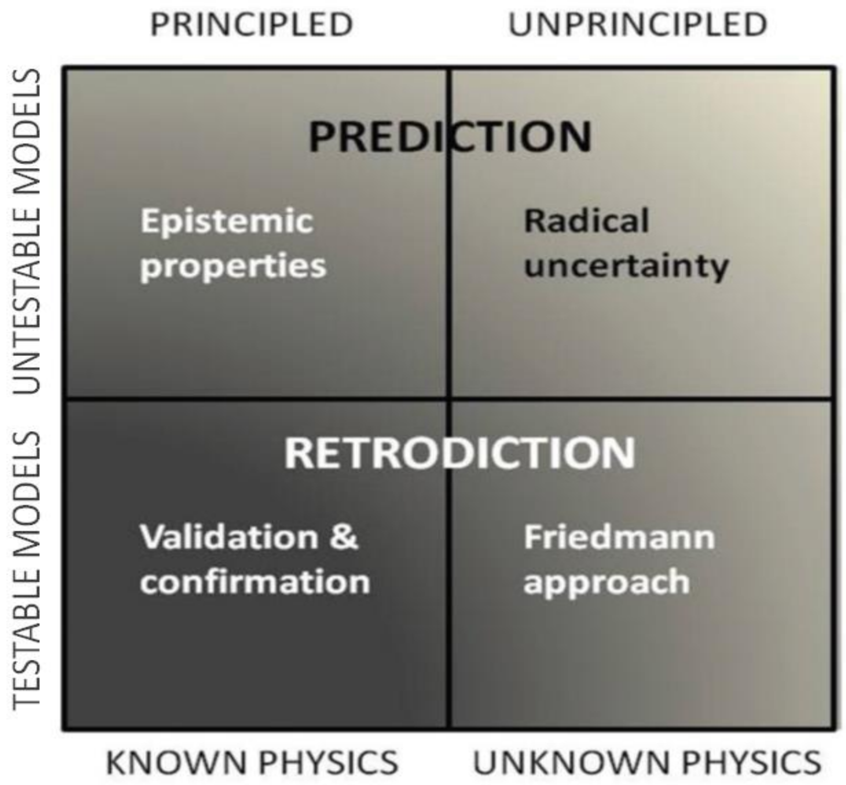
Martin Aston CEng MRAeS

Overview

- **STEP is one of the biggest engineering challenges seen in decades**
  - A First Of A Kind (FOAK) programme with all associated risks, opportunities and uncertainties
  - Requiring corresponding development within the definition, validation and delivery processes
- **Innovative digital solutions are needed to:**
  - Manage risk associated with significant epistemic uncertainty
  - Facilitate innovative design space exploration and ensure robust decision-making
  - Provide secure and efficient engagement across an evolving (and emerging) supply chain
  - Automatically capture and reuse tacit knowledge
  - Manage large volumes of data for an extended period of time

Overview

- **Such processes must also……**
  - Be developed and proven within aggressive timescales and cost constraints
  - Accommodate technological and commercial evolution… within both the STEP programme and the wider information management environment
  - Be compatible with existing and emerging regulatory environments
- **Innovative use of advanced digital systems is key to successful delivery**

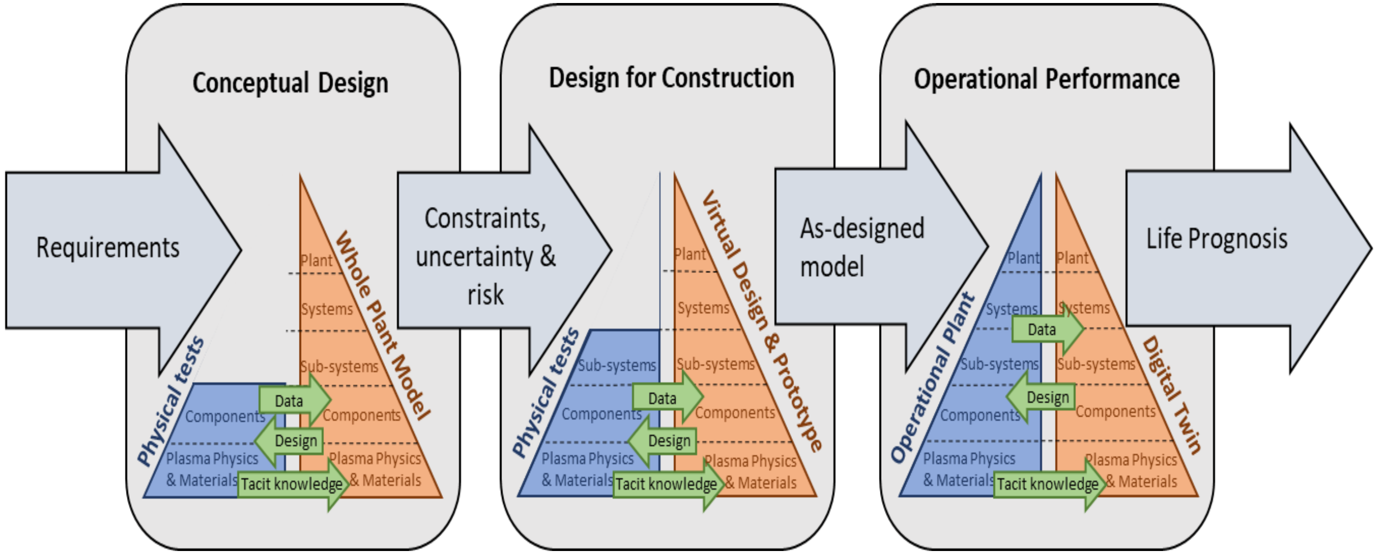


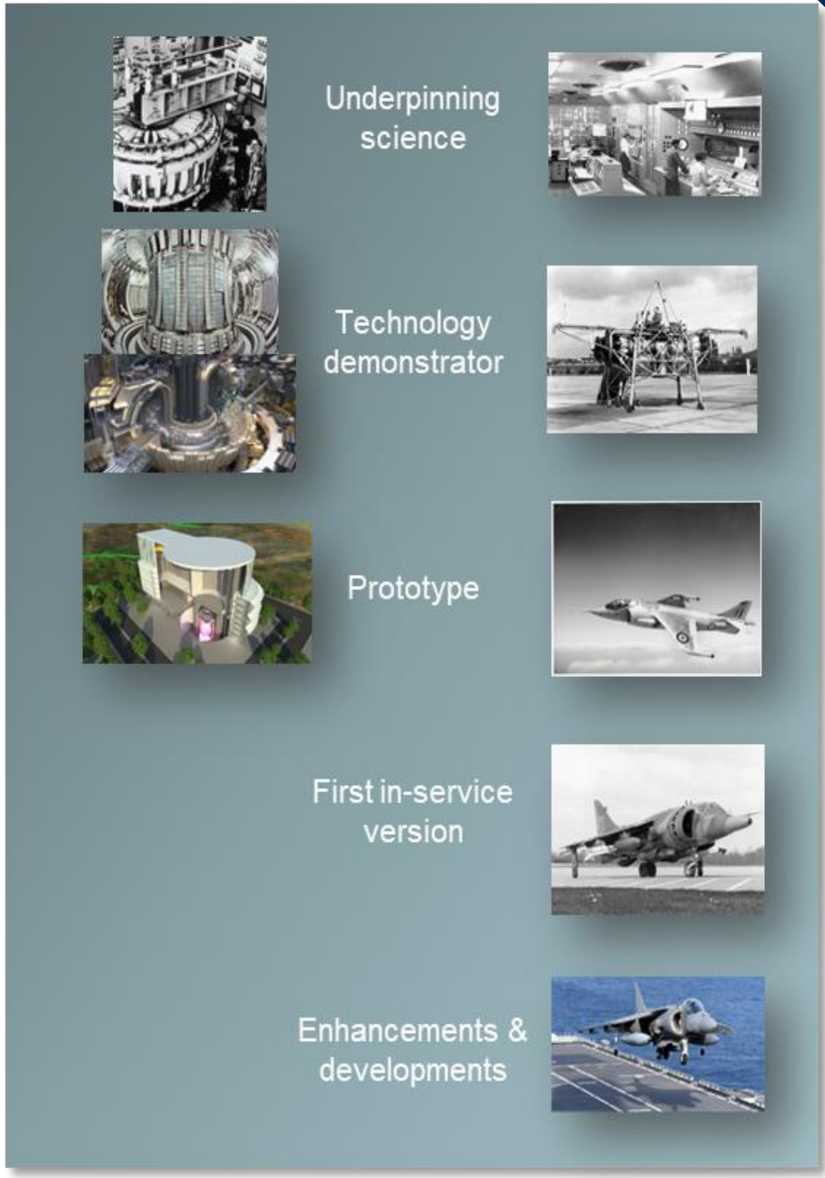
Patterson, E. (2015). On the credibility of engineering models and meta-models. *J. Strain Analysis*, *50*(4), 218-220.

Product Development & Realisation

UK Atomic Energy Authority

- The goal to deliver an ambitious prototype facility (vs a technology demonstrator) requires both innovation and increasing rigour





Product Development & Realisation

UK Atomic Energy Authority

Enabled by innovative, digitally-enabled processes

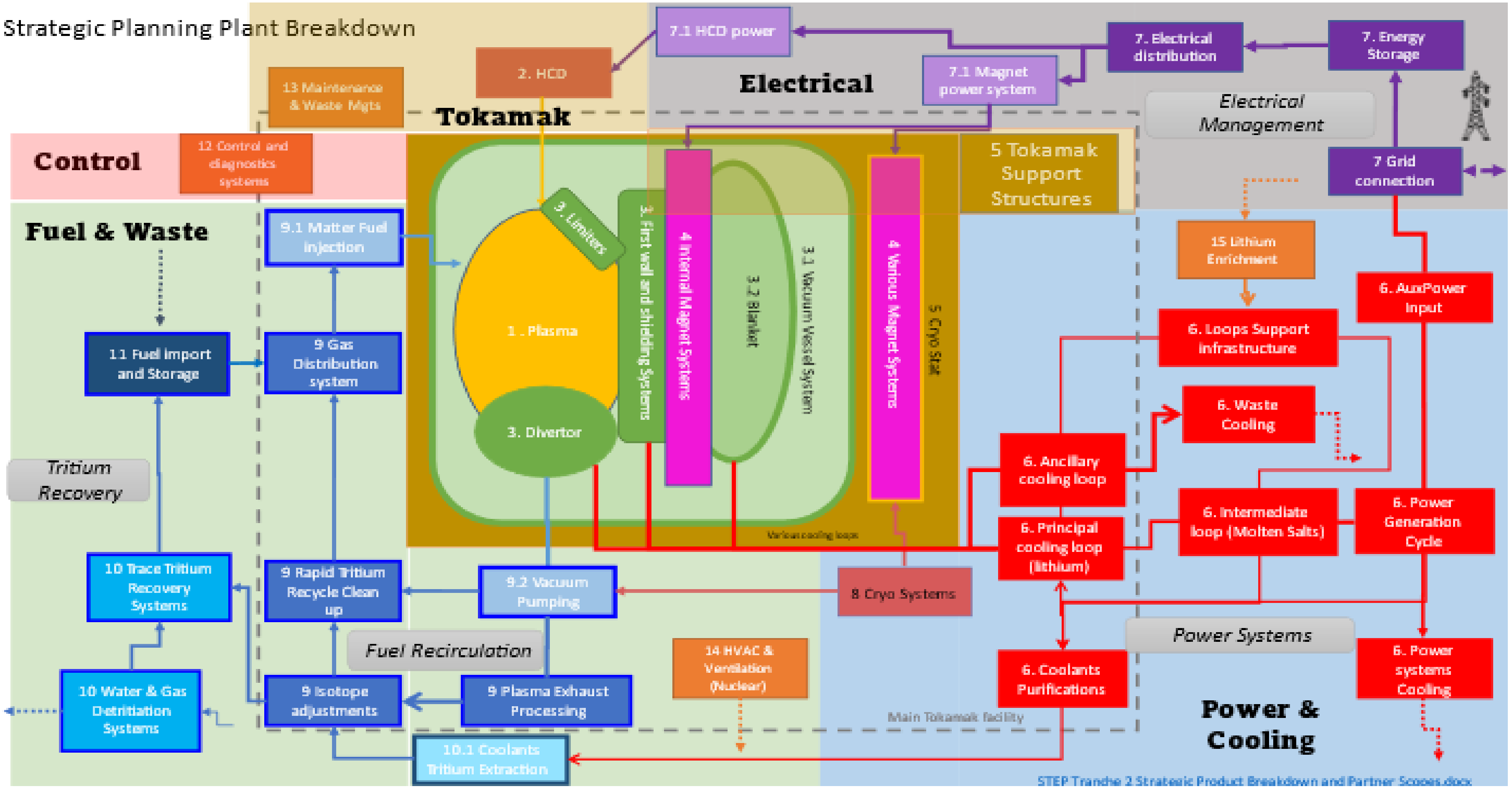
- Federated and integrated information management systems across a broad, diverse and evolving supply chain
  - Addressing a broad spectrum of disciplines from science to construction
- Model-based systems to support both facility definition and innovative manufacturing processes
- Multi-physics, multi-fidelity design space exploration environment
- Rigorous traceability, trust and uncertainty management
- Digital shadow populated by ongoing simulation & test outputs for more informed decisions and enhanced solution selection
- Robust application of BIM* methodologies throughout the plant definition and construction phases

* *Building Information Modelling*

Integration & Regulation

UK Atomic Energy Authority

Information management systems must facilitate enterprise integration and accommodate evolving commercial & regulatory* demands



** Regulatory environment continues to evolve - not part of the Office for Nuclear Regulation*

Integration & Regulation

UK Atomic Energy Authority

Key enablers include

- Democratisation of advanced information systems
  - Delivered through a platform-agnostic, trusted and affordable environment
  - Available and secure
- Affordable access to high performance computing
  - Supporting simulation and uncertainty management
- Synthetic, real-time collaborative environments
- Efficient searching of existing and emerging knowledge bases – widely accessible
- Secure and accessible shared data repositories
  - Ensuring traceability, provenance and trust
  - Supporting long term data curation
- Widespread application and compliance with relevant international standards

Possible solutions

UK Atomic Energy Authority

Information/data creation and management systems are constantly developing

- STEP must pace development and be ready to embrace all opportunities

Innovation in information & data management systems is key to STEP's successful delivery

- Unlocking long term ambitions, whilst consolidating short term foundations

Possible solutions

Potential elements include

- Actionable, interconnected Digital Twins
  - Delivering design space exploration, proven regulatory compliance and knowledge capture/re-use
  - Accommodating multi-fidelity, multi-physics simulation
  - Embracing the Gemini Principles to ensure consistency of approach
- Artificial Intelligence and Machine Learning
  - To expand knowledge envelope and accelerate compliance, safety and functionality analysis
- Innovative, emerging collaboration and information management platforms
  - Transforming collaborative development across the entire product enterprise
  - Providing long term, searchable data curation
- Exascale computing
  - To unlock high fidelity simulation and uncertainty analysis

Facility challenge

Mark Kisbey-Ascott

Plant Operations Lead

UK Atomic Energy Authority

https://www.iter.org/doc/www/content/com/Lists/WebText_2014/Attachments/127/platform_drone_october_2021_1_small_snc.jpg

HinkleyPointC
Helping Britain Achieve Net Zero

https://edf.thirdlight.com/file/1425560347/55520435453/width=-1/height=-1/format=-1/fit=scale/rev=1/t=465660/e=never/k=5e1f4ca3/1.%20HPC%20J-0.%20View%20South%20Across%20the%20conventional%20island.jpg

Site Facilities

UK Atomic Energy Authority

The site has numerous facilities, each with its own unique combination of hazards and challenges.

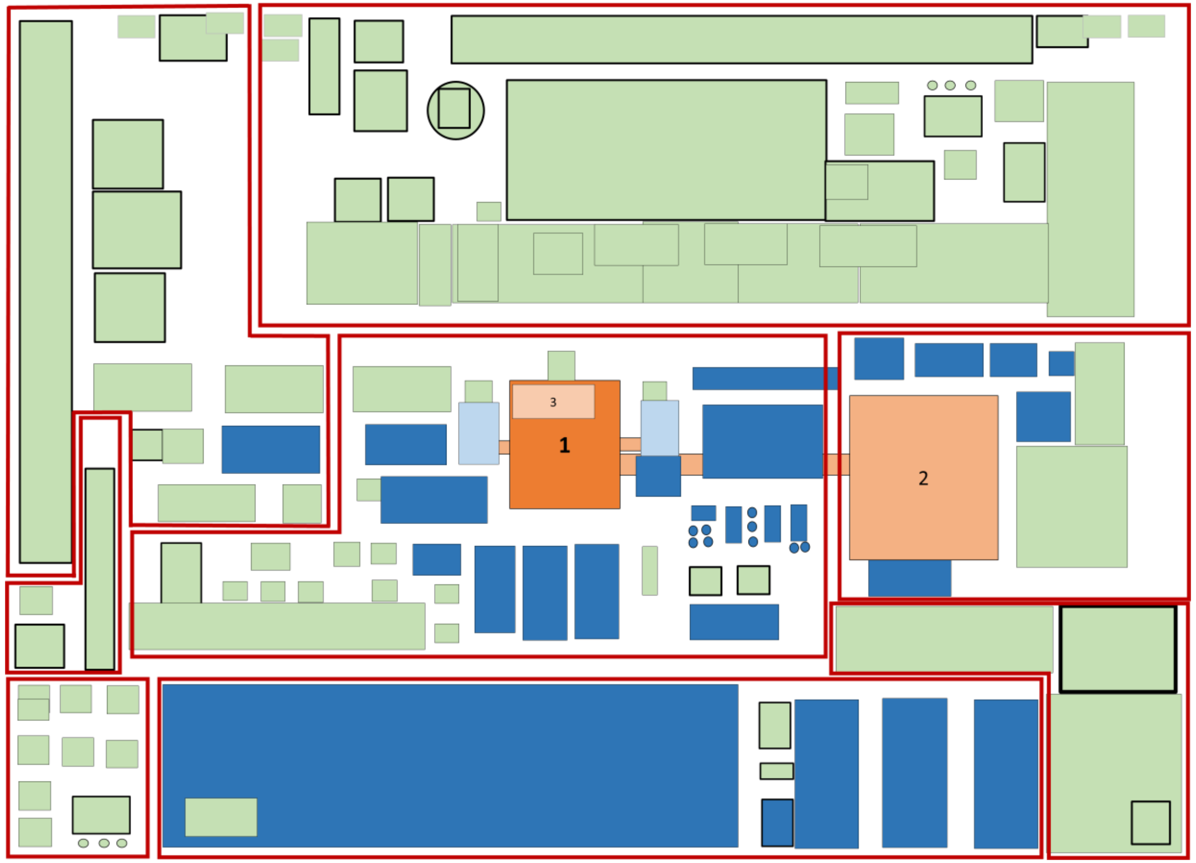
The tokamak must be supported in a suitable facility which is accessible for maintenance and for interfacing systems.

Large capacity ancillary systems must be housed close by and the site is supported by offices, laboratories, and logistical buildings.

Early site layout work has been used to drive site characterisation to aid facility design and development.

The layout roughly breaks down into 3 challenging groups:

1. Novel facilities
2. 'First of their size' facilities
3. 'Common' facilities



Facility Challenges - Novel Facilities

The novel facilities have technical challenges in technology development, integration, and implementation across all engineering disciplines

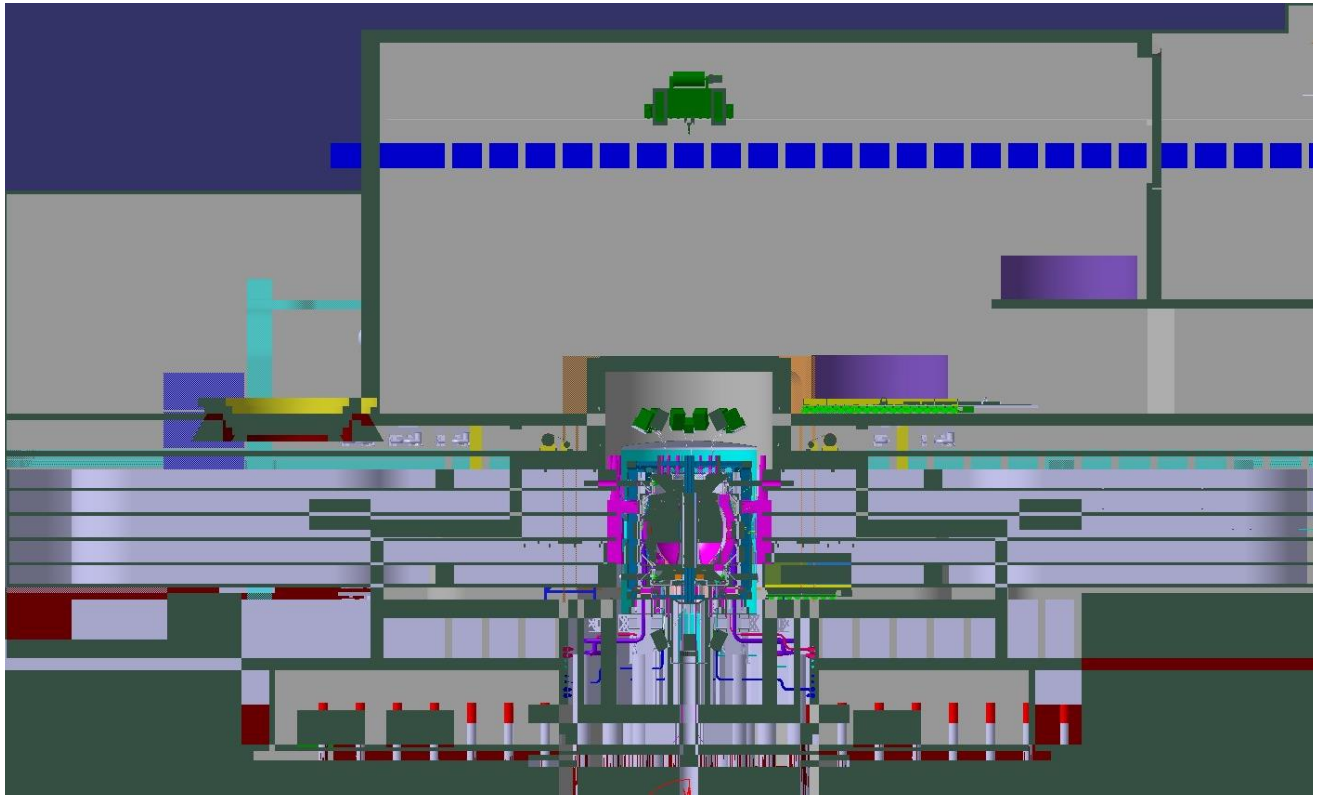
1. The Tokamak Building
2. The Tokamak Logistics Centre
3. The Tritium Handling Facility

Novel Facility 1 - Tokamak Building

UK Atomic Energy Authority

Challenges

1. Tokamak building packaging:
    1. Tokamak and its services
    2. Primary heat exchangers
    3. Tritium recovery & fuel recirculation systems
    4. Lithium conditioning plant
    5. Diagnostics
    6. Tokamak pressure release vessels
    7. Primary system pressure relief
    8. Remote maintenance access
2. Shielding
3. Structural Support
4. Construction with large excavation
5. Availability
6. Interfacing between building and tokamak systems



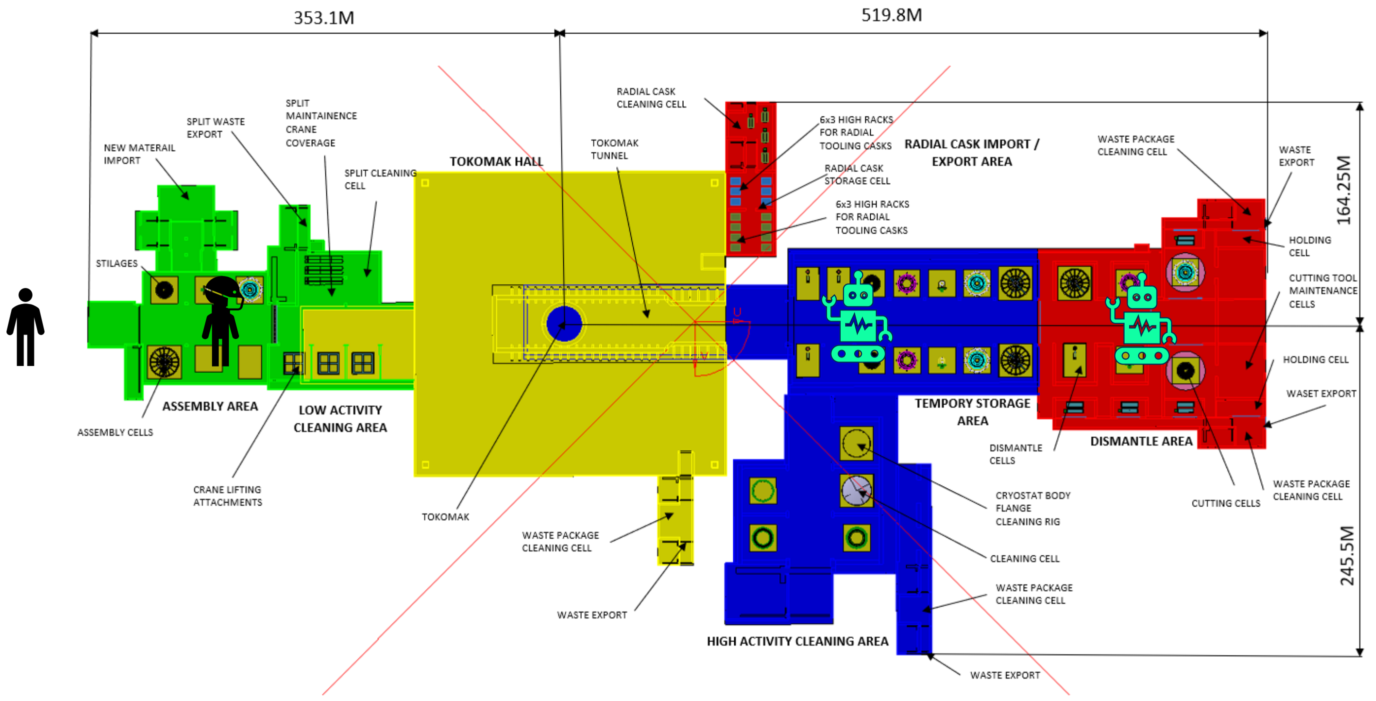
Novel Facility 2 - Tokamak Logistics Centre

The tokamak components, when replaced, are irradiated, and must be stored and processed.

The tokamak logistics centre imports new, clean components for installation and processes used, radioactive line replaceable components.

Challenges

1. Shielding
2. Structure and Layout
3. Handling of large, heavy irradiated components
4. Remote maintenance flexibility

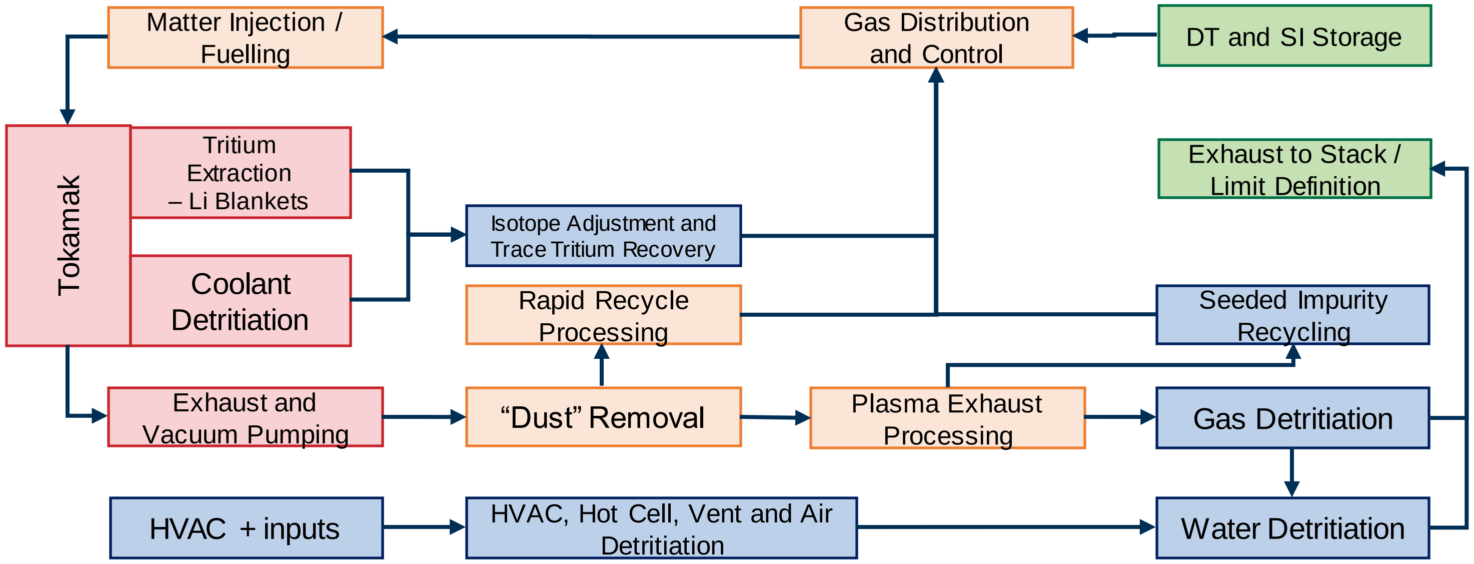


Novel Facility 3 - Tritium Handling Facility

The tritium handling facility is the primary location for processing, storing and distributing Tritium and other fuels.

Challenges

1. Tritium Inventory Management
2. Tritium Containment
3. Interfaces with lots of systems
4. Technology development



Facility Challenges - First of its size facilities

The first of its size facilities describe buildings and systems which have been created before, but have not yet been used at this scale.

A large proportion of the site are given to the balance of plant systems. These typically support the tokamak in operating and exporting power.

Facility Challenges - First of its size facilities

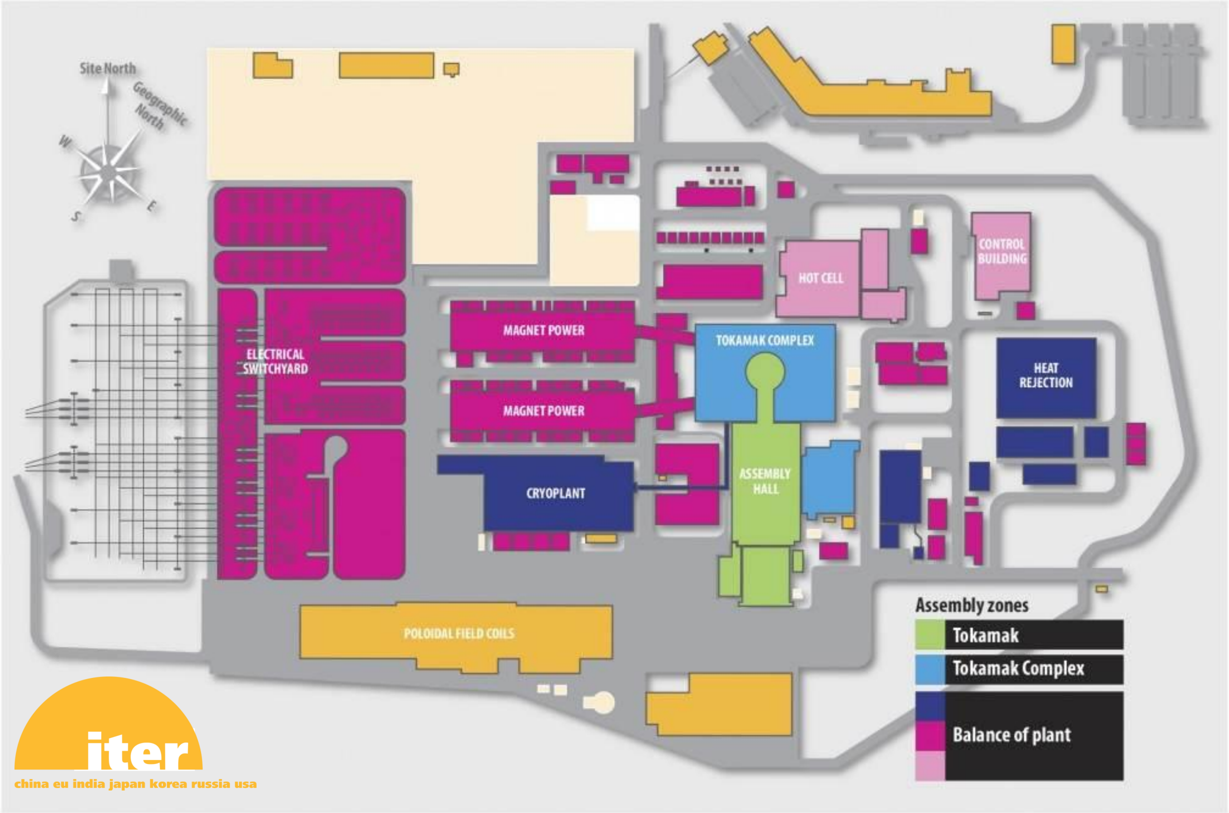
UK Atomic Energy Authority

Example facilities

- Heating and Current Drive
- Power suppliers
- Switchyard(s)
- Cryoplant
- Magnet manufacturing
- Heat Rejection
- Power Generation

Challenges

1. Scaling the current technologies
2. Required proximity to tokamak
3. Interfacing between building and systems

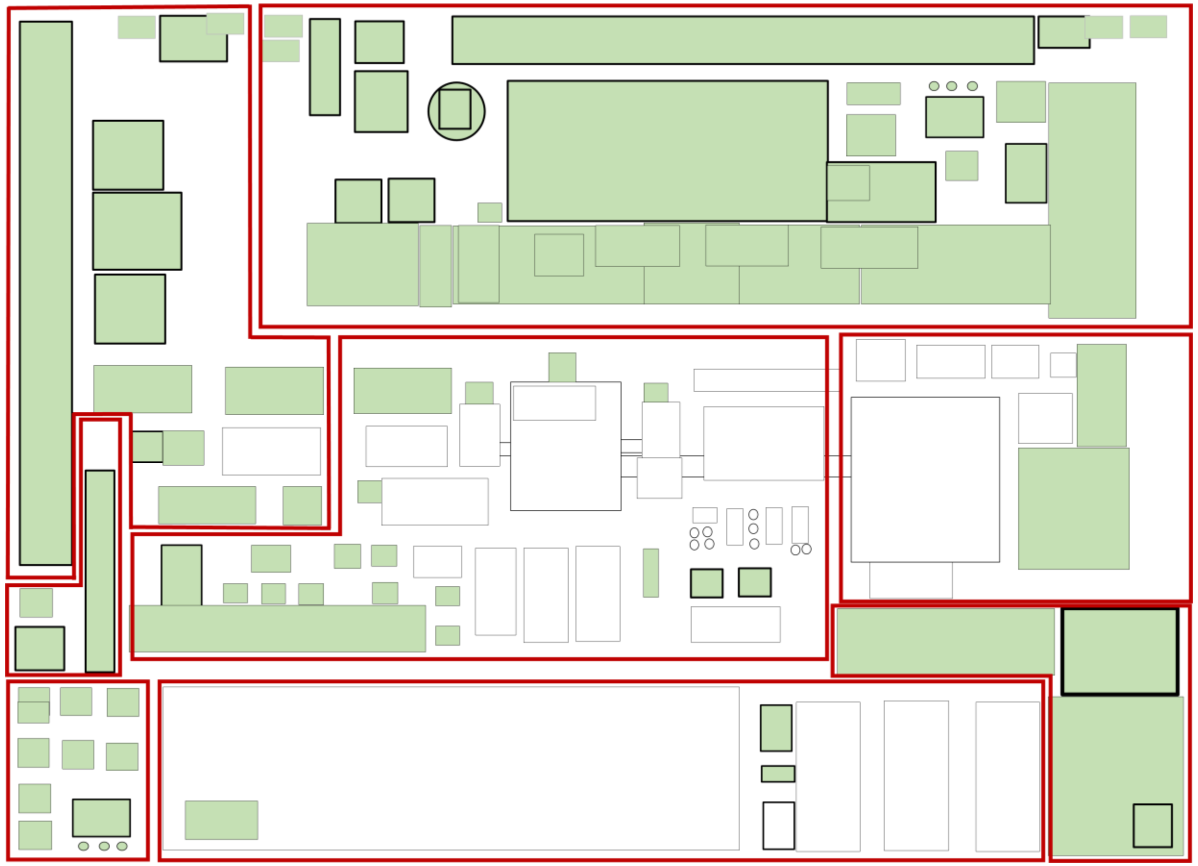


Taken from Iter: https://www.iter.org/construction/AssemblyOverview

Facility Challenges
"Common" Facilities & Large Site Management

"Common" refer to other facilities which aren't as challenging by themselves, but as a large site, add complexity.

These facilities are numerous and spread across the site and include facilities such as office buildings, storage spaces, control rooms, hands-on laboratories, industrial waste handling etc.



Facility Challenges
"Common" Facilities & Large Site Management

UK Atomic Energy Authority

Challenges

- Site construction scheduling
- Interfacing between numerous buildings
- Temporary storage, areas and works
- Working to a challenging schedule
- Safety management on site
- Logistics management on site

UK Atomic Energy Authority

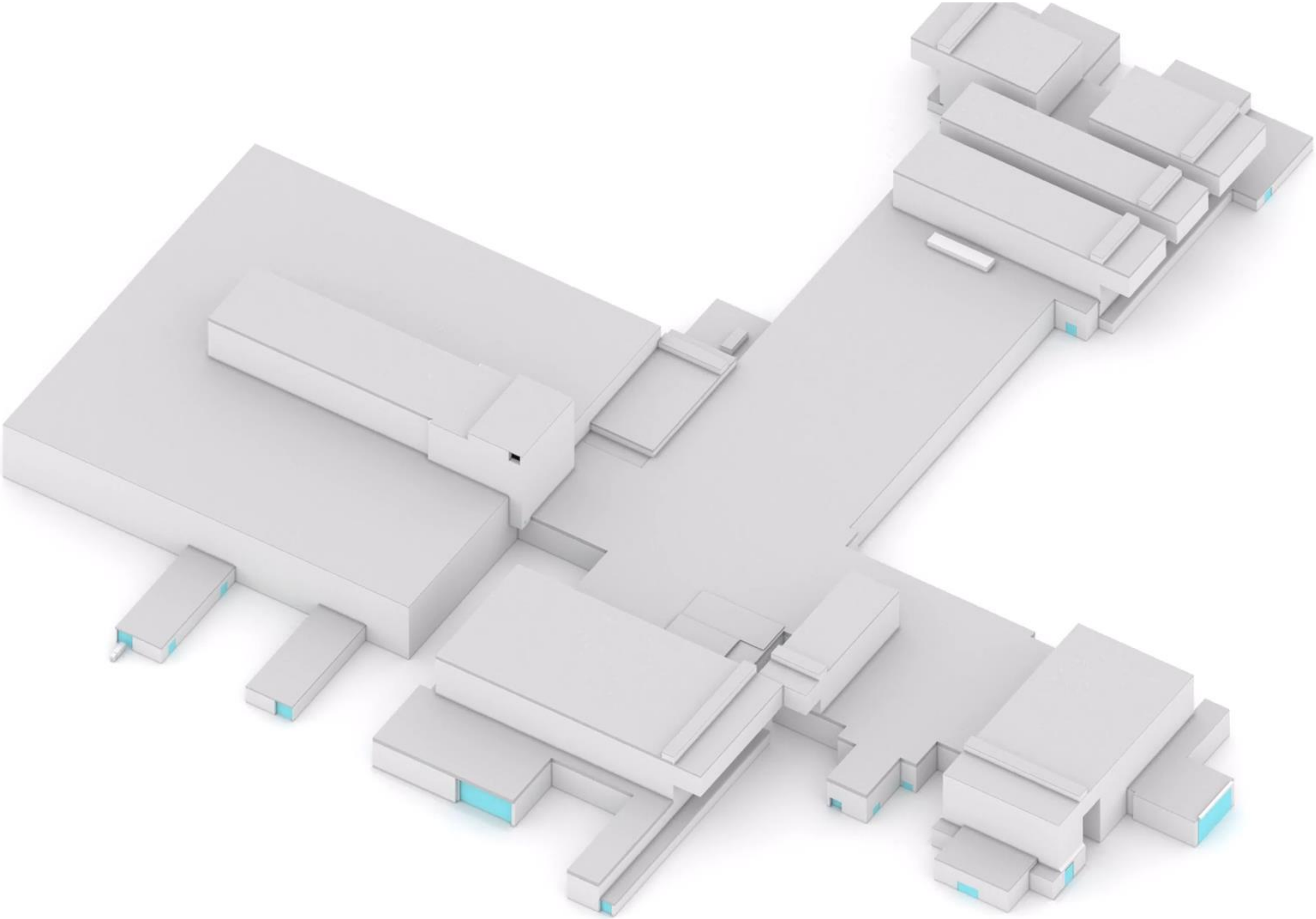
Field assembly and remote maintenance challenge

Roel Verhoeven CEng, FIMechE

STEP Engineering Manager

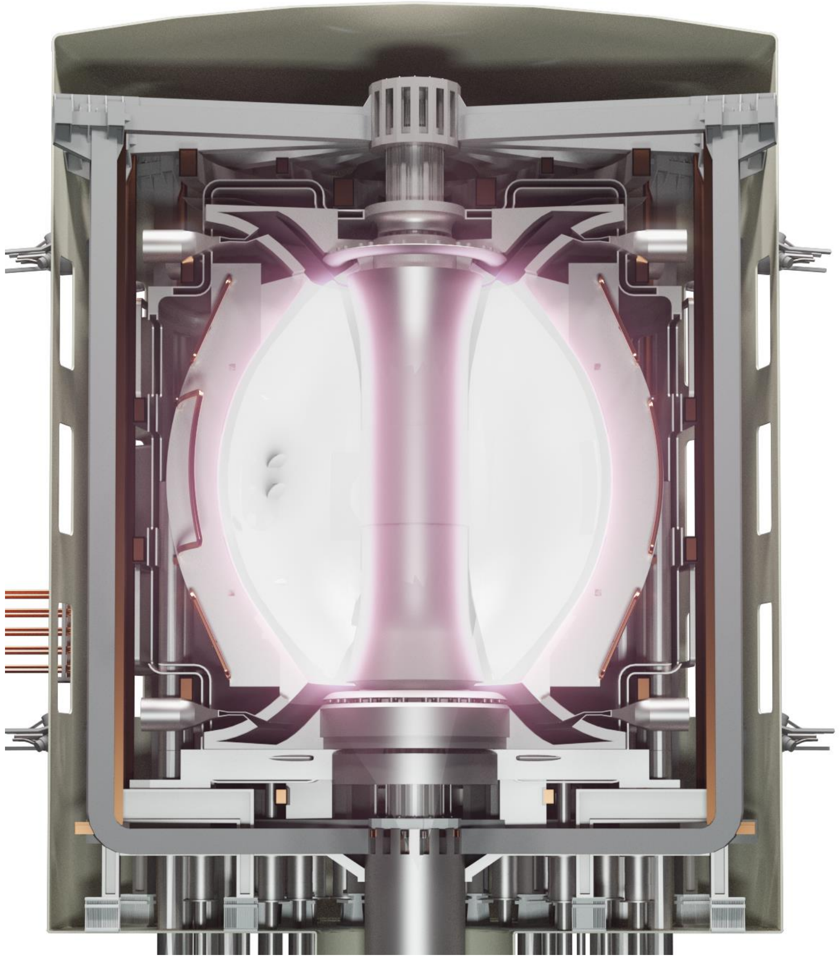
Tokamak Logistics Centre Video

UK Atomic Energy Authority



Note: the designs shown in this video are indicative and some of them are out of date

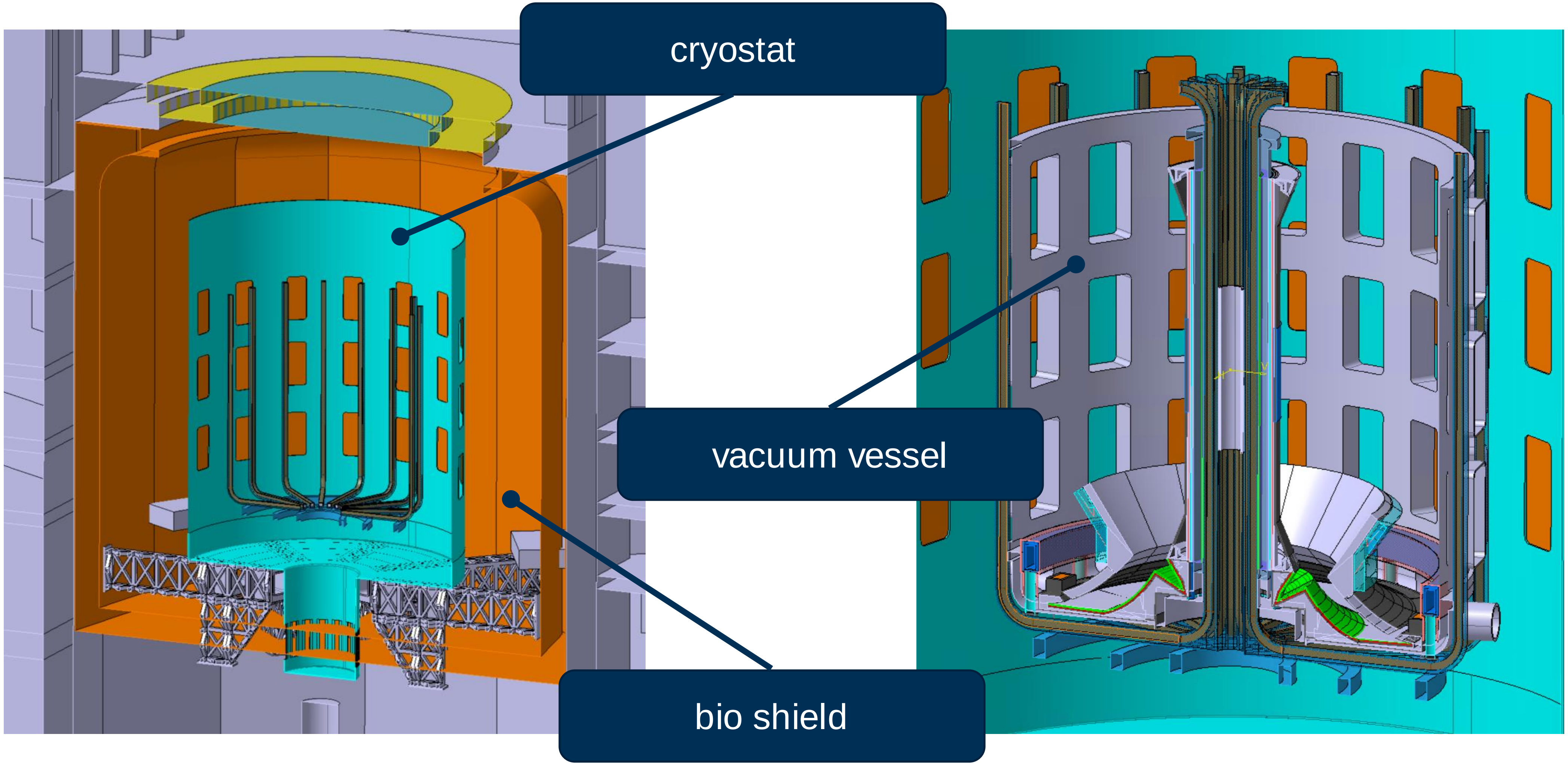
Main assembly & maintenance



- Fully remote maintenance and assembly (although initial build and initial operation phase may permit human access)
- Wide range of temperatures of components (20K to 600degC)
- Accurate positioning essential
- Connecting and disconnecting services
- Large forces when in use
- Heavy components (~1000tonnes)
- Operational deformations of materials

Tokamak anatomy

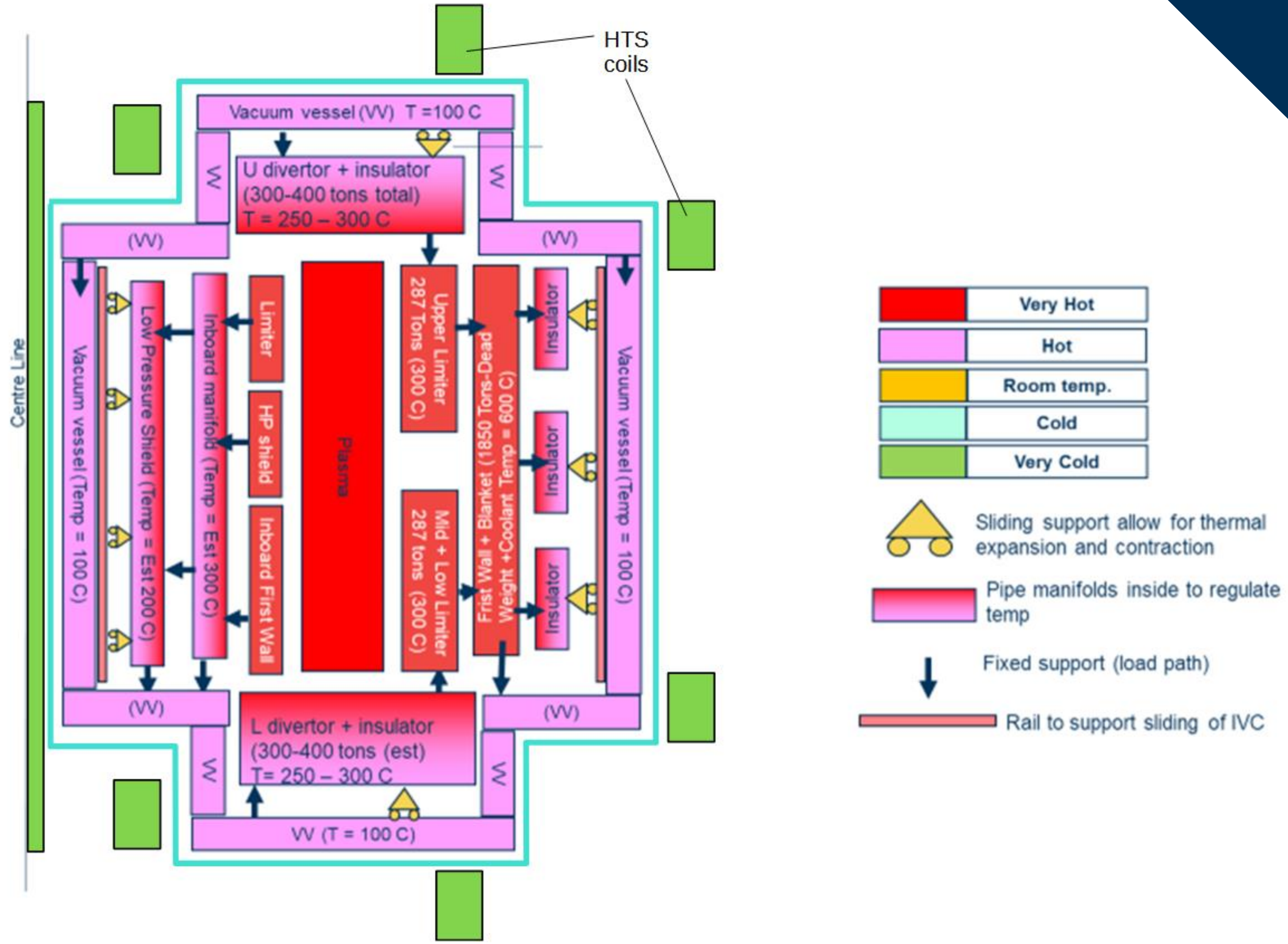
UK Atomic Energy Authority



Thermal

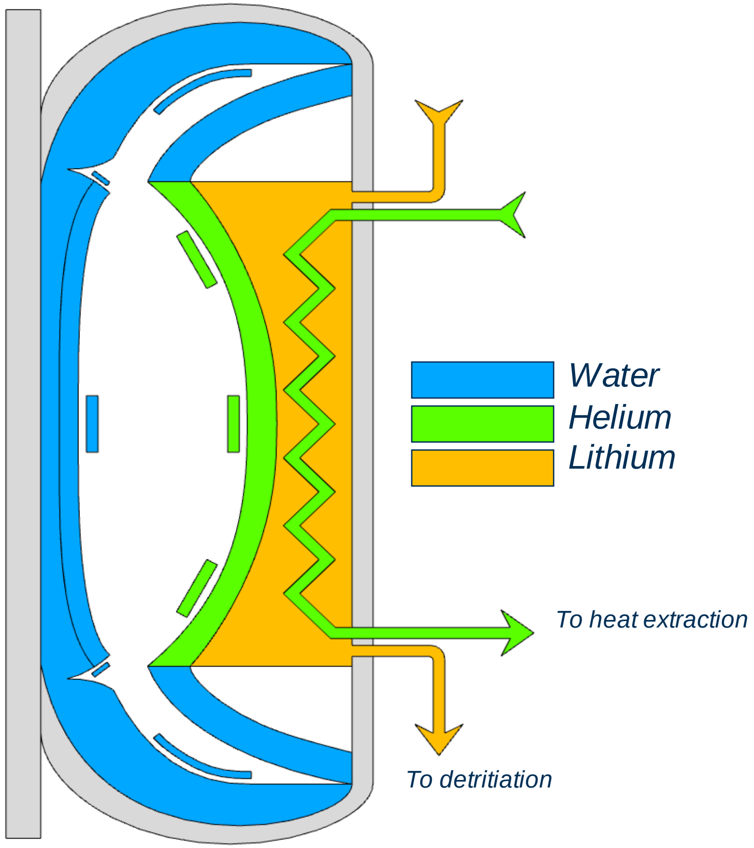
Very large temperature differences within the STEP machine

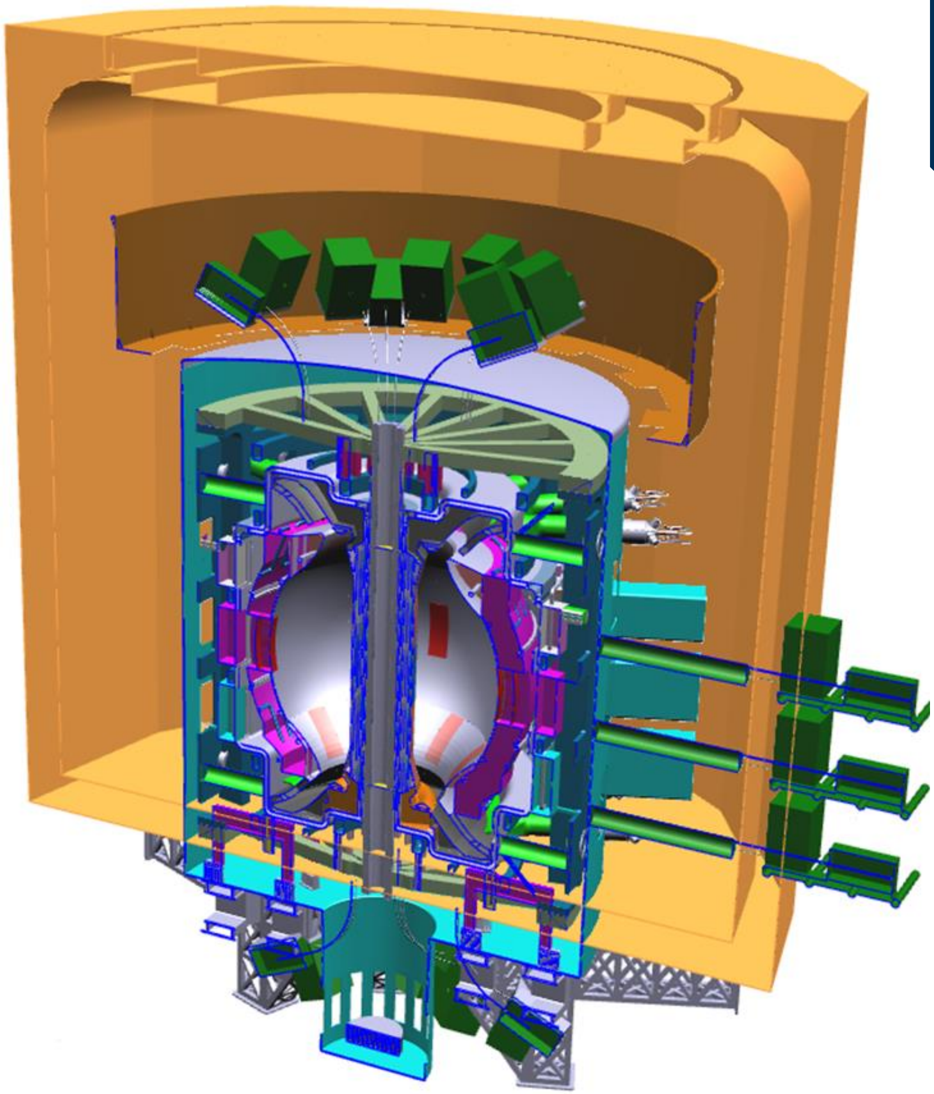
- differential thermal contraction
- requirement to limit heat loading onto very cold components (superconducting coils)
- inherent tension between limiting heat flow and supporting large forces



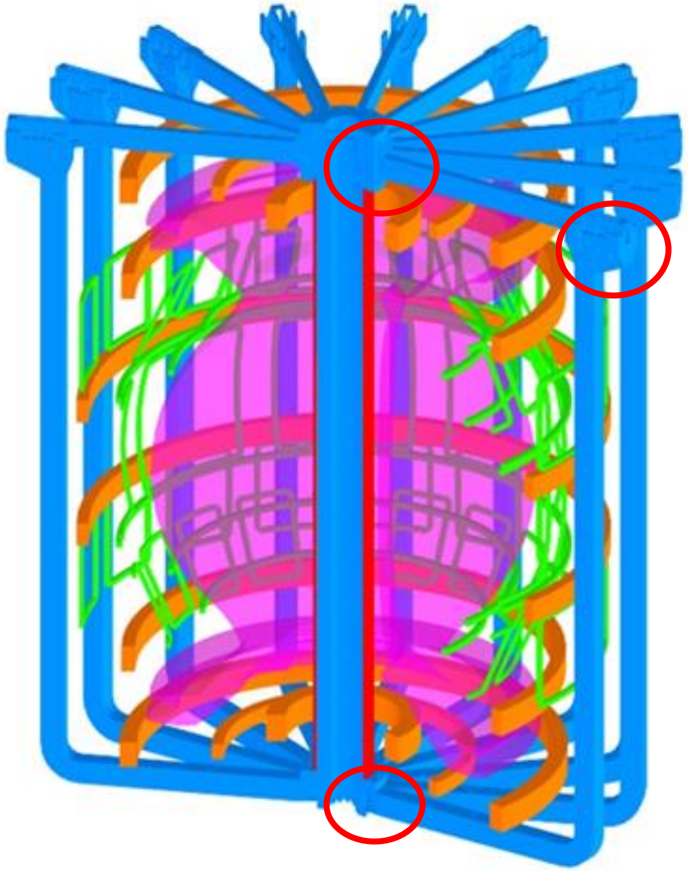
Services

- Power
- Fluids
  - cryogenic helium
  - molten lithium
  - water
  - hot helium
- Diagnostics





Re-mountable electrical TF joints



The magnetic cage consists of a combination of (mostly) superconducting and (some) resistive coils

To allow maintenance and installation the TF coils feature re-mountable connections in the HTS coils

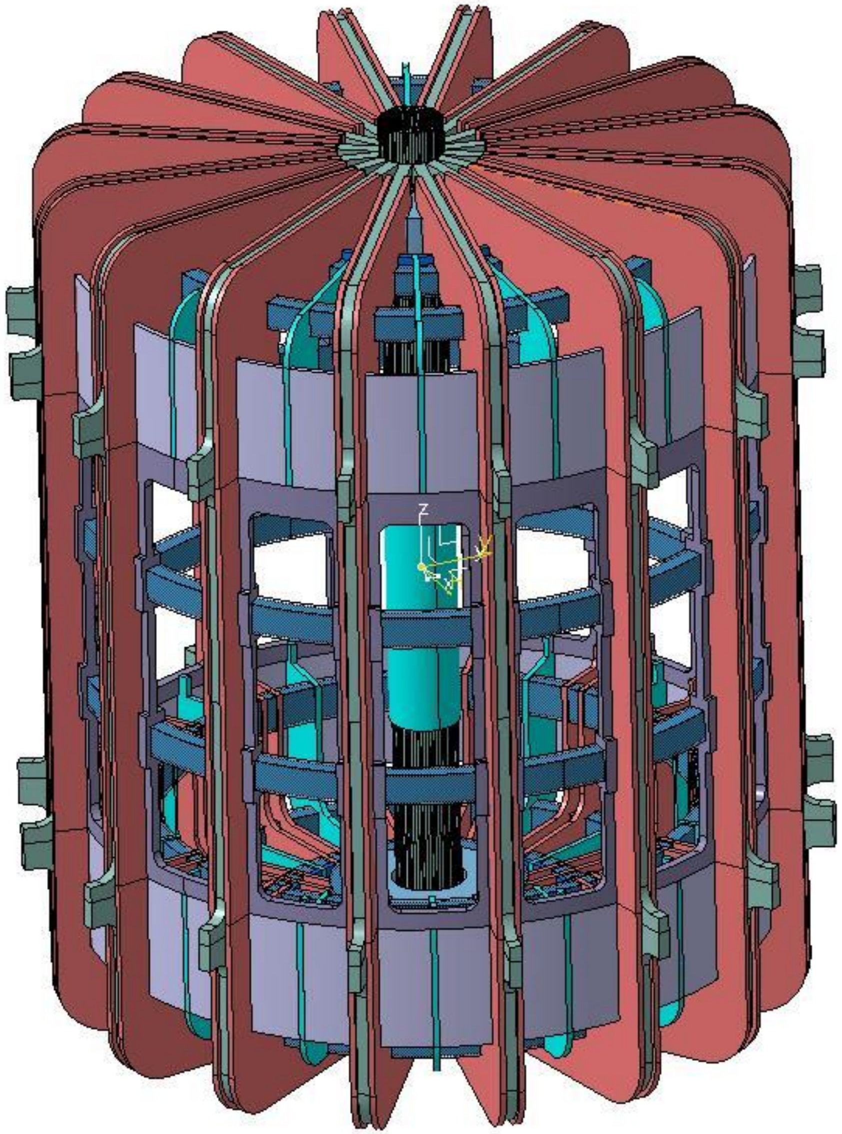
There are about 960 of these, each carrying about 60kA

The resistance needs to be about 1 nΩ in order not to require too much cooling power

Potential solution is to use differential contraction to provide preload onto electrical connection

Magnet assembly and support structure

UK Atomic Energy Authority

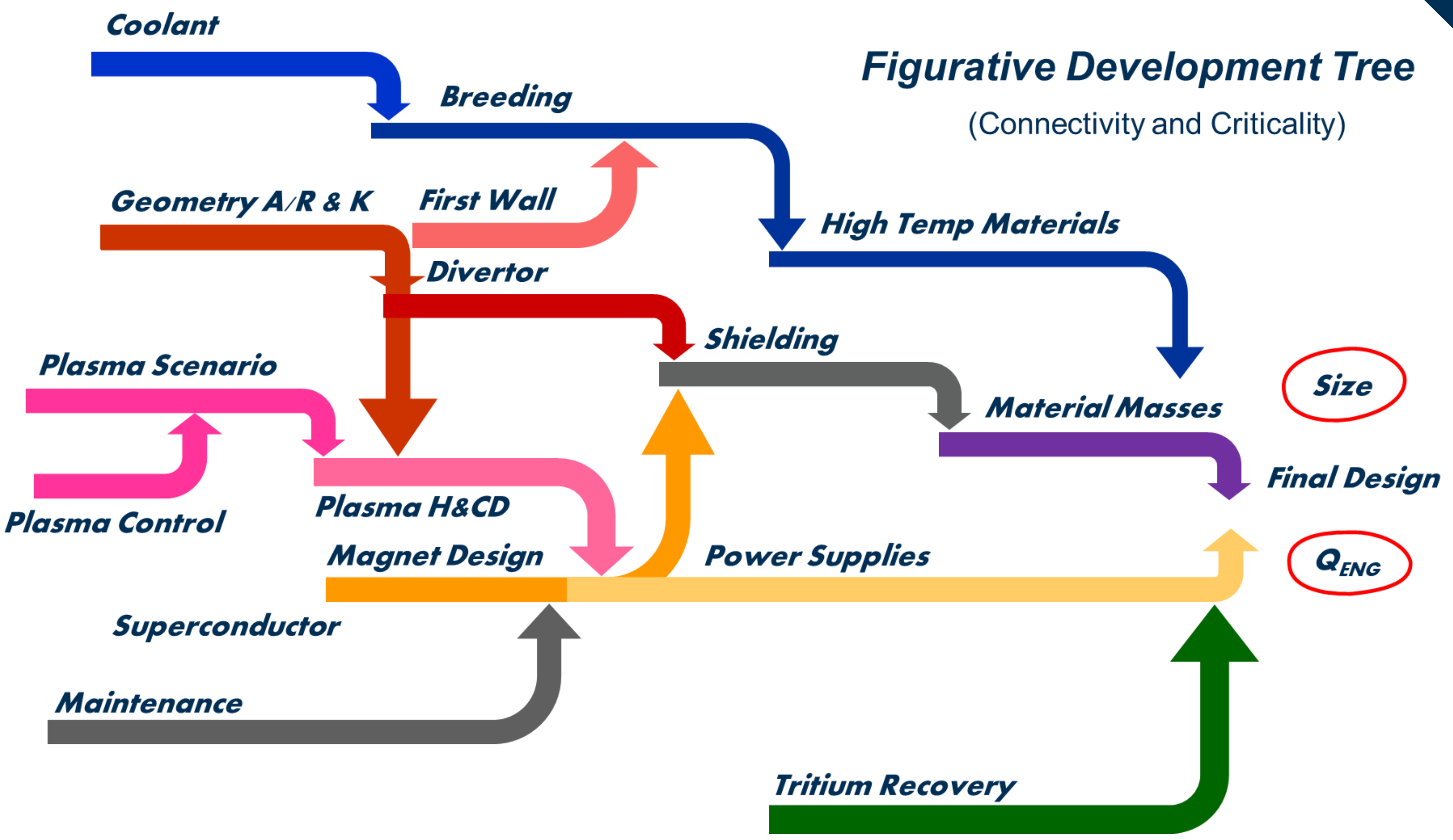


- Very high electromagnetic bursting forces in TF coils (50MN) require very robust coil support structure.
- Structure needs to be compatible with maintenance strategy
- The area close to the centre is a challenge due to tight space constraints

Interconnected Design Challenge

UK Atomic Energy Authority

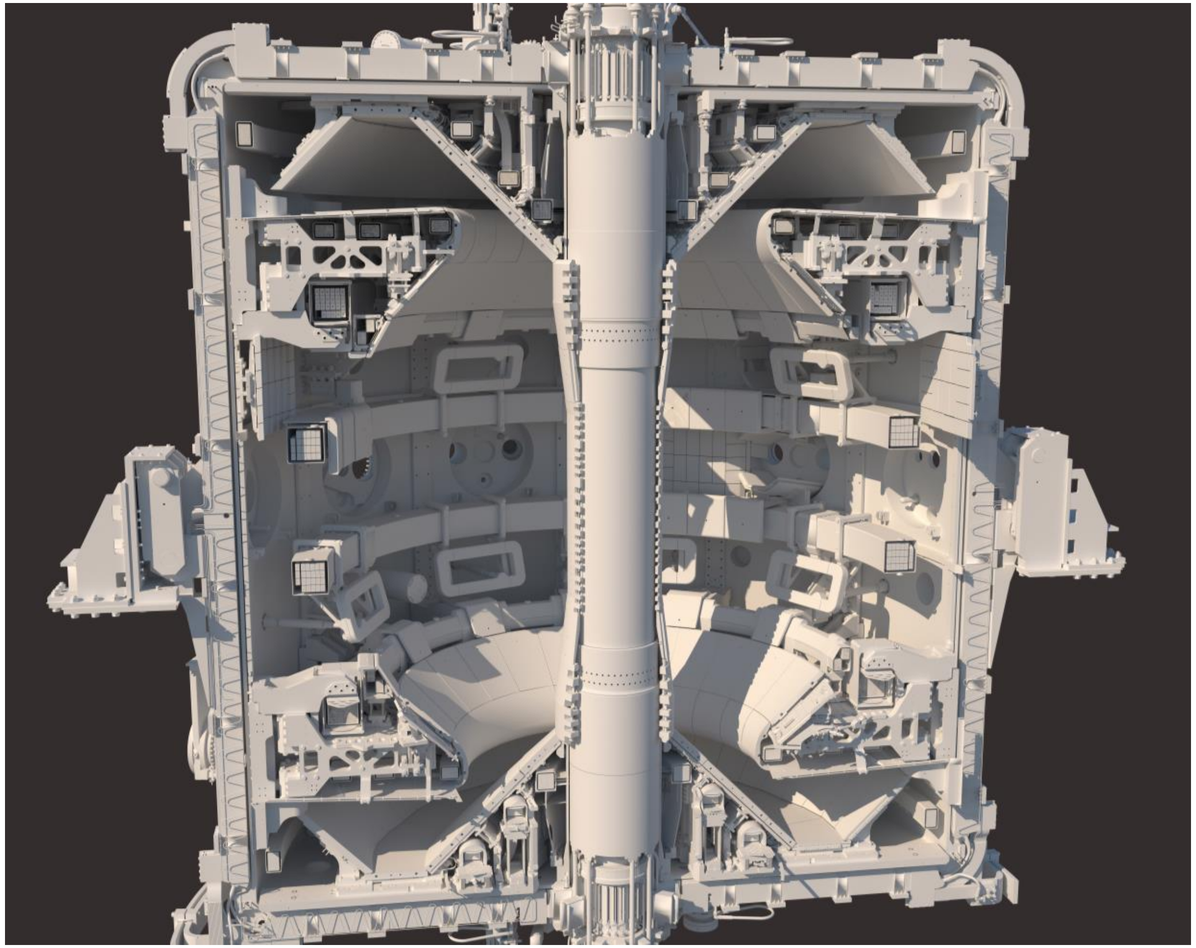
- Many aspects of the STEP design are inter-related
- Components cannot be designed in isolation (or at least not in the early stages)
- A one-team approach is therefore vital



Fusion & design expertise

UK Atomic Energy Authority

- The UKAEA STEP team has extensive fusion experience
- Design expertise has been gained from the domestic fusion programme and collaborations with the wider fusion community
- Due to the scale and complexity of STEP, the expertise of an industrial engineering partner and construction partner will be vital.

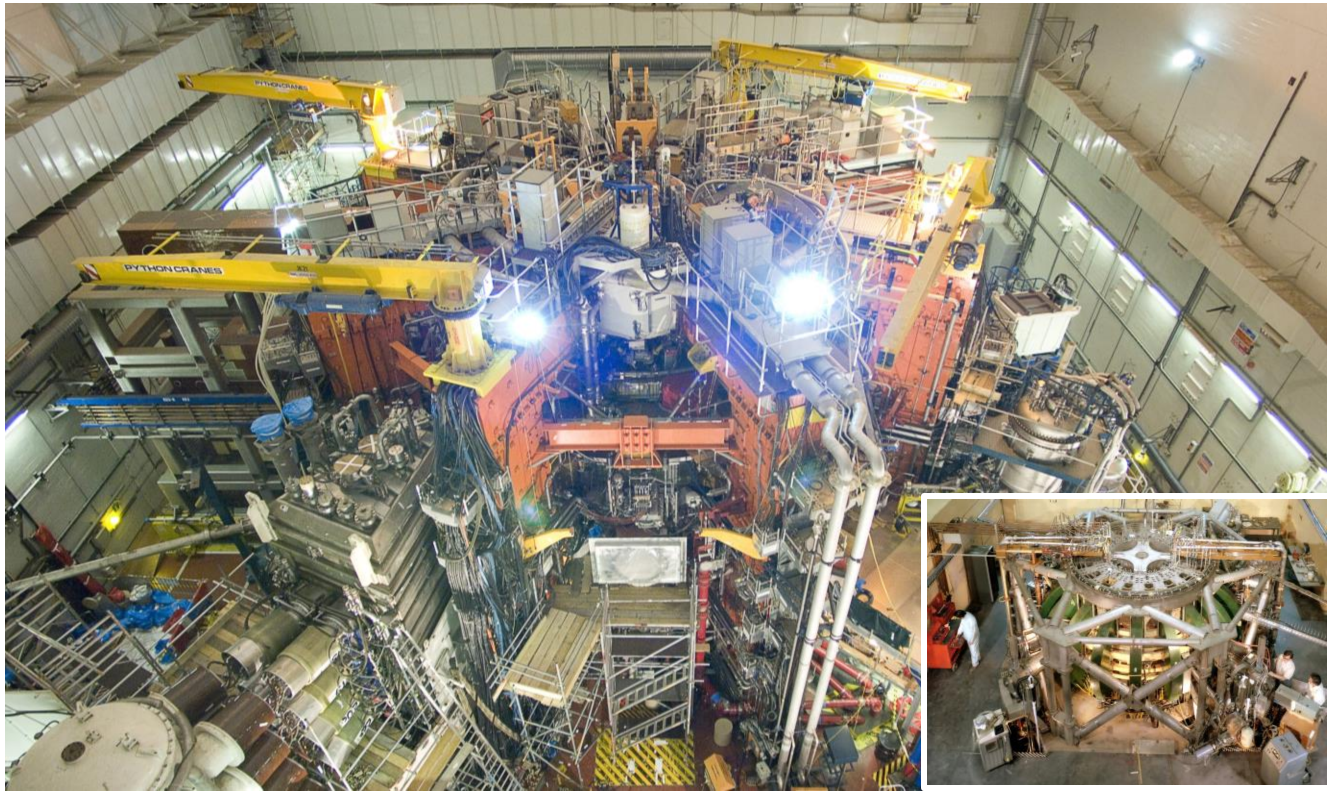


MAST-U cutaway

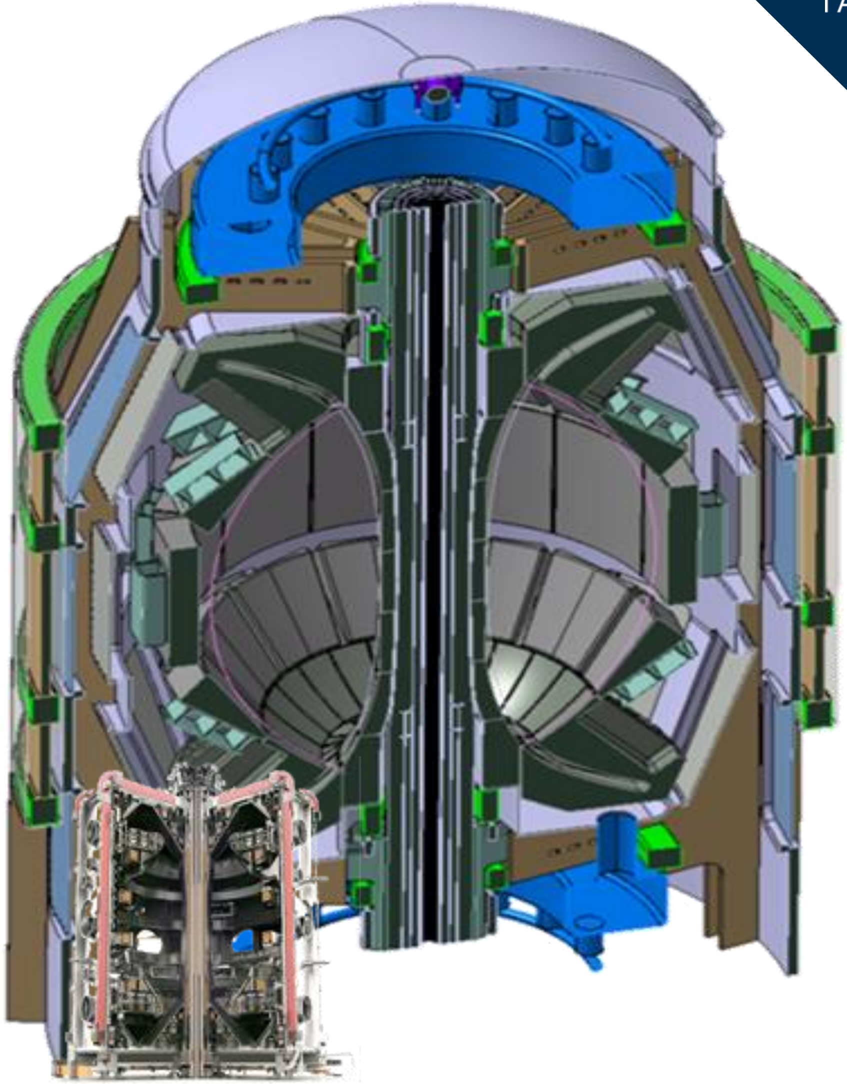
So, to round up..

Chris Waldon

Looking back to look forward…



PLT (R=1.2m) → JET (R=3m), with no decent models at the time
JET was 0.01% p.a. of UK GDP in 1977



MAST-U (R=0.9m) → STEP (R~3m)
STEP might be ~0.05% p.a. of UK GDP (in 2020)

So, what happens next?

Sarah Palmer

So, what happens next?

- **Further market engagement events will be held on**
  - Whole Plant Partners (WPP) - technical
  - WPP - commercial
  - Overall supply chain

- **Request for Information questionnaires (RFIs) will be issued**
  - Further understanding of current market capabilities and capacities
  - Market feedback and appetite on key areas of the WPP procurement

UK Atomic Energy Authority

Thank you.

Please take a few minutes to complete the feedback forms.

Any questions, contact procurement@step.ukaea.uk
If you'd like to find out more about fusion or UKAEA please take a look at these resources:
https://www.gov.uk/government/organisations/uk-atomic-energy-authority
https://ccfe.ukaea.uk/
www.step.ukaea.uk
https://www.youtube.com/channel/UCyb9vG8oLE4XvZZLYpcDcFw

UK Atomic Energy Authority

STEP

Whole Plant Partners engagement

22 February 2023