EUROfusion

Overview of DEMO Physics Priorities

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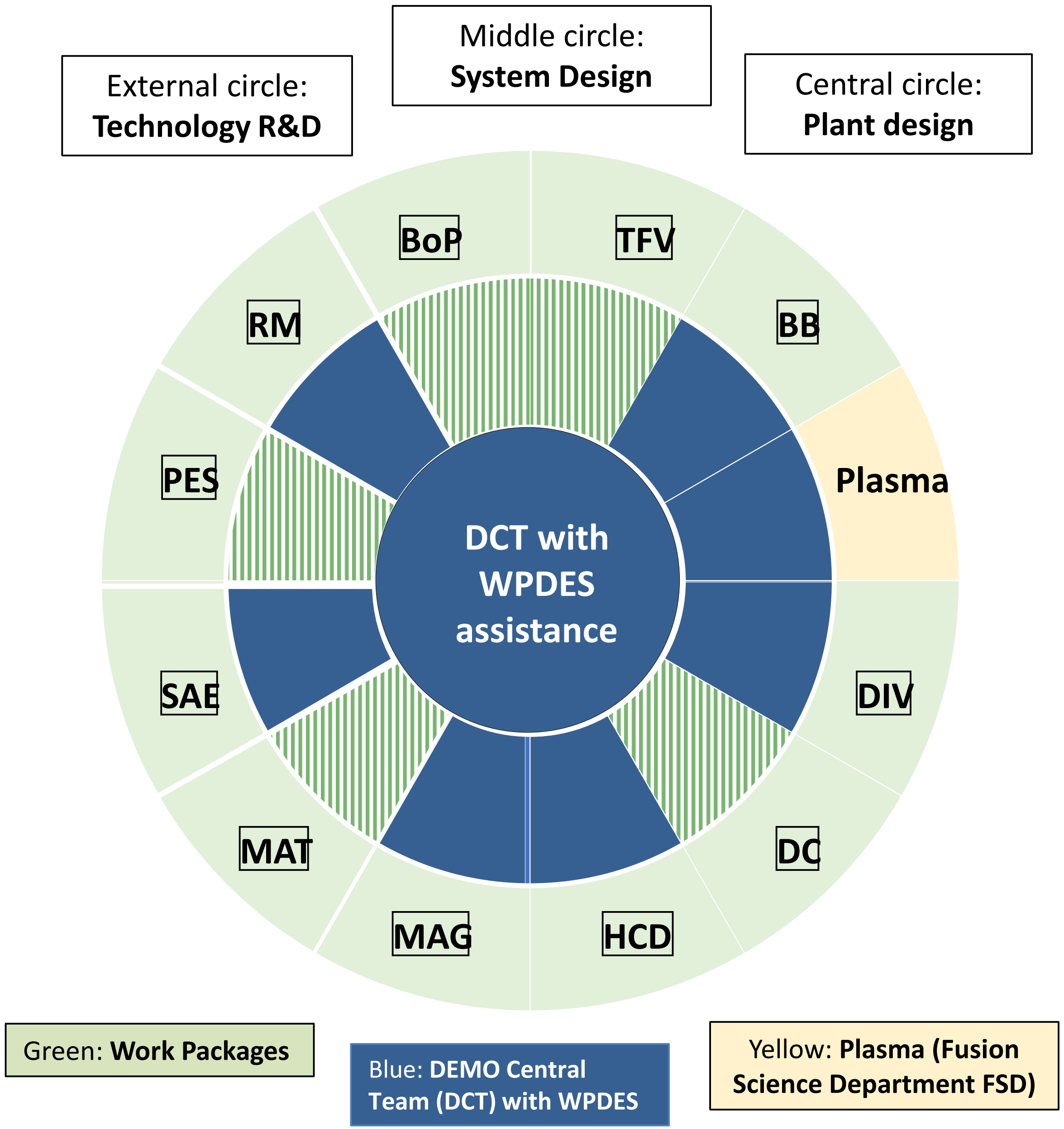
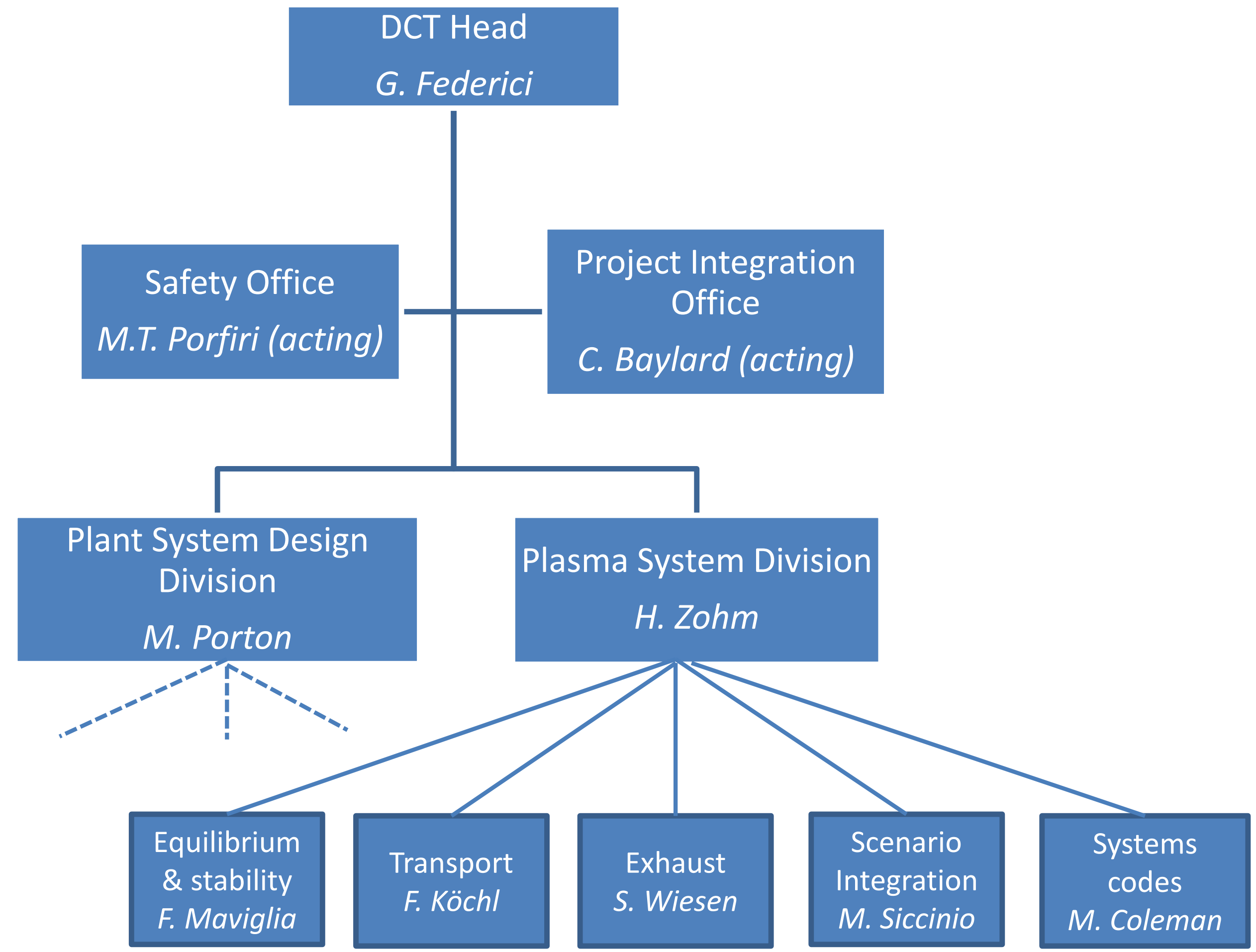
DEMO physics in EU Framework Programme 9 (FP9, 2021-2025/2027)



DEMO Central Team (DCT)



Goal: designing a 'qualified' plasma scenario for DEMO

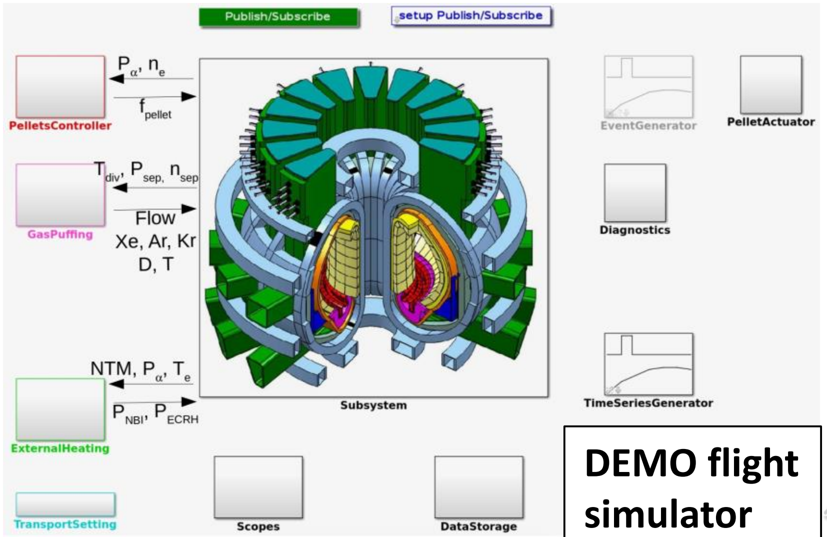
It is clear that the DEMO operating scenario cannot be a q_{95}=3 ELMy H-mode (ITER Q=10)

- as a consequence, the physics base for the DEMO scenario is at present insufficient

The present EUROfusion strategy for the DEMO plasma scenario is based around two tools

- a ***systems code*** containing 0-D stationary models for all physics and technology elements to design an operational point consistent with the engineering constraints
- a ***flight simulator*** linking a spatio-temporal plasma description to realistic sensors and actuators to develop and qualify an end-to-end ‚safe' (controllable) discharge design

While being used for scoping/design, tools are updated constantly according to progress physics and technology. Implies constant dialogue with the DEMO WPs and FSD.



DEMO flight simulator

We set up a bi-weekly FTD-FSD meeting discussing our needs and how to address them in FSD (theory and experiment)

- the following 3 talks result from these meetings

How do we select the 'high priority' items presented to FSD?

There are many open questions for the DEMO physics scenario. FSD 'wishlist' guided by

- the most urgent areas where ***experimental investigations*** (aided by interpretative and predictive modelling capabilities) are needed for the design of the ***EU-DEMO Baseline***.
- topics prioritize aspects which are of ***high importance for DEMO***, but ***not (yet) covered sufficiently by ITER studies***.

Other aspects, although of primary importance, are assumed to be ***sufficiently covered by ITER-related activities*** inside FSD or elsewhere in the worldwide programme (2020 list):

- ***disruptions***: largely co-aligned with WPTE ITER studies (both avoidance and mitigation).
- ***advanced tokamak core***: strong element of AUG internal programme, DIII-D, now possibly an important EUROfusion subject in post D-T JET, and then JT60-SA (see later)
- …(***many more***)

Note: aim is always physics understanding towards predictive capability, 'demonstration' on present day devices usually not sufficient for credible use in DEMO scenario

Priorities identified in 2020 (as presented at the WPTE planning meeting 07.12.2020)

Based on this approach we identified the following high priority topics in 2020:

- ELMs and ELM-free scenarios ($\Rightarrow$ *status summarized in the talk by M. Wischmeier*)
- Limits to core radiation fraction
- Divertor detachment control

($\Rightarrow$ *status summarised in the talk by S. Wiesen*)

- Access and termination ($\Rightarrow$ *status summarized in the talk by E. Joffrin*)
- High beta core scenarios (after JET D-T, subject of next FSD-FTD meetings)

The remainder of the talk describes the three main present work strands in PSD

- They will most likely lead to further high priority items for FSD

Strand 1: constraints on the DEMO pulse length

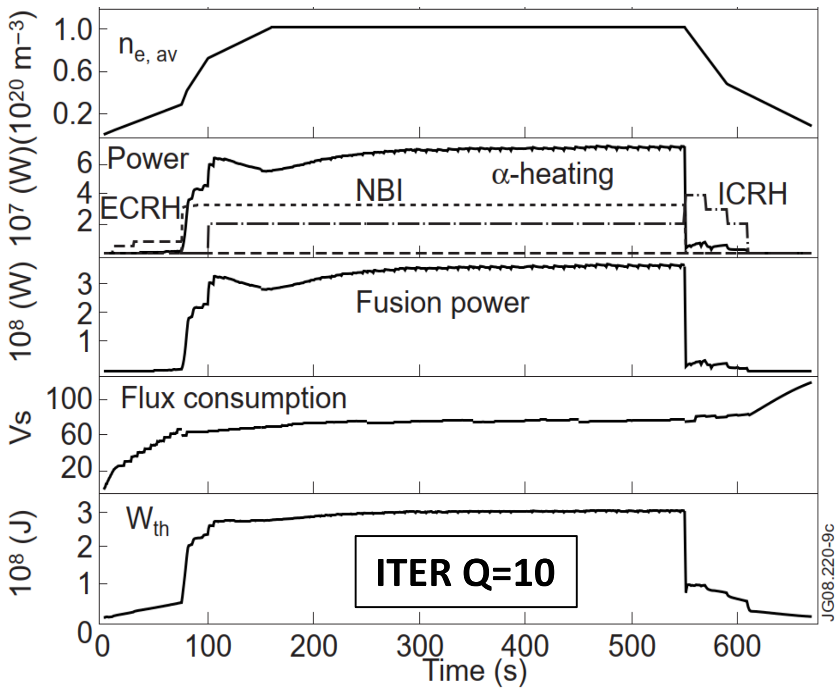
The overarching requirement is to generate enough dpa for verifying blanket life time

- 20 dpa (starter blanket) + 50 dpa (advanced blanket) lead to 5.4 yrs of full power operation at 2 GW ⇒ 24.000 pulses at 2 hrs pulse length

This leads to a number of problems that could be relieved by longer pulse length

- less load cycles relax the fatigue constraints (coils, in-vessel components…)
- decrease of the number of (delicate) ramp phases
- higher average electric output and efficiency

While steady state operation is still not within our envelope of assumptions, we explore a number of options to increase the pulse length



Strand 1: constraints on the DEMO pulse length

The following items are studied in this context:

- re-evaluation of the steady state loop voltage shows that previous PROCESS estimate was too pessimistic
- we are upgrading the flight simulator to study ramps (coupling transport code & free boundary equilibrium to the control system using realistic sensors and actuators)
- this tool will be used to optimise ramp up to achieve target q-profile with minimum flux consumption (presently approximated by a simple Ejima coefficient)
- adapt fusion power waveform to balance of plant, i.e. much slower than previously assumed (~ 10 minutes ramp) – decoupling of current and fusion power ramp
- possible introduction of (axisymmetric) in-vessel control coils can relax constraints on current ramp by providing better stability margin
- optimisation of use of PF coils for providing additional Vs (re-visit shape requirements)
- together with engineering, we discuss options to provide more OH flux

Strand 2: 3-D coils

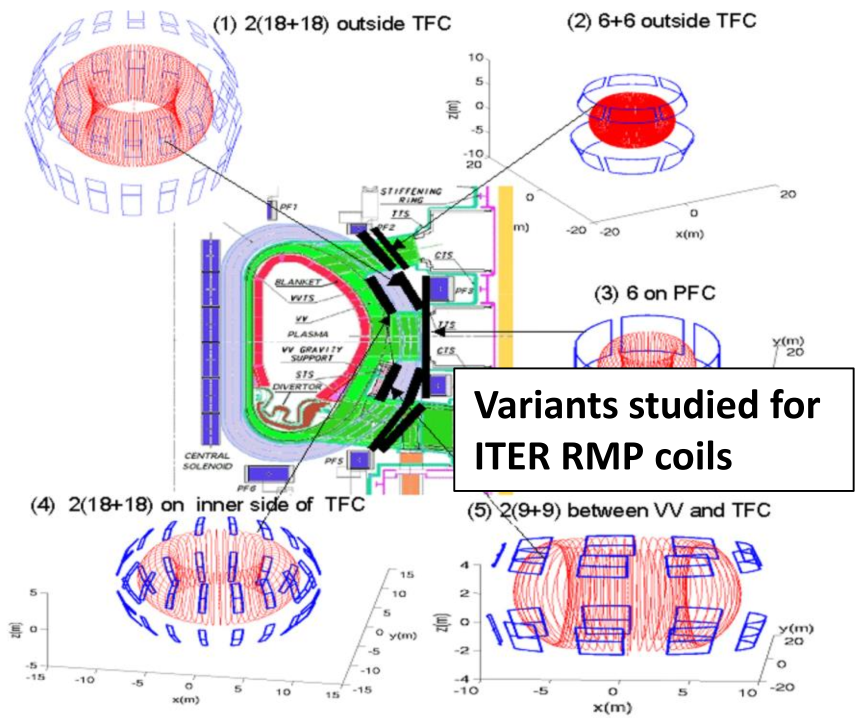
The present baseline does not foresee any 3-D coils. Introducing these will allow

- active correction of unavoidable error fields (probably a must)
- manipulation of the relative phase of locked tearing modes for NTM control by ECCD
- application for ELM suppression or mitigation (if needed)
- additional knob for tailoring of edge profiles (e.g. rotation shear for no-ELM regimes)

Contrary to ITER, we can design these coils with all applications in mind from the start

- can one set of coils do the job?
- since we do not foresee active RWM control, coils could be ex-vessel and superconducting

Presently reviewing the different physics requirements as input to the design process



Strand 2: 3-D coils

The following items are studied in this context:

- characterisation of expected error fields: Monte-Carlo approach for shape/positioning errors in coils system + nonaxisymmetric structures (ports, feeders…)
- requirements for error field correction – consider switching from 3-mode vacuum compensation to plasma response compensation
- re-visit criteria for ELM suppression / mitigation
- requirements for moving a locked mode in front of the ECCD launchers
- study options to use 3-D coils for affecting edge profiles (additional transport, NTV)
- characterise impact of 3-D fields on exhaust (lobe strucures)

We do have a strong science programme on this in the EU (tokamak and stellarator!) covering many of these aspects already, but expect to come up with targeted questions

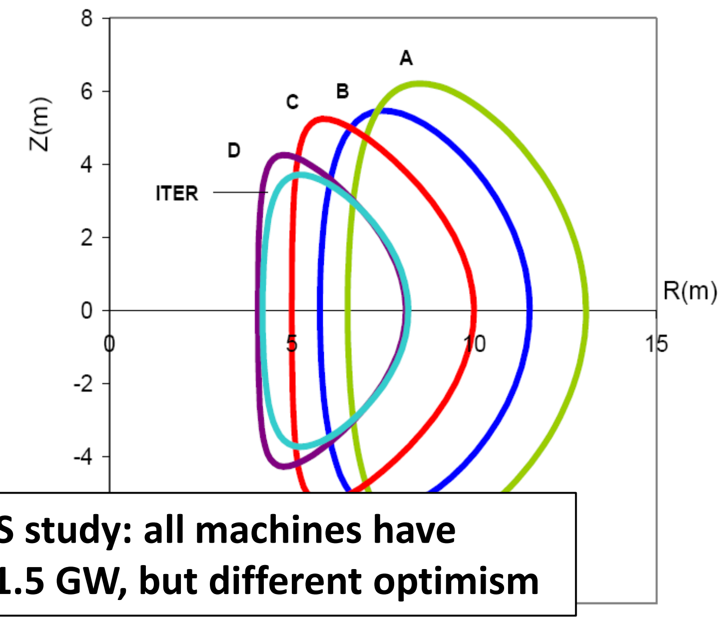
EU DEMO is by far the largest size DEMO proposal worldwide

- this is due to a combination of conservative (realistic) approach in both physics and engineering as well as the unprecedented level of detail with which the complex system has been analysed in FP8

This strand reviews the physics assumptions, taking into account more recent findings from the programme to evaluate their potential to make the machine more attractive

- will have to improve our predictive capabilities in these areas by a combination of experiment and theory
- note that we still exclude Sci-Fi assumptions ;-)

In parallel, also engineering assumptions reviewed to identify avenues for improvement (we have started with the magnets)



PPCS study: all machines have P_{el}=1.5 GW, but different optimism

Strand 3: ‘optimum physics’ DEMO

The following items are studied in this context:

- use flux pumping to create ‘hybrid-type’ central q-profiles (just above 1)
- understand how an ELM-free pedestal can be optimized, e.g. characterise better the impact of shape (triangularity) on the plasma (present choice is copied from ITER)
- assess the beneficial effect of edge CX on radiative losses
- consolidate assumptions on intrinsic impurity content based on the validation of pedestal impurity screening on JET
- understand how to exploit best beta and fast particle stabilization of ITGs
- quantify the control requirements and adapt the burn point (Q)

The present target could be called a ‘hybrid core combined with an ELM free edge’ – we will need to understand how this can be validated in our programme

Summary and outlook

The high priority topics identified in 2020 are being fed into the programme

- ELMs and ELM-free scenarios ($\Rightarrow$ *status summarized in the talk by M. Wischmeier*)
- Limits to core radiation fraction
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($\Rightarrow$ *status summarised in the talk by S. Wiesen*)

- Access and termination ($\Rightarrow$ *status summarized in the talk by E. Joffrin*)

From the present work, more topics arise, to be discussed in future FSD-FTD meetings

- High beta core scenarios (flux pumping has never been reported from JET!)
- Non-axisymmetric fields (need clear requirements from physics side to optimize design)
- …

The new instrument of FSD-FTD coordination meetings has started off very promising

- Important that we now implement our joint plans – everyone is invited to join!