EU DEMO Design Point Studies

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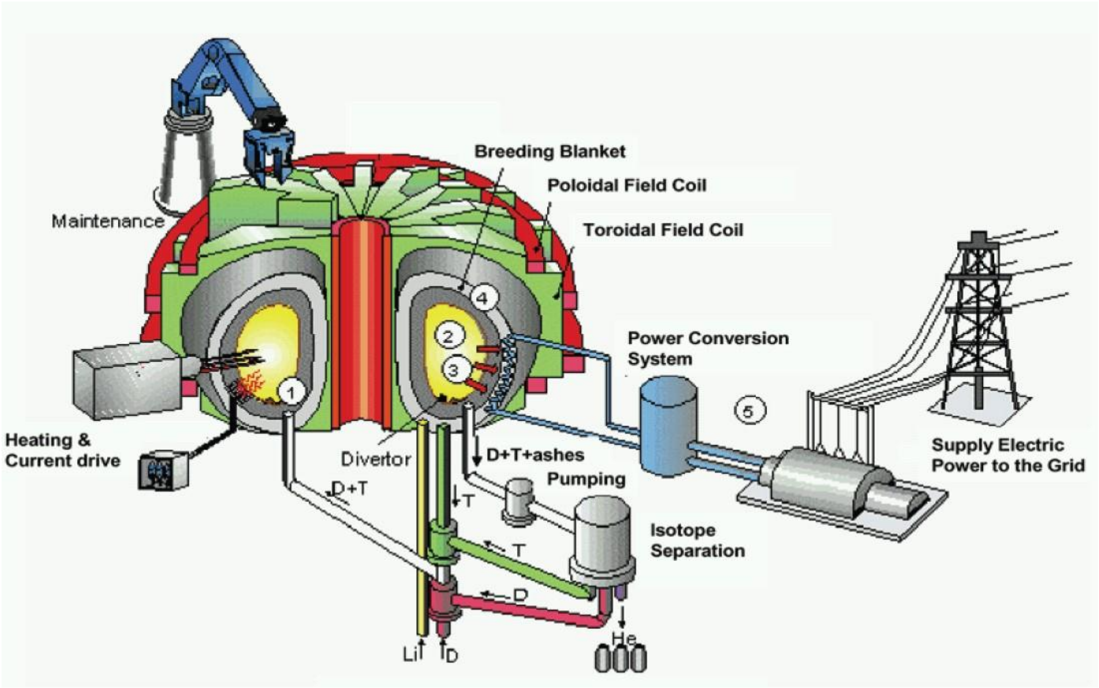
EU DEMO Design Point Studies

- Conceptual power plant design
  - Systems codes
- What is DEMO?
- Design point development
- Design choices
  - Pulsed vs steady-state
  - Aspect ratio
- Uncertainties
- Further steps

Systems codes

Used to develop many conceptual designs with a range of materials and technology assumptions

Every major plant system is modelled:
- Site and buildings
- Heat and power systems
- Magnets (TF and PF)
- Shield and vessel
- Blanket
- Divertor
- Plasma
  - Fusion power
  - Confinement
  - Pressure and density limit
  - Radiation
  - Bootstrap current
  - Etc. etc.



Used to determine power plant costs and ultimately cost of electricity. Used for conceptual design and economic studies. EU systems studies use PROCESS, based at CCFE[1].

[1]Kovari et al, *PROCESS: a systems code for fusion power plants – part 1: physics*, accepted to FED 2014

Systems codes

Fast calculations

0D models
•Simplified generomak physics for many systems simultaneously
•Use guidelines, correlations
•Gives overall operational design point – the major plant parameters

1D/2D models
•Equilibrium, current drive
•Assume profiles, boundaries
•Calibrate design point

Detailed models: 1D/2D/3D, engineering analysis
•E.g. MHD, SoL physics, kinetic studies
•Calculate transport (core and edge), evolve profiles self-consistently
•Confirm and refine design point

Slow complex calculations

What is DEMO?

- Ultimate goal of fusion research – to supply electricity
  - Economically
  - Sustainably
  - Safely
- At some point, we must demonstrate that fusion is a credible energy source. This is what DEMO is intended to do.
- Targets:
  - Production of significant electrical output for significant time
  - Tritium self-sufficiency
  - Operation of all supporting/enabling technologies for commercial fusion power, bearing in mind: safety, reliability, availability, maintainability, inspectability
- Does not have to be technologically or physically optimised: *e.g.* target availability of 30%, not cheapest electricity

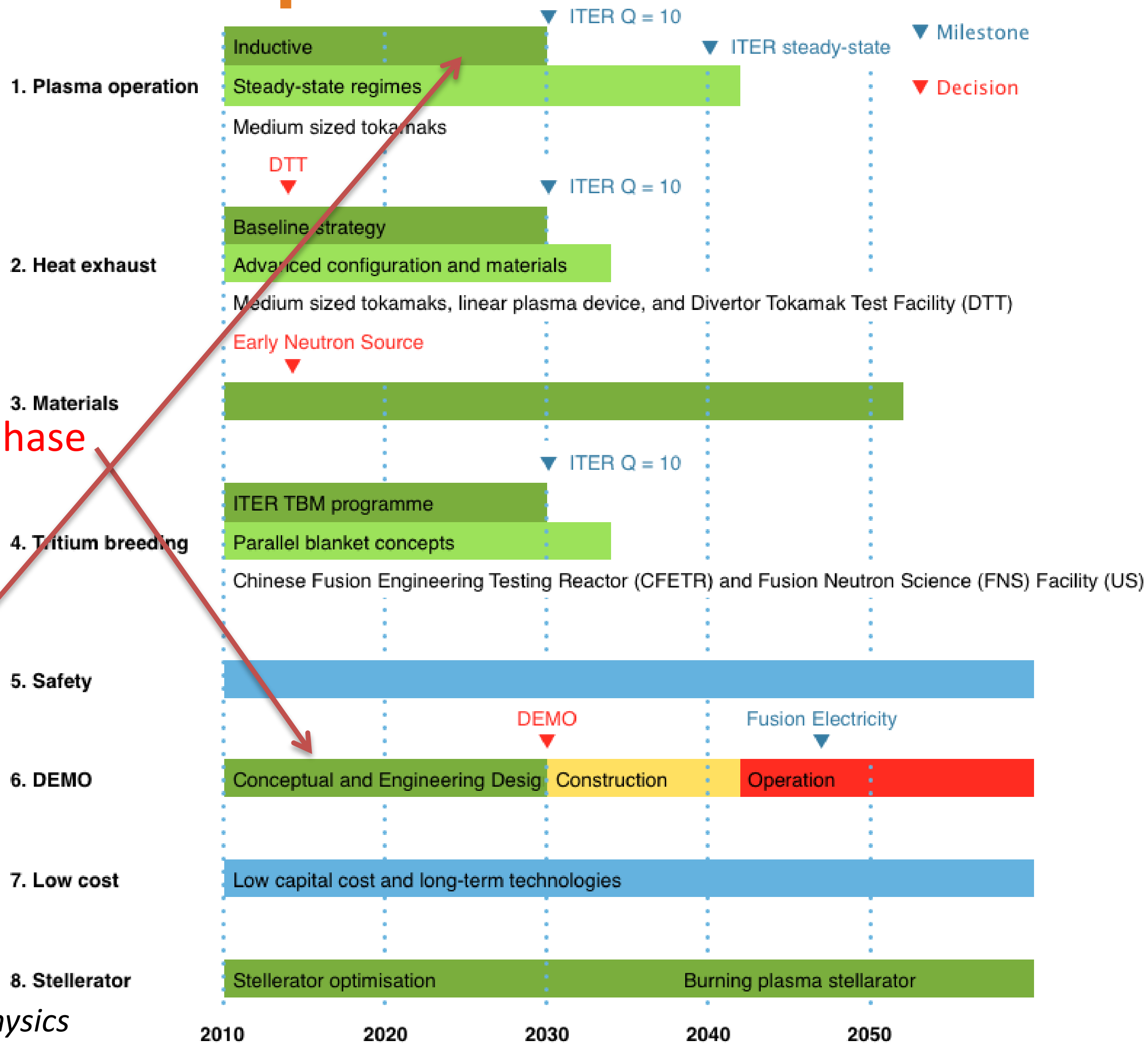
Batistoni et al, *Report of the ad hoc group on DEMO activities*, CCE-FU 49/6.7, 2010

EU Roadmap for DEMO

Currently in conceptual design phase

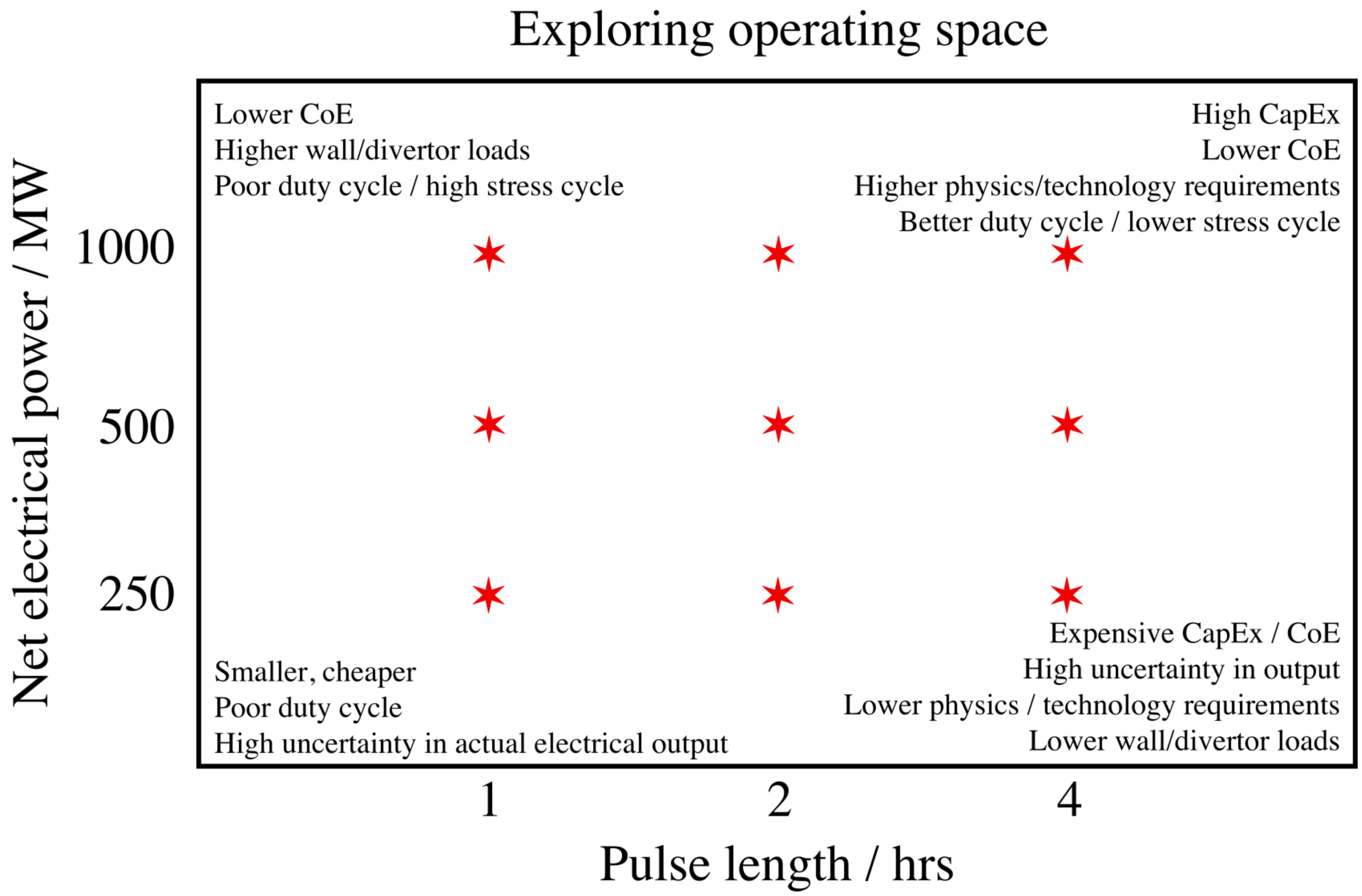
Very aggressive timeline

Based on ITER Physics Basis[1]



[1] See Wenninger et al, *Advances in the Physics Basis for the European DEMO Design*, PPC/P4-19

What is DEMO?



Federici et al, *Overview of EU DEMO design and R&D activities*, FED 89, 2014

What is DEMO?

- EU view: ITER should demonstrate
  - Robust burning plasma physics regimes
  - Conventional divertor solution
  - Validation of breeding blankets
- “Early DEMO” with well-established technology and regimes of operation (*i.e.* inductive)
- Modest but equal extrapolation in all areas (*i.e.* no magic solutions to technical problems)
- Based on current materials, technology, and physics knowledge

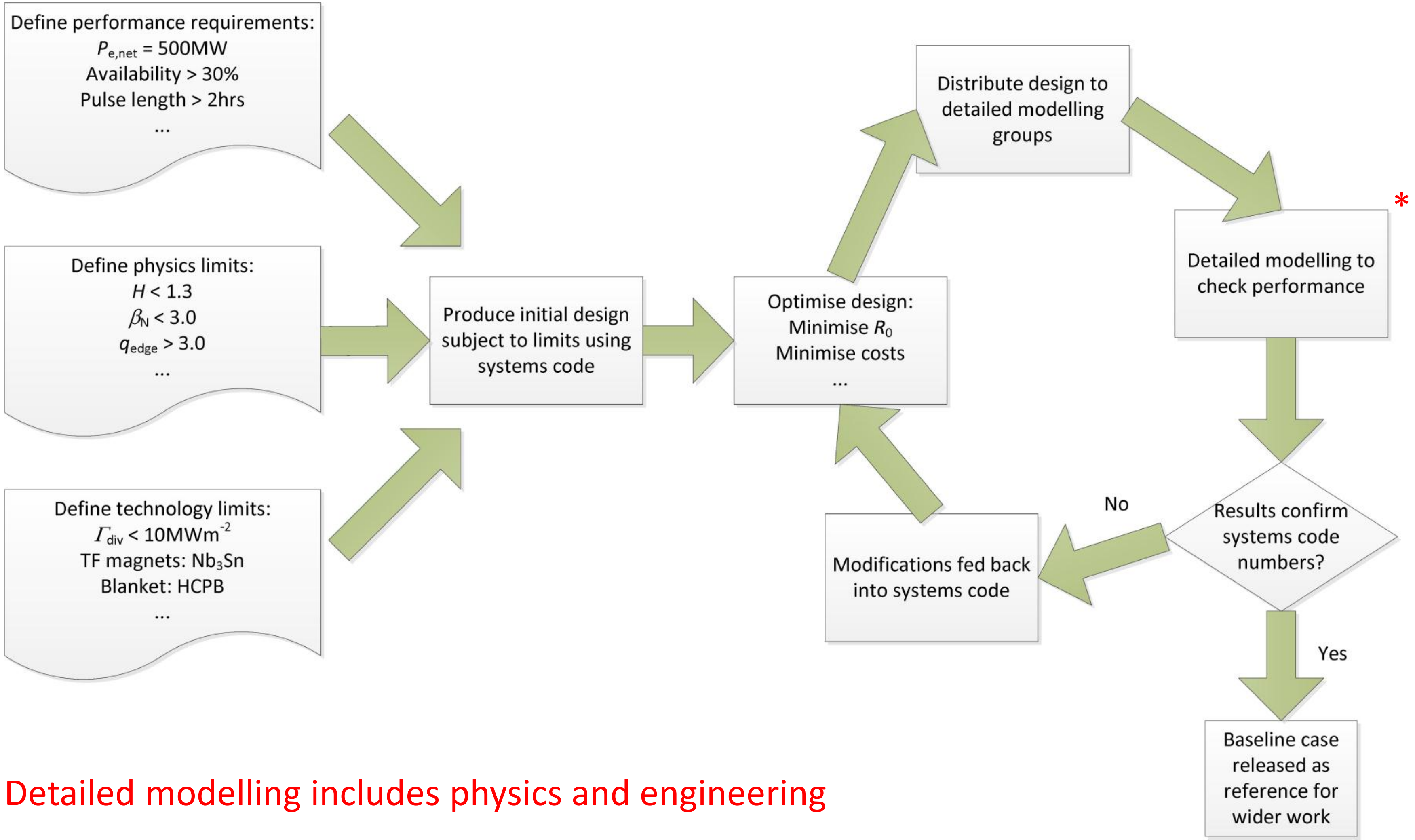
DEMO targets / limits

Values are inputs to systems codes: either targets or limits (except recirculating power)

Divertor power limit achieved through impurity doping and high radiation fraction (other solutions may be available)

Value	DEMO1	Notes
Physics		
β_N limit	3.0	Total β_N, performance usually limited by *H*-factor instead
H_{98}-factor limit	1.1	Radiation-corrected (uncorrected 'experimental' factor is ~0.1 lower)
q_0 / q_{95}	1.0 / 3.0	
$<n_{line}>/n_G$	1.2	Assuming n_G is a pedestal limit; tGLF predictive transport simulations indicate density peaking
Operation	Pulsed / 2 hr	
Heating and current drive		
Power (MW)	50	DEMO1 power principally for burn control; extra probably required to reach burn
E_{beam} (keV)	1000	Higher energy gives higher γ_{CD}
η_{WP}	0.4	Wallplug efficiency, $\eta_{WP} = P_{inj}/P_{electrical}$
Divertor		
P_{div}/R_0 (MW m^{-1})	17.0	DEMO1 based on ITER values
Balance of plant		
P_{recirc} (MW)	300	Principally current drive and coolant pumping
η_{th}	37%	~150MW coolant pumping power gives overall plant efficiency of ~24%
$P_{e,net}$ (MW)	500	Ultimate electrical output target

Design point development



* Detailed modelling includes physics and engineering

Giruzzi et al, *Modelling of pulsed and steady-state DEMO scenarios*, TH/P1-14

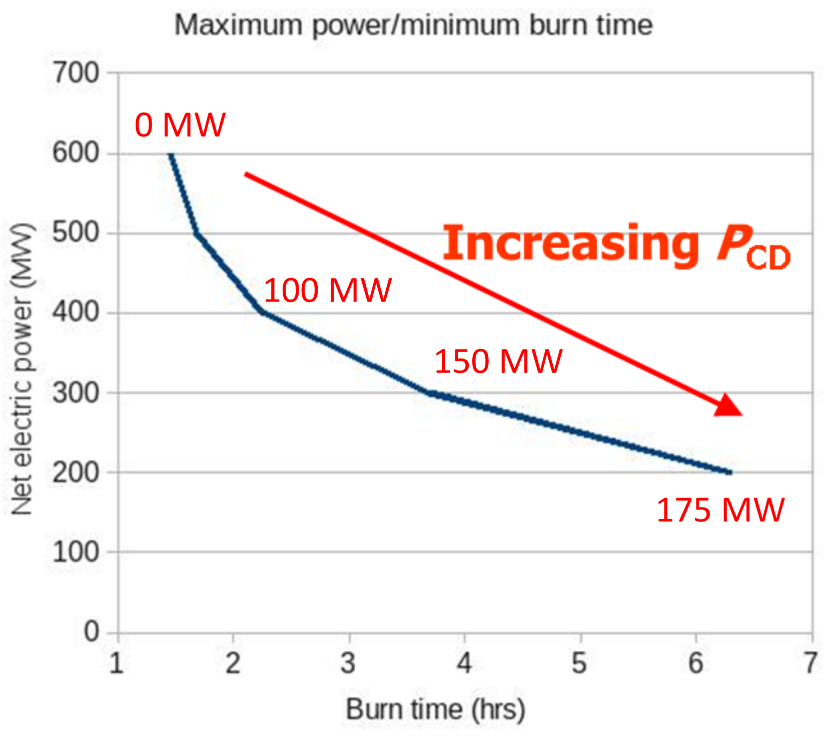
Design choices – pulsed vs steady-state

- Increasing pulse length requires significant current drive power
  - Increasing recirculating power reduces net electrical power or requires higher fusion power
  - Increased injected power and fusion power means higher power density and greater loads on divertor

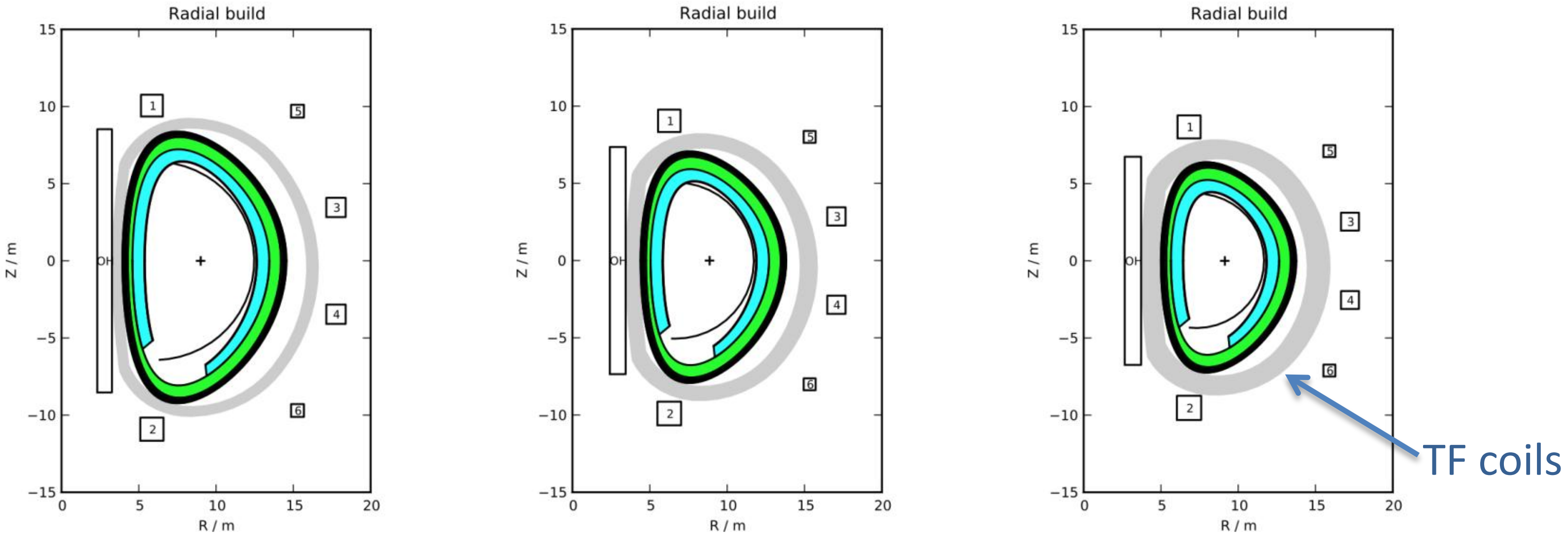
- Pulsed is "easy option"
  - Plenty of data, but difficult to control current profile
  - Cyclic stresses on components
  - Energy storage required?

- Steady-state preferred for power plant but requires high f_{BS} scenarios, efficient and reliable CD systems…

- "Early DEMO" is pulsed, but EU also exploring steady-state machine



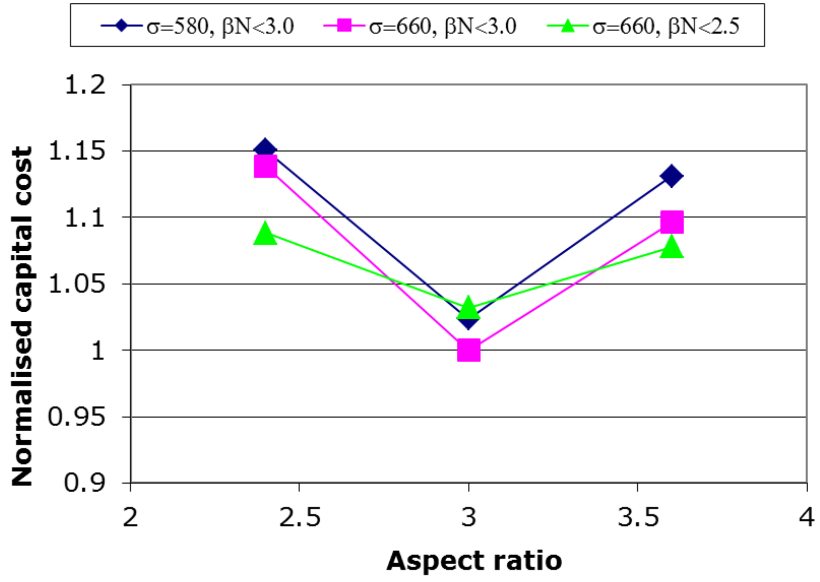
Design choices – aspect ratio



A = 2.6 *A* = 3.1 *A* = 3.6

- Scan of varying aspect ratios with scenario and engineering analysis
  - (Minimised major radius)
  - Transport modelling, access requirements, engineering feasibility
  - Cost estimates: lower *A* has lower field – cheaper magnets?
  - Trade-offs / limitations at each design point
    - *E.g.* Low aspect ratio size set by pulse length; large aspect ratio size by confinement

Design choices – aspect ratio



- Magnets are significant fraction of cost (~30%)
  - Reducing magnetic field can reduce costs
  - But other considerations including cost of larger VV/shield/blankets, increased RH costs for larger components…

Uncertainties

- Major uncertainties in extrapolation of physics
  - Particularly treatment of radiation[1]
- Choice of scenario uncertain (diagnostics and control, H&CD, stability of high radiation fraction…)
- Effects of TF ripple on plasma/fast particle confinement force larger coils – effects on access/RH/etc.
  - What is appropriate value?
- Divertor protection

[1]Ward et al, *International Systems Code Benchmark for DEMO*, 2nd IAEA DEMO Programme Workshop, Vienna, Dec. 2013

Further steps

- Incorporation of uncertainties into PROCESS systems code to assess robustness of operating point
- Development of DEMO Physics Basis and DEMO operating scenario to ensure best chance of success
- Further development of DEMO workflow to pass plant operating points through successively more detailed analysis in integrated way.

Summary

- EU DEMO operating points based on “near-term” physics and technology
  - Results in a ‘conservative’, low power-density design
  - DEMO not intended to be a commercial power plant but proof of concept
- Established workflow for evaluation of operating points from many angles and assessing conflicts/issues not captured by systems code
- Evaluation of areas where we need to know more; where uncertainties have greatest impact on performance
- Comprehensive scoping of operating space taking place to establish DEMO operating point “most likely to succeed”