UK Atomic Energy Authority

SYSTEMS CODES RAPPORTEUR PART I

PREPARING SYSTEMS CODES FOR POWER PLANT CONCEPTUAL DESIGN

J. Morris, M. Coleman, S. Kahn, S.I. Muldrew, A. J. Pearce, D. Short,
J. E. Cook, S. Desai, L. Humprey, M. Kovari, J. Maddock, D. Vaccaro

Introduction

Current status

PROCESS and BLUEPRINT used in EU-DEMO and STEP pre-conceptual design phases

- Additional UKAEA focus on building up spherical tokamak model detail in codes.

Systems codes at UKAEA are being retooled for later stages of conceptual design.

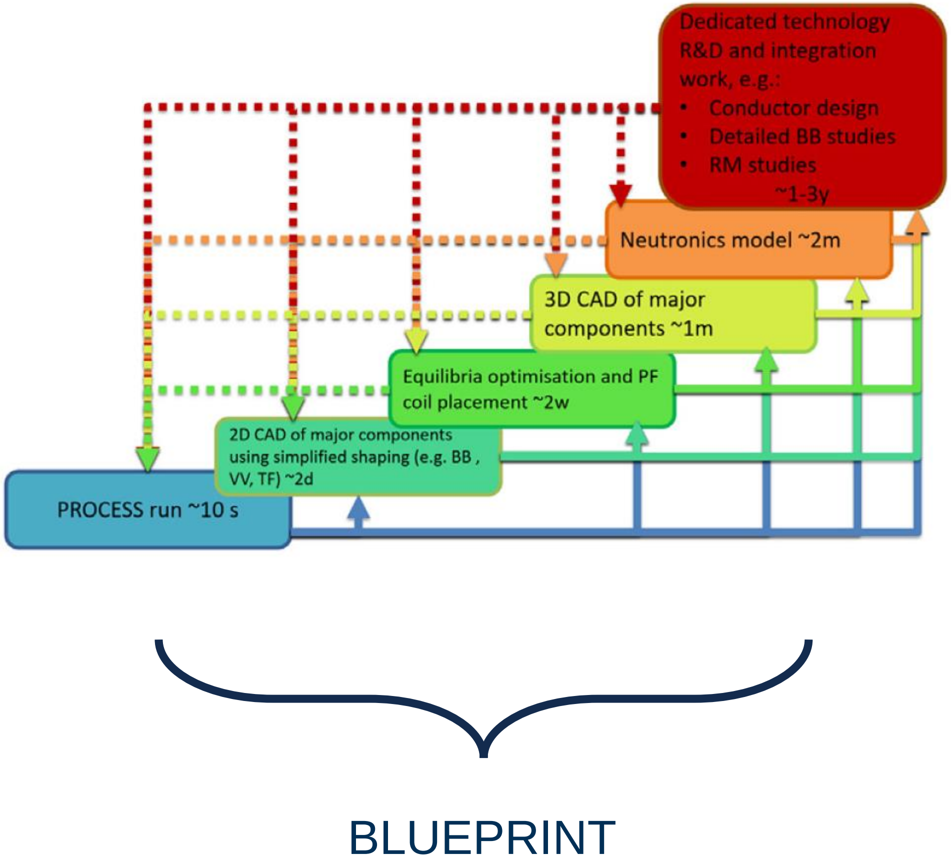
Aim is to move systems codes to cover the middle of the design cycle.

- BLUEPRINT already covers a number of these areas

Evolve PROCESS to be modern python package library for 0-D, 1-D modelling.

EUROfusion TSVV-14 project – Multi-fidelity systems code for EU-DEMO

- Kicked off April 2021
- Target is open-source reactor design tool



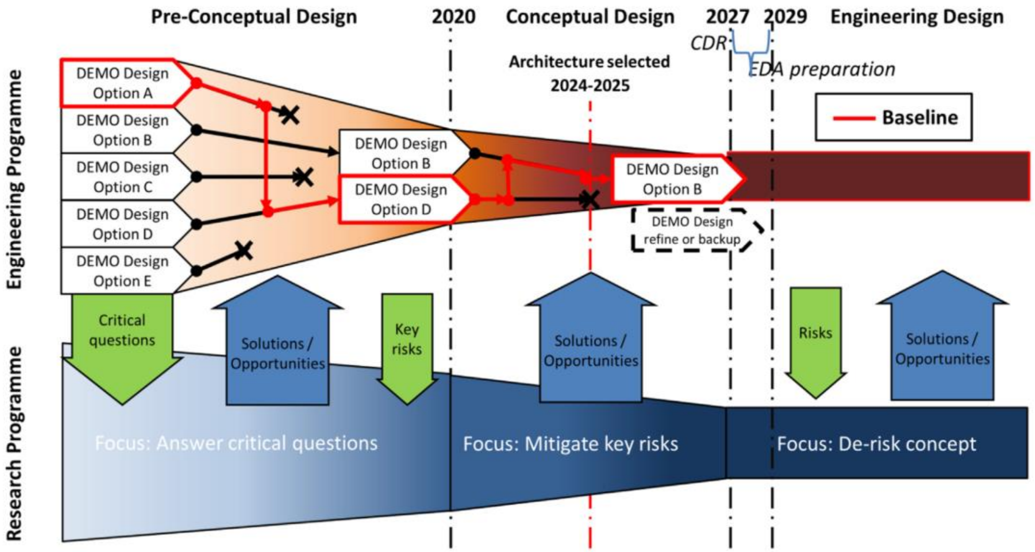
Introduction

Future needs

As power plant projects move into the conceptual design phase and beyond the use case for systems codes expands.

Going forward there will be a need to have the additional capability to:

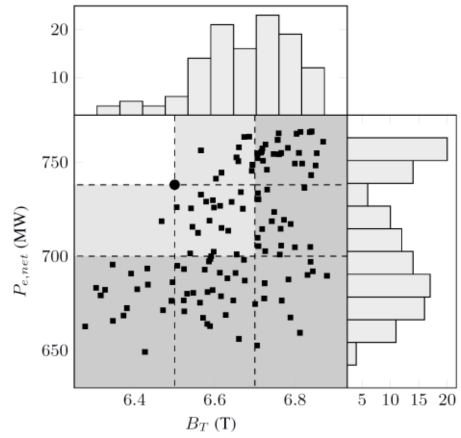
- Carry out detailed costing analysis of a given concept design. Providing estimates with uncertainties on the sub-system costs, up-front capital cost and the cost of electricity.
- Perform detailed uncertainty quantification on power plant designs that have fixed geometry and engineering parameters to determine the impact of underperformance and if there is a solution to return to the target goals.
- More detailed models for plant sub-systems. Expanding the number of 1-D and 2-D models.
- Rapid generation of 3-D CAD data of the machine.



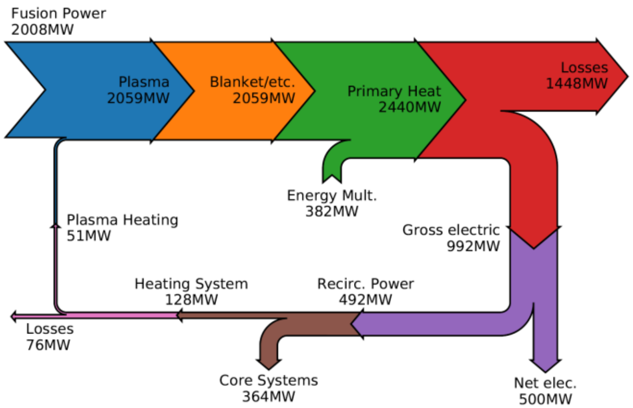
PROCESS

Capability

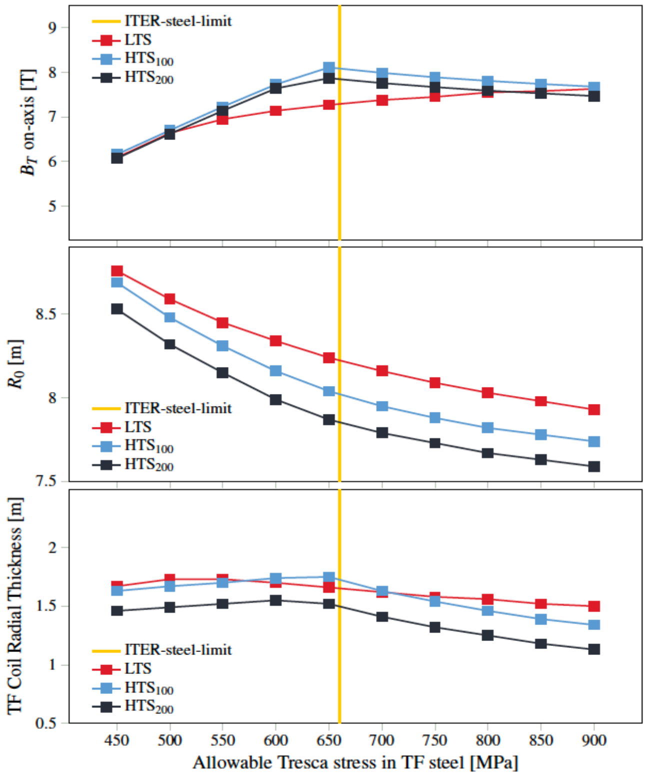
Sensitivity analysis



Power balance modelling

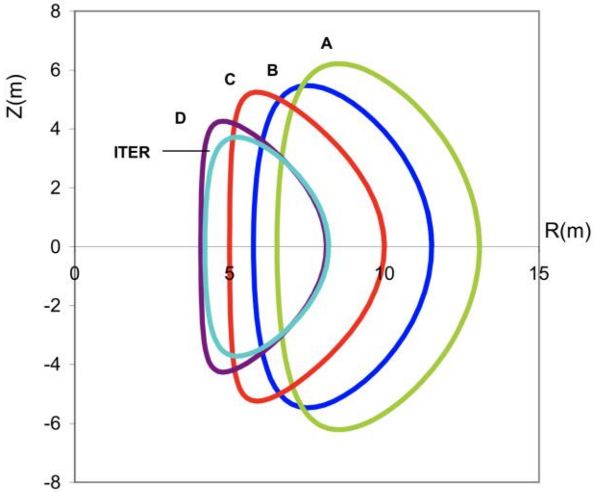


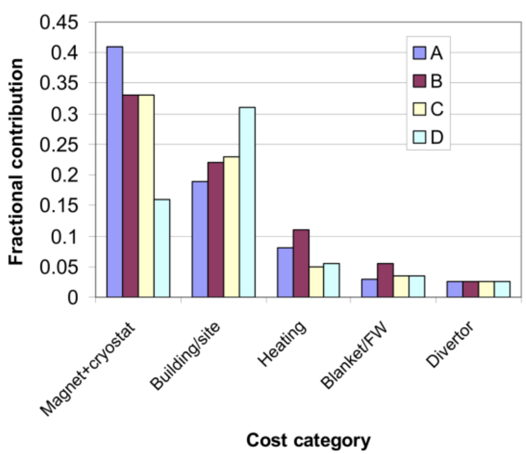
HTS – REBCO



PROCESS

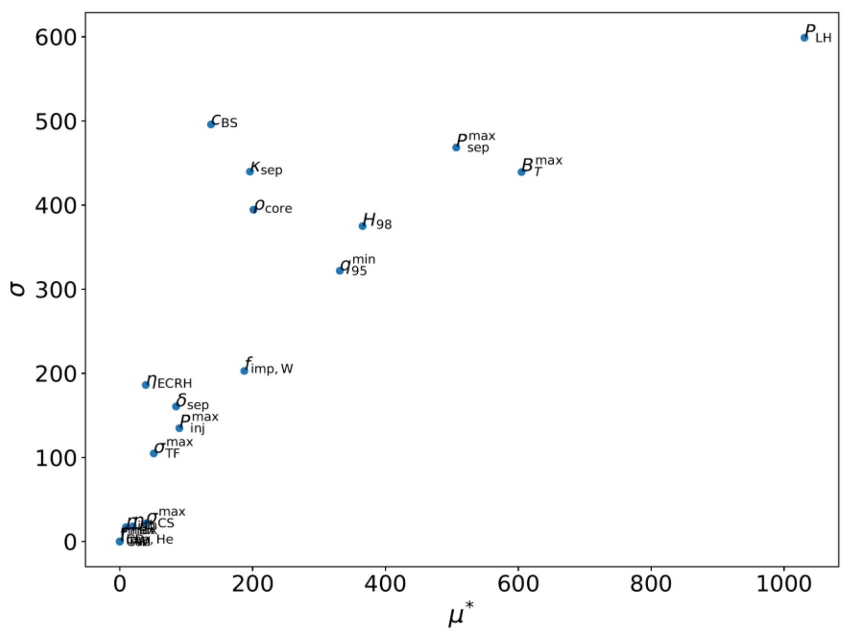
Capability – cost modelling





The method of elementary effects, which is also known as the Morris method, is a sensitivity measure for ranking the parameters in order of effect on a model output.

This new method in PROCESS is relatively computational inexpensive as compared to variance-based methods



Plot of the absolute mean against the standard deviation of the elementary effects for each parameter for the capital cost of a DEMO-like with a fixed radial build, requiring Pnet,el ≥ 400MW and maximising fusion gain Q as the figure of merit.

UK Atomic Energy Authority

Spherical Tokamaks

New additions

Within PROCESS there are a number of spherical tokamak specific options that have been added

- ST centrepost (including resistive)
- ST plasma shaping
- ST plasma current scalings
- ST TF magnets

New option for resistive monolithic centre-column

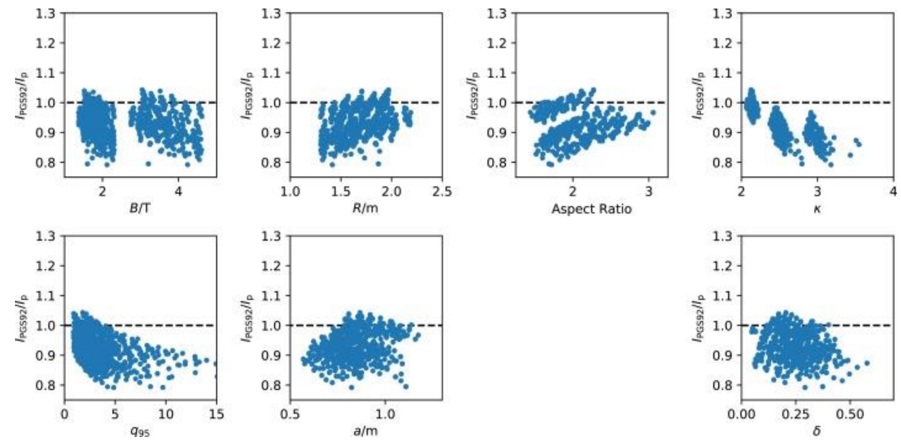
- with either picture frame or D-shaped return limbs.

To minimise resistive losses, the centre-column is tapered, being thinnest at the midplane where space is tightest and widening at the top.

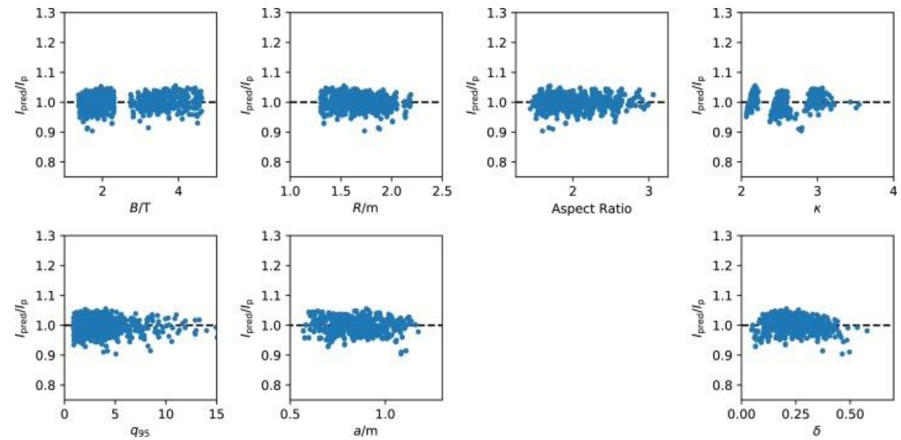
PROCESS and BLUEPRINT currently being used on STEP project, particularly magnet and costing work.

ST Plasma current scaling

Non-ST plasma current scaling vs. FIESTA



New ST plasma current scaling vs. FIESTA



TF Magnet Model
Updated stress and tension modelling

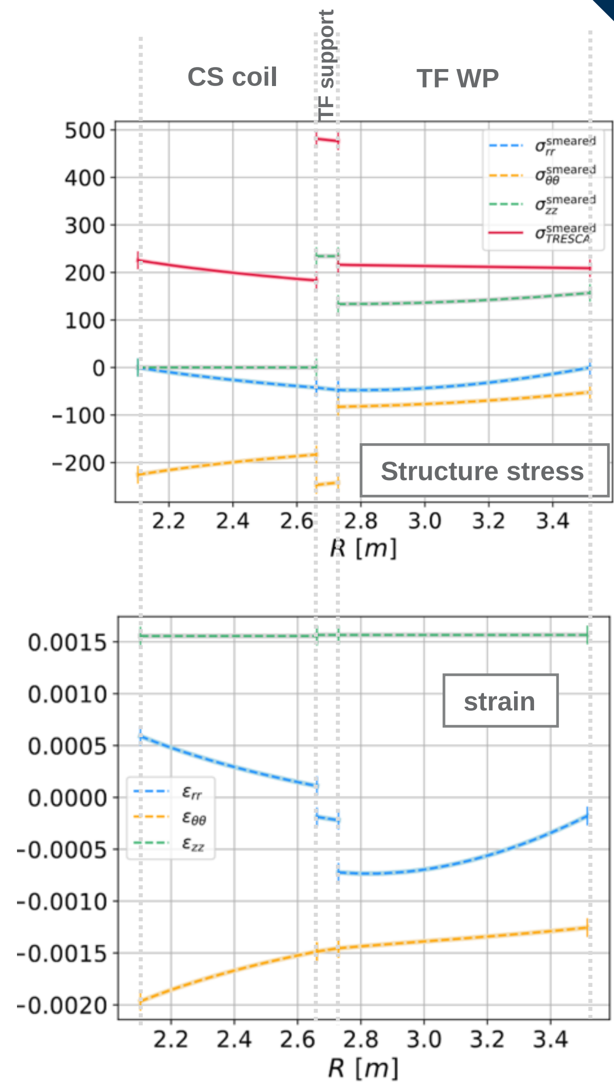
Inboard mid-plane stress model

- Stress model revised using generalized plane strain assumption
  - Valid for inboard TF geometry
  - Provides vertical stress distribution
  - Stress, strain and displacement radial distribution as output
- Formulation for any number of layers of different geometry
  → Advanced structural designs
  - Wedged TF bucked on CS
  - Graded Winding pack (under development)
- Vertical tension improvement (analytical)
  - Including conductor thickness effect
  - Calculated in/out tension split for sliding joints

CS-TF bucked design for DEMO-like machine

- TF structure reduction ~20 cm
- Not enough size reduction to justify design complexity at first inspection – investigations away from DEMO-like machines needed.

	R_0 [m]	B_T [T]	Aspect	ΔR_{TF} [m]
Wedged TF	8.79	4.84	2.84	1.22
CS-TF bucked	8.58	4.54	2.67	0.96

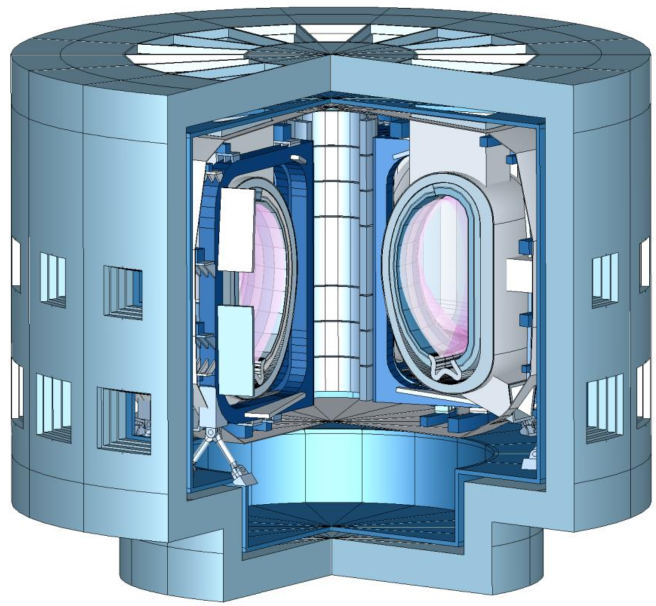


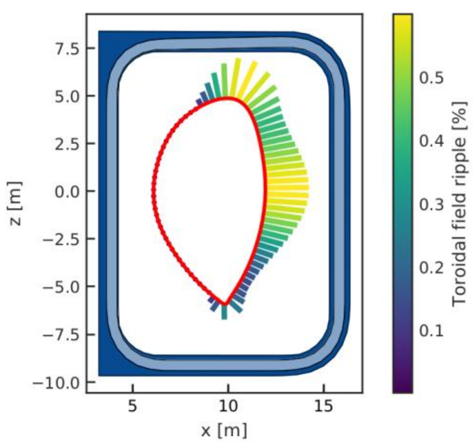
PROCESS stress/strain distribution for CS-TF bucked design

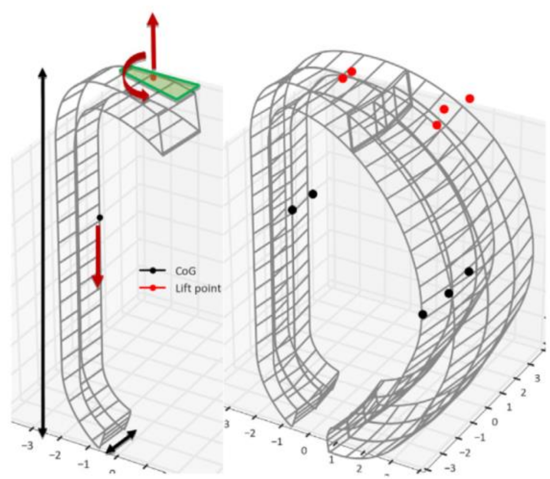
BLUEPRINT
Capability

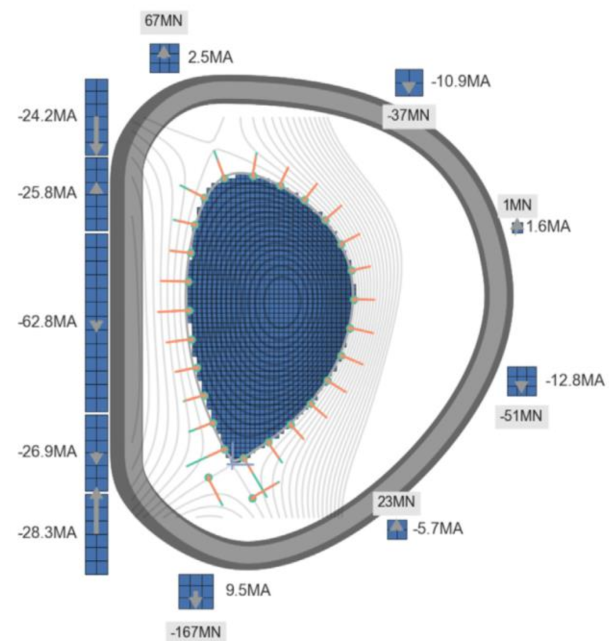
<u>Some key BLUEPINT capabilities</u>

- Toroidal field (TF) coil design
- Equilibria and poloidal field (PF) system design
- Remote handling engineering considerations
- 2-D geometry and 3-D CAD generation
  - with the goal of performing Monte Carlo neutronics simulations
- Fuel cycle modelling









Summary
TSVV-14

UK Atomic Energy Authority

Summary

- UKAEA will be leading the EUROfusion TSVV-14 task working together with KIT
- Create an open-source fusion power plant design framework and toolset
- The task will be built on the groundwork of merging UKAEA code BLUEPRINT and KIT code MIRA.

Key Outcome

Aim is to create a well supported and widely used open-source reactor design tool. It will be a useful tool for reactor design projects (e.g. STEP and EU-DEMO).

Summary
Outlook

UK Atomic Energy Authority

BLUEPRINT

Added

- Heat flux calculation from charged particles
- Spherical tokamak geometry
- PF coil optimisation in defined regions
- Enhanced interfaces to other codes – JETTO & PROCESS
- Computational speed improvements

Planned

- Merge BLUEPRINT with MIRA
- Open sourcing and build dev community
- Strong integrations with FEA libraries
- 2-D/3-D radiation models
- 2-D TF magnet winding pack analysis
- Plasma vertical stability model
- Coupling of 1.5-D transport solver PLASMOD and free-boundary EQ-solver

PROCESS

Added

- New sensitivity analysis tools
- Advanced divertor geometries
- 1-D SOL model
- HTS – REBCO
- TF magnet layered stress modelling
- Spherical tokamak models

Planned

- Refactor – python package + API
- Further spherical tokamak models
- Updated costing models with available contract data
- Continued UQ tool development
- Modelling of EU-DEMO performance robustness
- Integration with BLUEPRINT-MIRA

UK Atomic Energy Authority

Thanks for your attention.

Part 2 to follow…