STEP Inboard System – Architecture and Technology Development Overview

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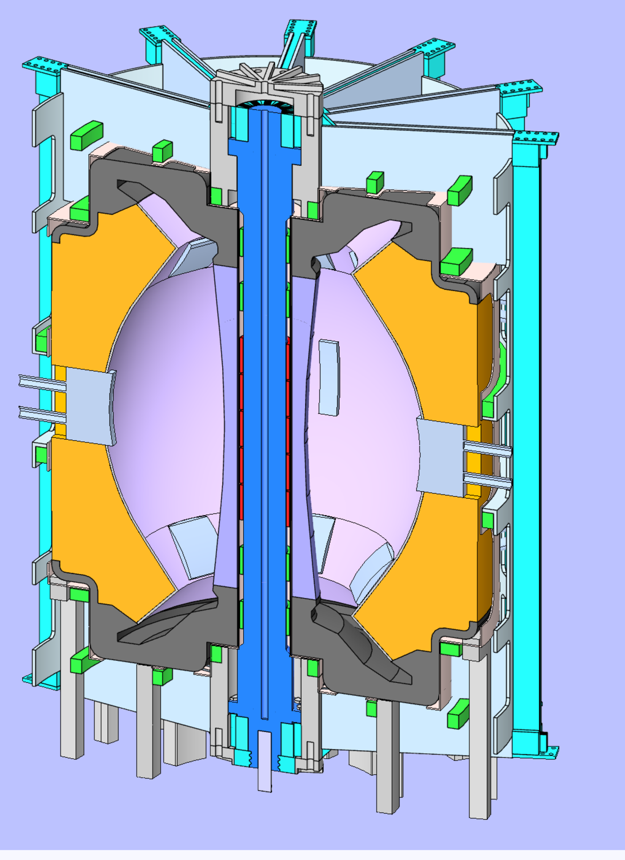
Abstract

The STEP programme has the mission to deliver a UK prototype fusion energy plant, targeting 2040 and a path to commercial viability[1].

The design of inboard build is a fundamental challenge for the STEP Prototype Plant (SPP). The spherical tokamak geometry of the SPP means the inboard radius drives the size, and hence overall cost, of the machine[2]. The SPP Inboard System protects the central column magnets from heat, particle, and neutronic loads while using this captured energy for power generation. Innovative designs and novel technologies are needed for the SPP Inboard System to fit these spatial constraints, particularly considering the complex integration with the magnet systems.

The architecture of the inboard system consists of three distant radially-layered regions: I. Vacuum Vessel & Low-Pressure Shield, II. High-Pressure Shield, and III. Inboard First Wall [3].

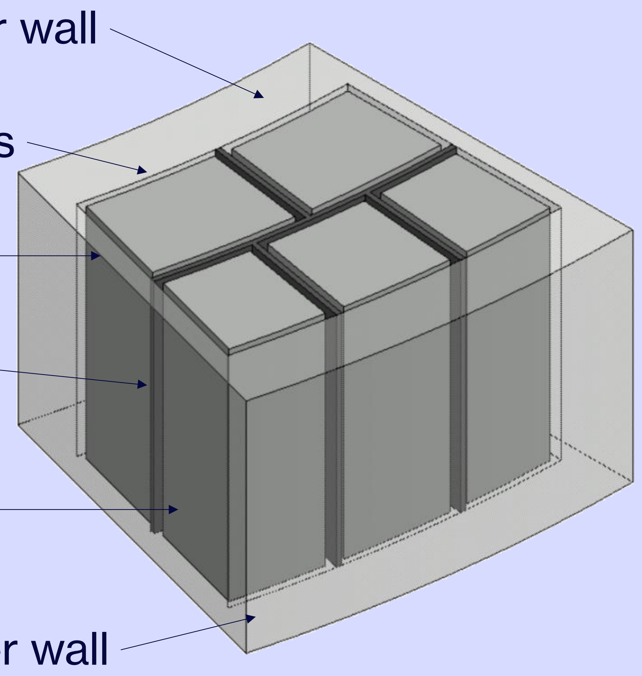
STEP



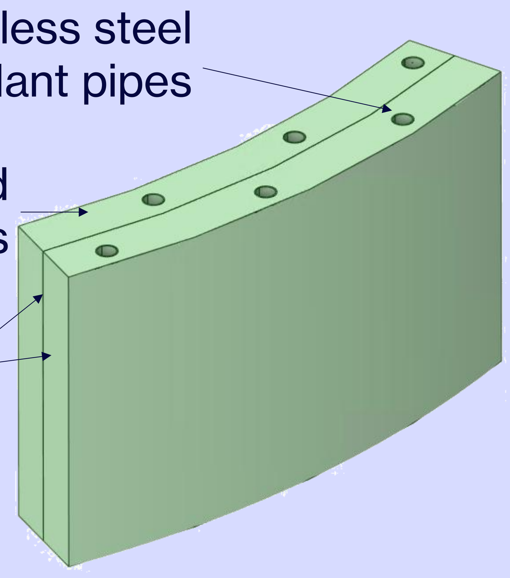
Fusion Power	1.6-1.8 GW
Net electric power	100-200 MWe
Inboard Build	1.9 m
Major Radius	4.275 m
Magnetic Field	3.0 T
Plasma current	20-25 MA
Elongation	~3
Triangularity	~+0.5
Plasma Edge	Edge Pedestal
HCD Mix	EC + EB
Primary Divertor Configuration	Dynamic DN
Secondary Divertor Config (Inboard)	Flat Top: X Type Ramp Up: Perpendicular
Secondary Divertor Config (Outboard)	Extended Leg
TF Conductor Type	REBCO
Primary Maintenance Access Route	Vertical
Remountable Toroidal Field Coils	12 TF coils (3 Remountable joints per TF)
Peak Steady State Divertor Heat Flux	<20 MW/m^2
Tritium Breeder Material / Breeding ratio	Li_2O / >1.0
Centre Column / Divertor Coolant	D_2O & H_2O / CO_2 & H_2O
OB First Wall, Blanket, OB Limiter Coolant	CO_2 / He
Blanket Coolant Outlet Temperature	600°C

STEP Inboard Architecture

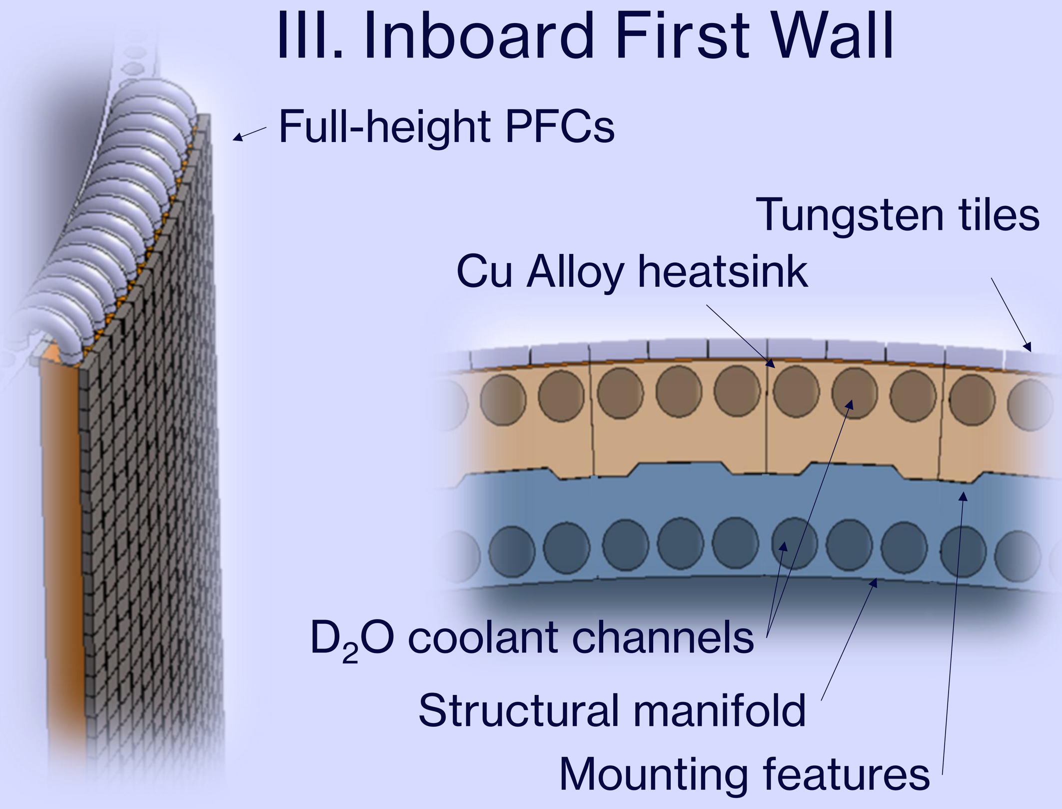
I. Vacuum Vessel & Low-Pressure Shield



II. High-Pressure Shield



III. Inboard First Wall



I. Vacuum Vessel & Low-Pressure Shield

Primary function:
- Attenuates remaining neutrons to magnet-compatible levels.
- Form the inboard part the vacuum barrier

Concept Design:
- Tungsten-based shielding blocks located within the VV H_2O cooling channels attenuate neutrons.
- Alignment features (inter-block, and block-to-VV) minimise shine paths, position blocks, and allow for irradiation swelling and differential thermal expansion.

II. High-Pressure Shield

Primary function:
- Attenuates (reflects, scatters, absorbs, slows down) neutrons and transfers resulting heat to a coolant for useful power generation.

Concept Design:
- Tungsten-based shielding blocks attenuate neutrons and conduct heat to embedded pipes.
- Embedded pipes allow high-pressure, high temperature water coolant, enabling useful power generation.
- Inter-block features for structurally connecting and aligning blocks, and minimising shine paths.

III. Inboard First Wall

Primary function:
- Protects other inboard components from heat & particle loads of the plasma
- Provides heat for useful power generation

Concept Design:
- W tile on Cu alloy water-cooled Heatsink PFCs for max thermal performance
- Enables long PFC lengths, potentially up to 'full height' of central column
- Stainless steel structural manifold supports PFCs through mounting features and returns used coolant.

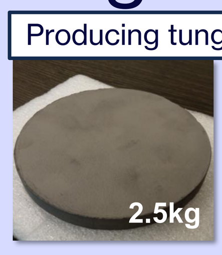
Materials, Manufacturing & Testing

Materials

Producing stainless steel plates

- Producing alloyed ingot
- Plate rolling & machining
- Composition analysis

Producing tungsten-based shielding material



- Composition exploration
- Forming trials
- Composition & phase analysis
- Scaling-up of process
- Mechanical Testing
- Ion-irradiation

Manufacturing

W tile on Cu alloy manu. trials
- W- Cu alloy joint trials
- Inspection & testing of joints

Shield block demonstrators
- Shield block forming
- Detailed features
- Assembly of blocks
- Joining trials

Shield embedded pipe trials
- Joining steel pipes to shield block
- Joining block-to-block

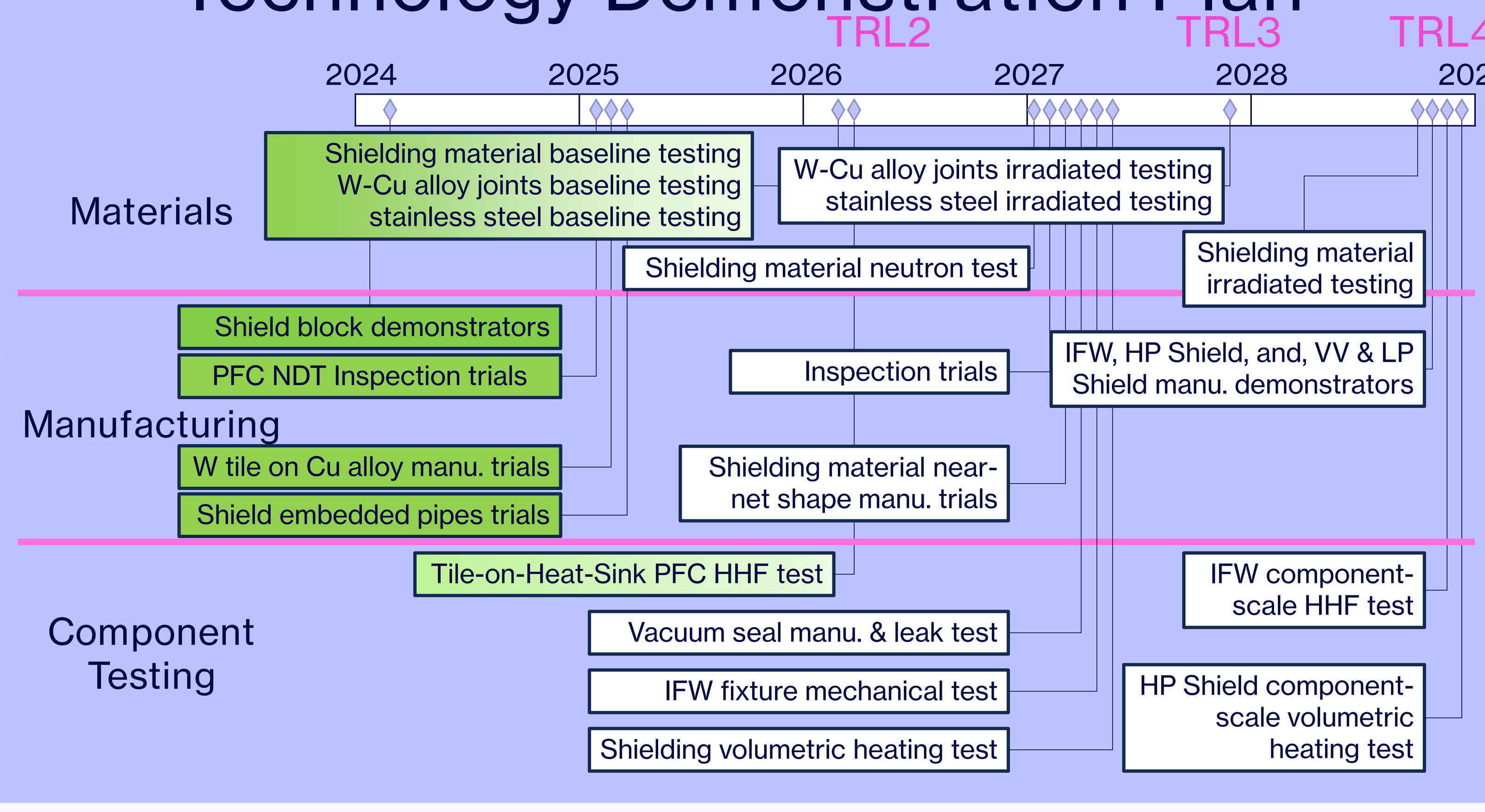
Component Testing

PFC NDT inspection trials
- Ultrasonic NDT inspection of PFCs
- Thick W armour inspection

Tile-on-Heat-Sink PFC HHF test (in progress)
- High heat flux testing of PFC
- Cyclic loading
- Post-mortem characterisation and interrupt results

Recent activities in materials development, manufacturing trials and component testing so far in support of technology demonstration of the STEP inboard system.

Technology Demonstration Plan



Technology demonstration plan covering the materials, manufacturing and component testing activities for the inboard system with the target of achieving at least Technology Readiness Level (TRL) 4 by 2029.

[1] C. Waldon et al., "STEP FORWARD: Building a first-of-a-kind fusion plant", SOFE, 2025
[2] J. Cane et al., "Managing the heat: In-Vessel Components," Philos. Trans. R. Soc. A., vol. 382, 2280, 2024
[3] J. Lilburne et al., "STEP Inboard Concept Design Architecture", SOFE, 2025