EUROfusion

Uncertainties in fusion power plant conceptual development

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This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Aim of European fusion research

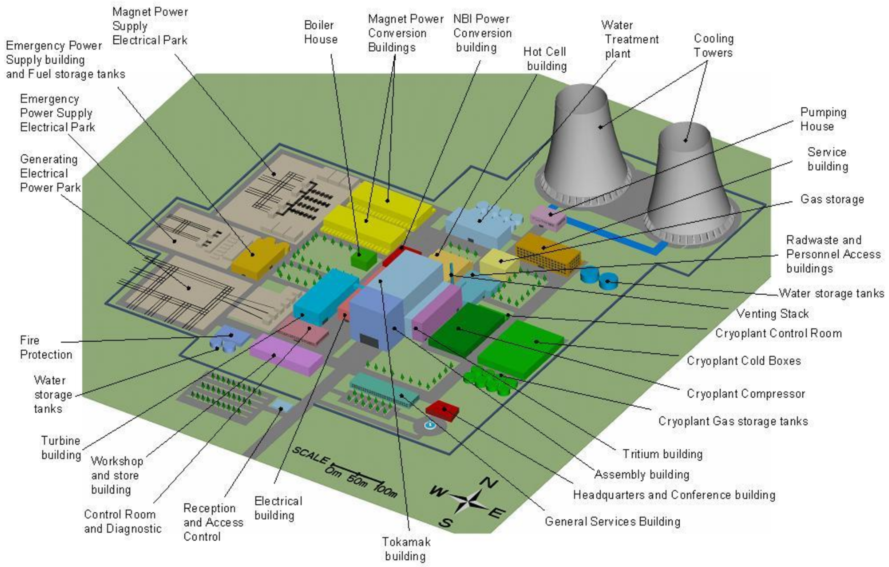
To supply electricity economically, sustainably, and safely.

DEMO is intended to demonstrate that fusion is a credible energy source:

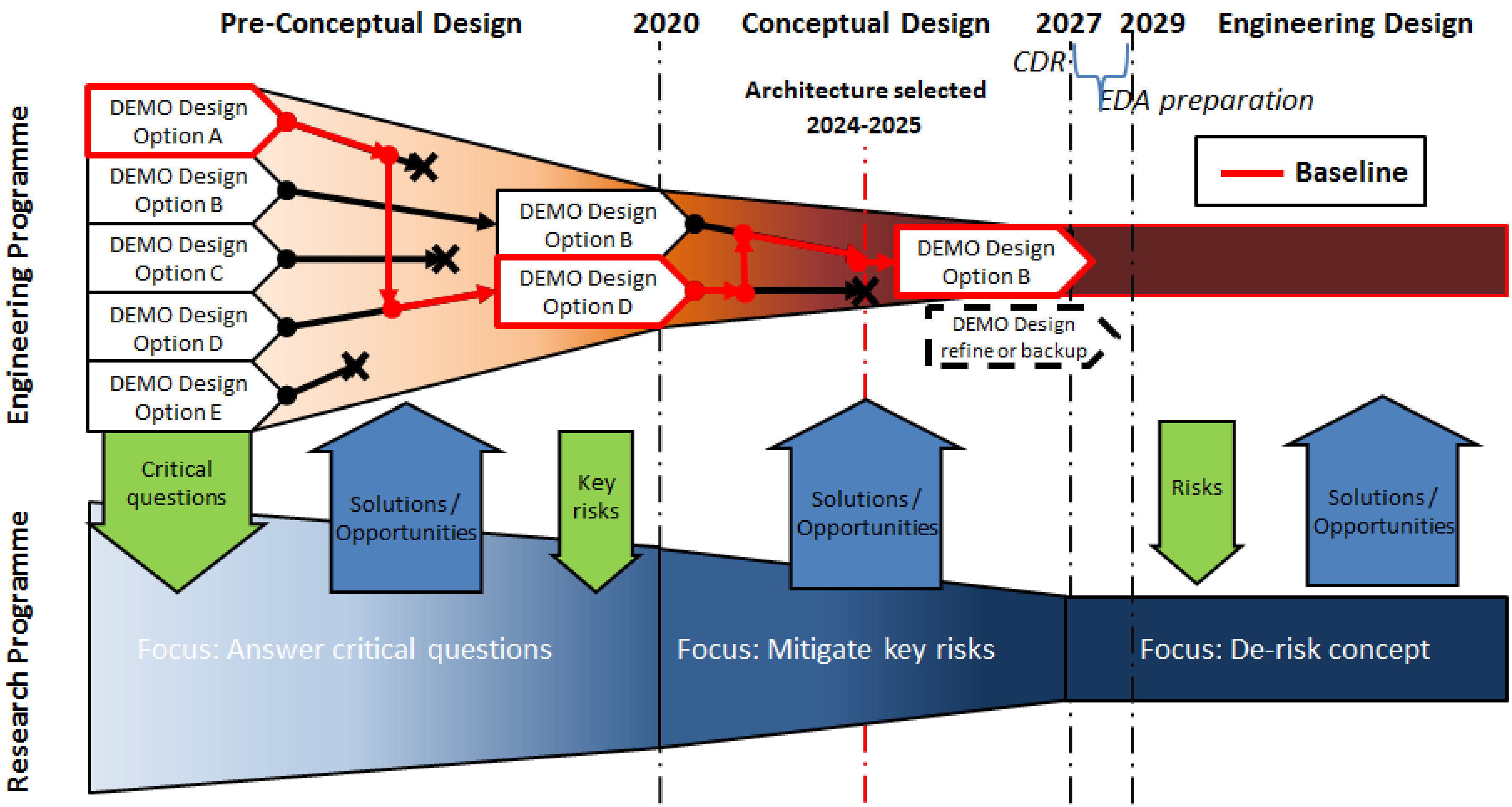
- significant net power for significant time
- tritium self-sufficiency
- functional demonstration of supporting power plant technology

The target for achieving this is 2050.

How can we be confident that DEMO will meet these goals?

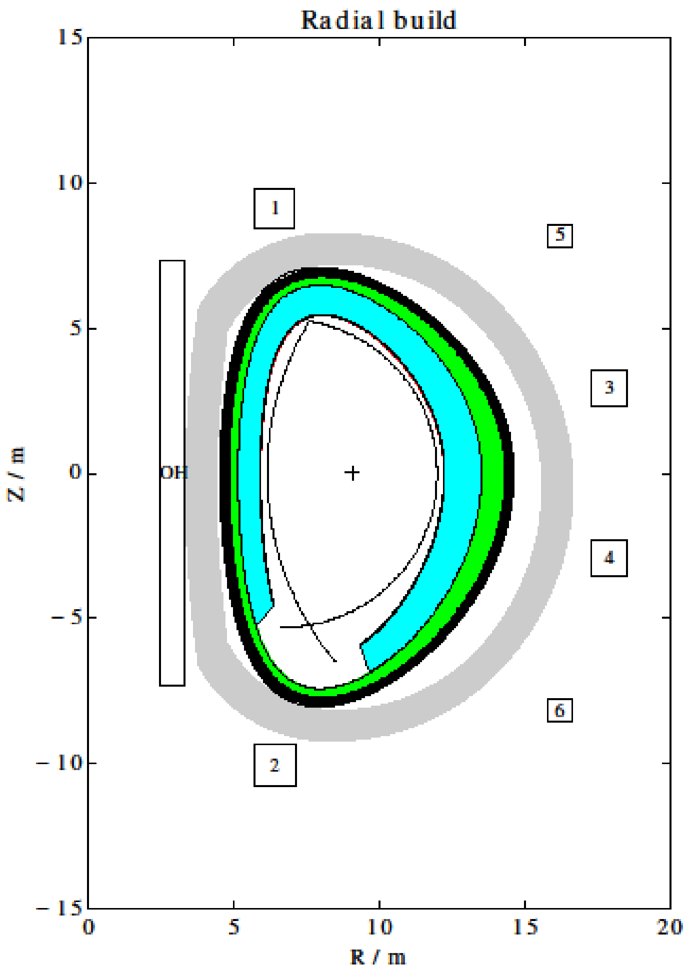


Design options



Timescales mean that technology or physics options must be ready for industrial scaling within 15 years: at least being reliably demonstrated in labs now. We cannot assume dramatic breakthroughs.

Baseline DEMO design



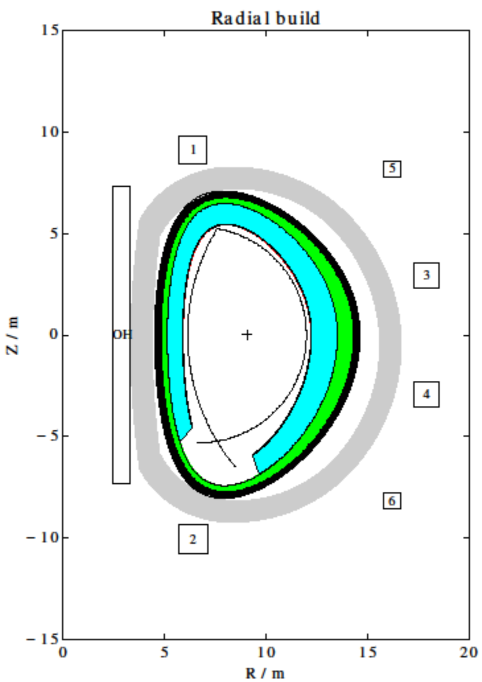
Parameter	DEMO1
R_0	9.1 m
A	3.1
κ_{95}	1.59
P_{fus}	2 GW
B_T	5.7 T
β_N	2.6
H	1.1

Targets: 500MW electrical output
2 hrs pulse length

Provides stable design basis for evaluation and development of supporting physics and technology.

Significant investment in engineering resources through the Projects to build up capabilities needed for integrated design processes.

Baseline DEMO design



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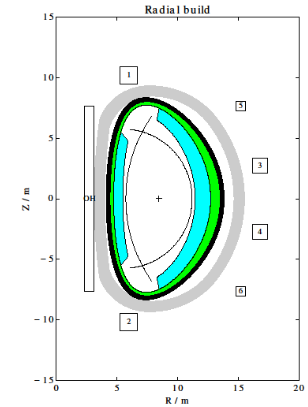
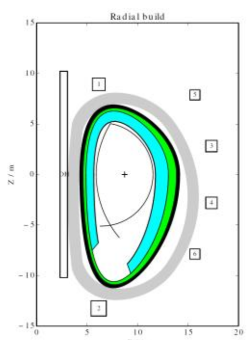
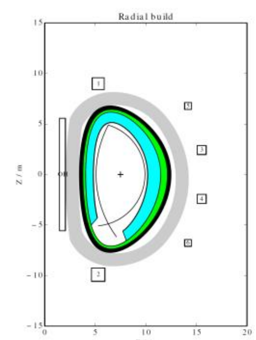


Double-null option:
Loss of TBR?
Complications of RH?



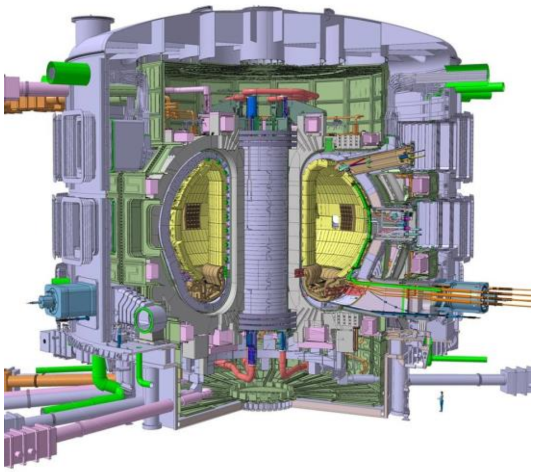
Advanced divertor option:
Super-X / Snowflake?
Magnet costs +25%



Steady-state option:
Recirculating power fraction +27%
More advanced physics/better divertor assumed

DEMO is different from ITER

DEMO is an additional extrapolation beyond ITER



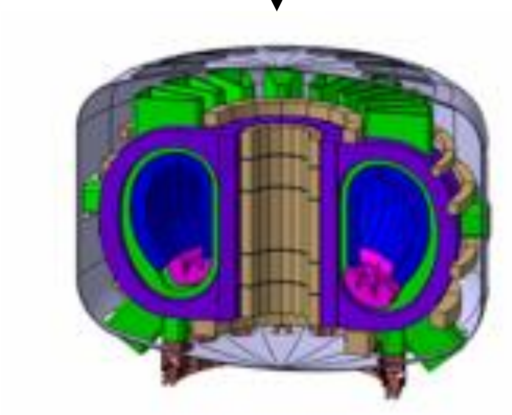
Optimised for RAMI, not experimental goals

Limited diagnostics; nuclear hardened; high fluence; significant in-vessel materials damage

Licensing as nuclear reactor likely.

- Potential for large T inventory on-site

In full operation dextrous RH interventions unlikely



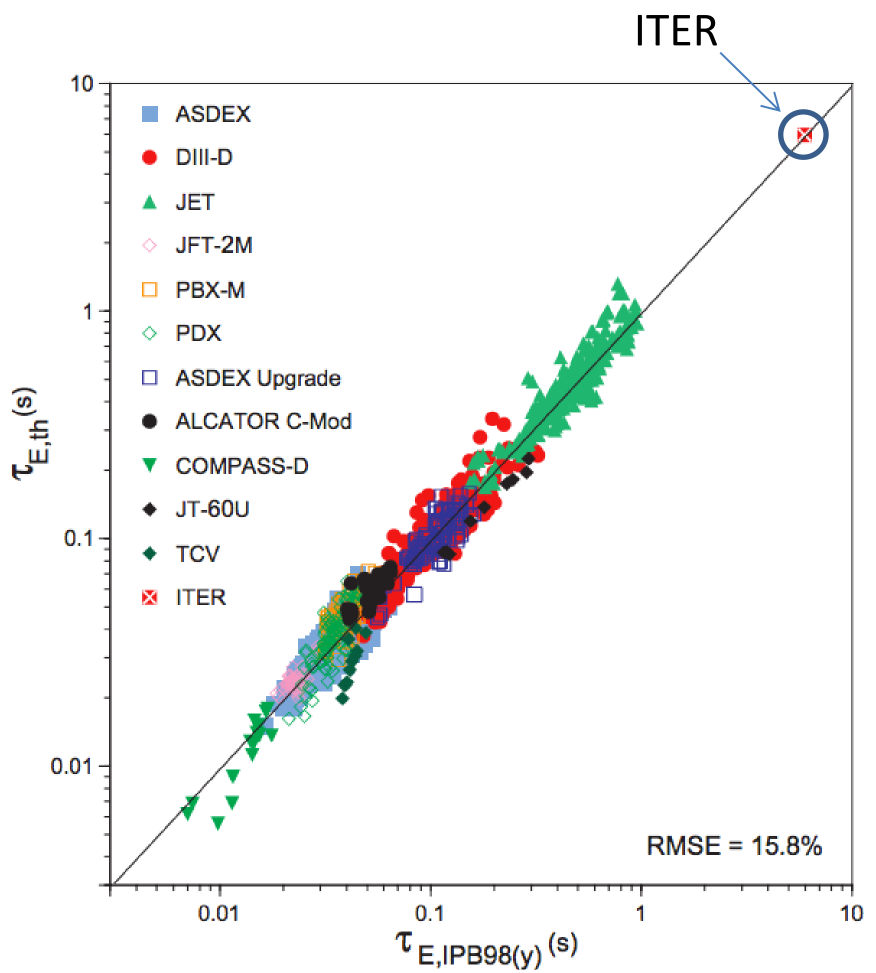
Limited operational flexibility: need to get it right first time

Confidence in achieving goals

We can take several approaches to reducing this risk:

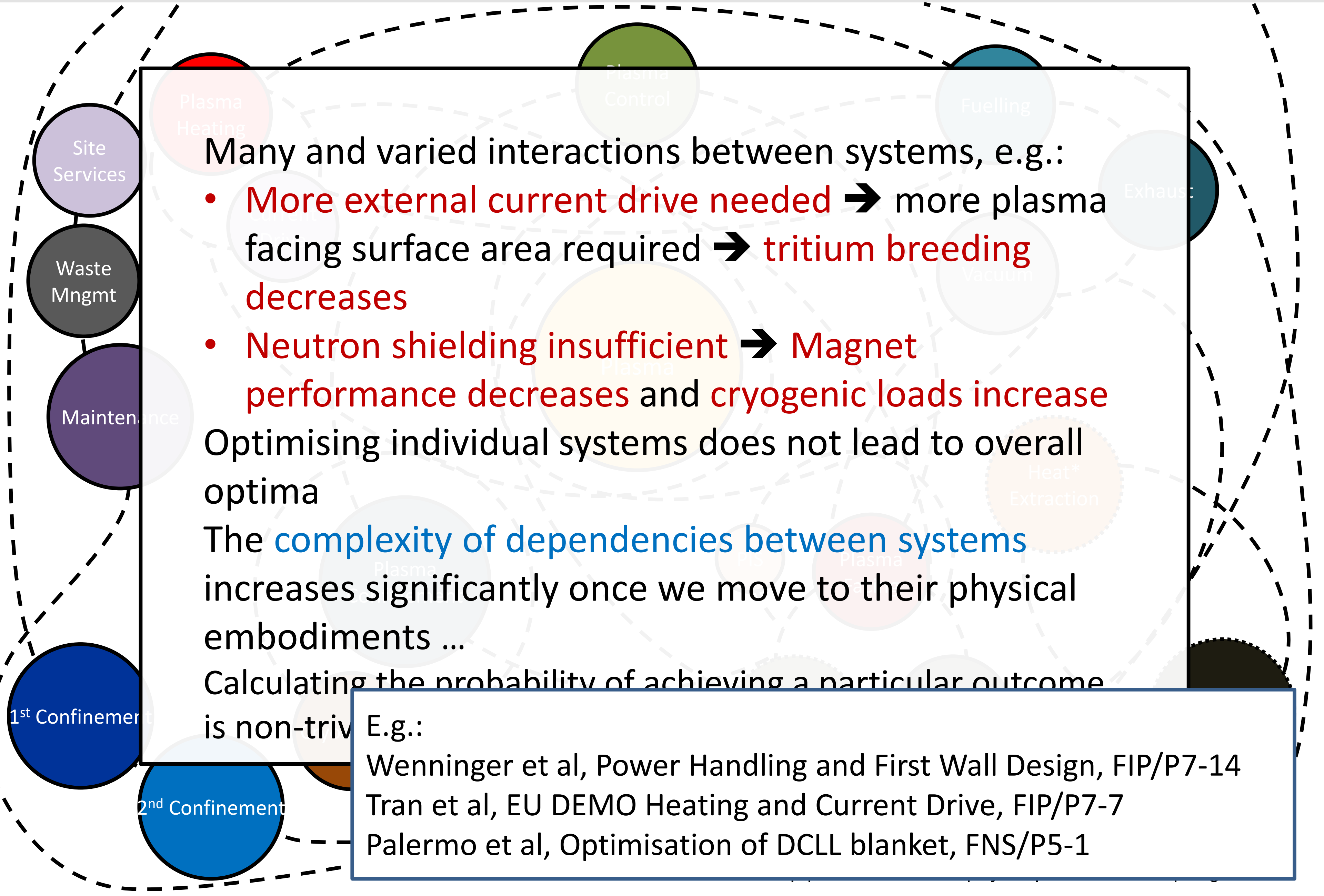
- Performance margins
- Reduce uncertainties
- Reduce targets and claim success regardless of outcome

If we can reduce the uncertainties, we can reduce the margins



DEMO has a similar confinement time to ITER, but the inputs to the scaling are further from the experimental basis.

A tokamak power plant is a complex being



Many and varied interactions between systems, e.g.:

- More external current drive needed → more plasma facing surface area required → tritium breeding decreases
- Neutron shielding insufficient → Magnet performance decreases and cryogenic loads increase

Optimising individual systems does not lead to overall optima

The complexity of dependencies between systems increases significantly once we move to their physical embodiments …

Calculating the probability of achieving a particular outcome is non-triv

E.g.:
Wenninger et al, Power Handling and First Wall Design, FIP/P7-14
Tran et al, EU DEMO Heating and Current Drive, FIP/P7-7
Palermo et al, Optimisation of DCLL blanket, FNS/P5-1

If we build DEMO, how will it perform?

We can approach this problem by fixing the 'controllable' parameters (such as radial build), and then running the systems code many times using stochastic sampling of uncertain parameters.

Parameter	Distribution	Mean	σ	DEMO
Upper bound on $\frac{n_e}{n_G}$	l/h Gaussian	1.2	0.1	1.2
Upper bound on H-factor	l/h Gaussian	1.2	0.1	1.1
Core radius for radiation correction	Gaussian	0.6	0.15	0.6
Thermal α-particle fraction	Gaussian	0.1	0.025	0.1
$\frac{n_W}{n_e}$	Gaussian	10^{-4}	5×10^{-5}	5×10^{-5}
Maximum ratio of $\frac{P_{\text{sep}}}{R}$ (MW/m)	Gaussian	15	2	17
Lower bound on L-H threshold limit	Gaussian	1.0	0.25	1.0
Bootstrap current fraction multiplier	Gaussian	1.0	0.1	1.0

Uncertainties mainly guesswork at this stage.

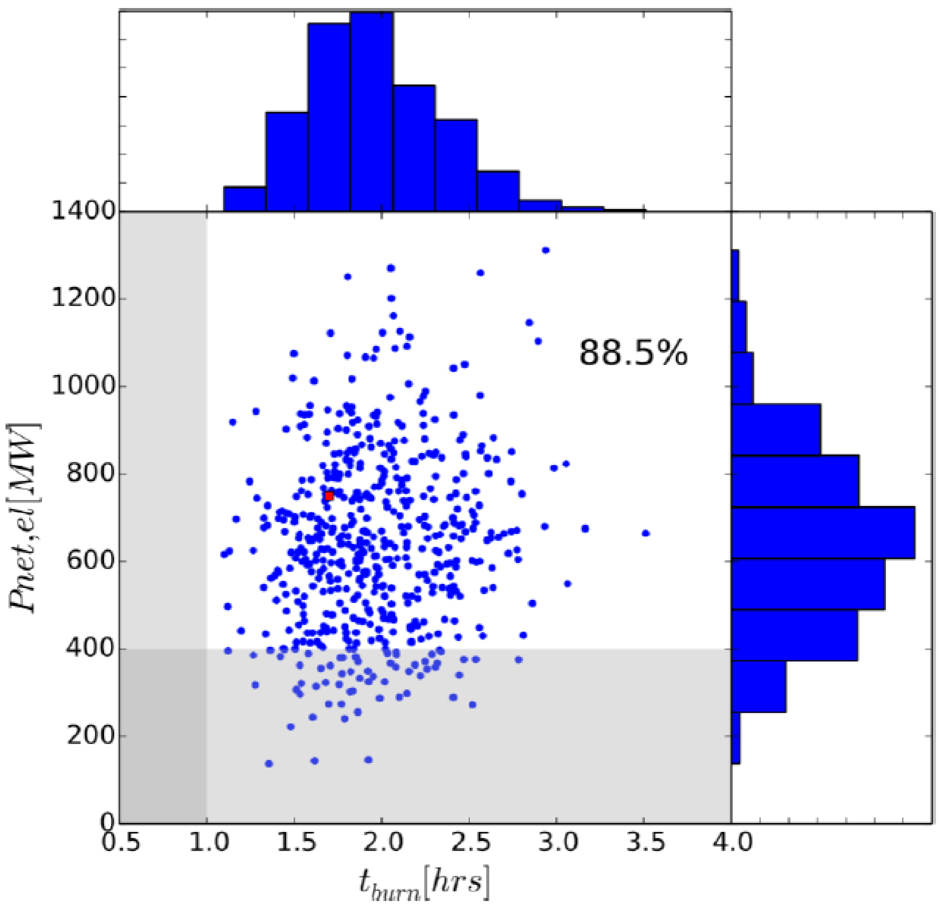
If we build DEMO, how will it perform?

With these uncertainties nearly 90% of cases perform ‘acceptably’.

Next steps:

Identify most important parameters and also those which interact, and focus research here to reduce uncertainties

Calibrate uncertainties



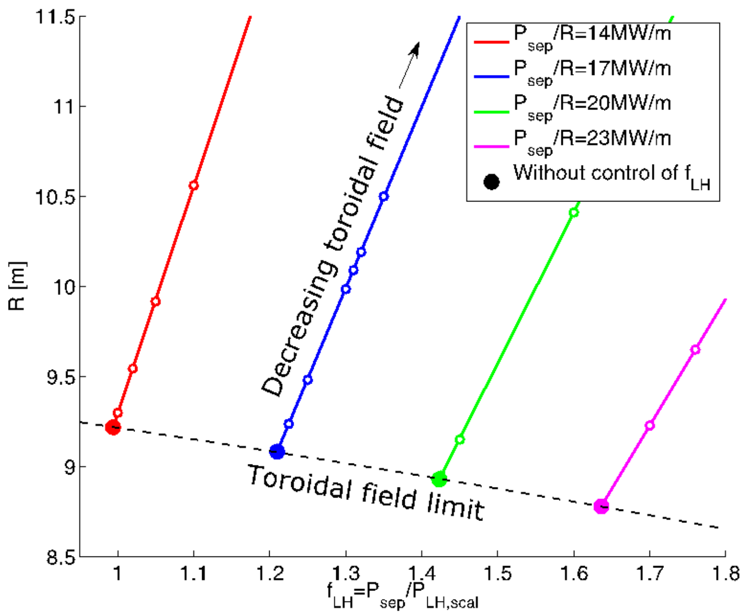
Targeting robust designs

As well as trying to understand what affects performance we want to know what limits we are leaning on.

Improved divertor performance can act as mitigation for a poor H-mode; without a good divertor there is little point going to higher field.

Also know we want to design a reactor at highest possible κ, but:

- vertical stability
- wall loads
- disruptions…?



Summary of baseline

EU-DEMO baseline case is ‘conservative’ as uncertainties are large and commensurately large performance target margins (for all systems) are included.

We have attempted to identify and avoid ‘cliff-edge’ performance boundaries.

Choices of technology and physics scenarios driven by near-term targets for electricity production from fusion.

Technical risks and design choices remain, but the baseline provides a soundly-established basis on which to base detailed evaluations of those choices

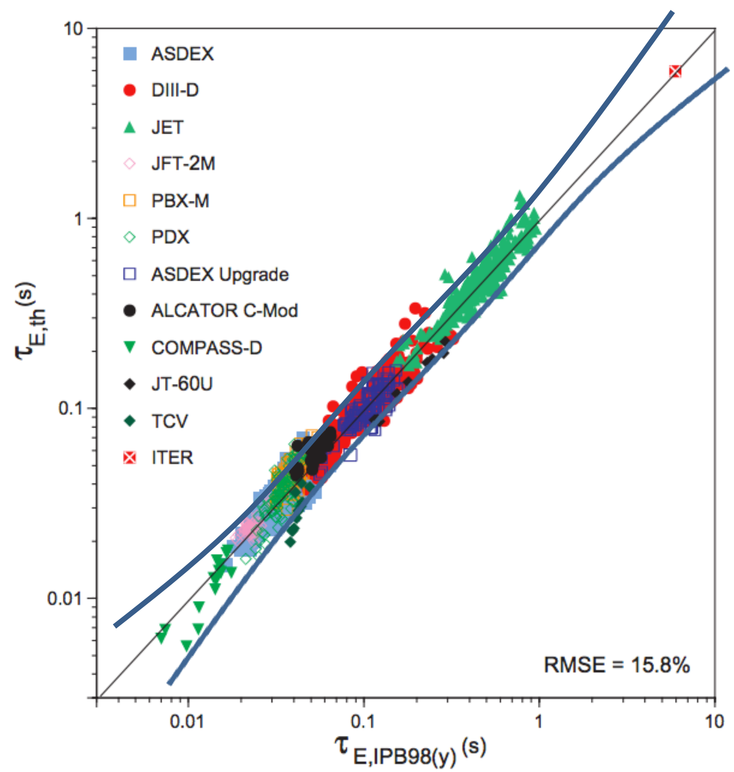
Sources of uncertainties

DEMO needs a well-established low-disruptivity scenario, with a burning plasma pressure profile, controllable with limited diagnostics and actuators.

We are guessing at the performance of such a plasma. More experiments and theory needed.

Need to know what we can reliably achieve in terms of H, κ, n_G in such a scenario as major sensitive parameters.

Would like scalings etc. to include confidence intervals.



Next steps

Where do we take this work?

- Identification of synergistic effects in multi-dimensional uncertainties
- Use of stochastic sampling to find ‘most robust’ designs – those most likely to achieve targets *despite* uncertainties
  - Not the same as ‘optimised’ design
- Iteration with scenario developers and technologists towards single, ‘best’, design point
  - Conceptual development is a *process*, and the baseline must evolve as new knowledge becomes available

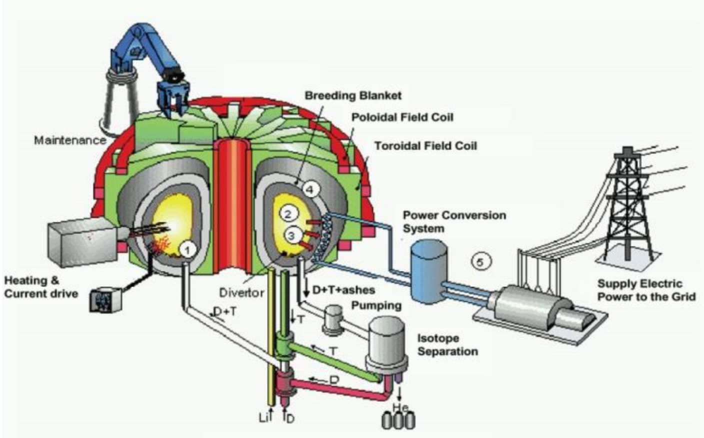
Summary

Quantification of uncertainties quantifies risks. Risk management is vital for complex projects even at conceptual design stage.

This allows confidence in final design performance and estimates of variations of loads on engineering systems.

Identifies where research may be most profitably focused to reduce overall operational uncertainty; reduction in uncertainty allows smaller margins and reduction in costs (as yet unquantified)...

At the end of the conceptual design stage: want confidence in the DEMO concept as we move to full engineering design.



Some posters and talks

Wenninger et al, Power Handling and First Wall Design, FIP/P7-14

Tran et al, EU DEMO Heating and Current Drive, FIP/P7-7

Palermo et al, Optimisation of DCLL blanket, FNS/P5-1

Morris et al, Qualification of Exhaust Solutions for DEMO-class Devices, FIP/P7-20

Brezinsek et al, Plasma-Wall Interaction Studies within the EUROfusion Consortium, EX/P8-41

Gilbert et al, Activation, Decay Heat, and Waste Classification Studies of the European DEMO Concept, FNS/1-2

Voitsekhovitch et al, Computationally Demanding Multiscale Fusion Physics Simulations and Integrated Modelling, TH/P2-12

Cabal et al, Exploration of Different Global Energy Scenarios Using EFDA Times, SEE/P7-4