DEMO Parameters – Preliminary Considerations

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This work was jointly funded by the EPSRC and by EURATOM

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Outline

- DEMO link to PPCS
- Background to PPCS
- Physics issues
- Possible assumptions for DEMO
- Pulsed or Steady State
- Conclusions

The work presented here is ongoing and useful for purposes of discussion. The targets and design assumption for DEMO are not yet fixed.

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Introduction

- EU is presently considering the performance targets for DEMO and its technology and scientific basis.
- These discussions are ongoing but, in parallel, we are carrying out systems studies to clarify implications and guide decisions.
- This presentation highlights some of the ongoing work

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DEMO in Relation to PPCS

- The PPCS considered a range of possible future power plants.
- The present discussions are to decide where in this range DEMO should lie and what modifications to make in the light of experience over the last 5 years.
- DEMO will serve as a target for the EU fusion programme but is expected to change as work progresses.

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PPCS Background

- The PPCS looked at a range of power plant technologies, to compare their relative safety, environment and economic properties.
- A common basis was used for each plant model, using a systems code PROCESS which incorporates (updated) physics relationships from the ITER Physics Design Guidelines (Uckan et al)
- PPCS was not a physics study although it inevitably touched on the key physics issues for a fusion power plant.

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Power Exhaust is the Key Issue

- In the PPCS the most important issue was the power exhaust.
- The maximum tolerable divertor heat flux imposed strong constraints on other aspects of the conceptual designs.
- This remains the case for DEMO and is presently being re-visited in more detail.

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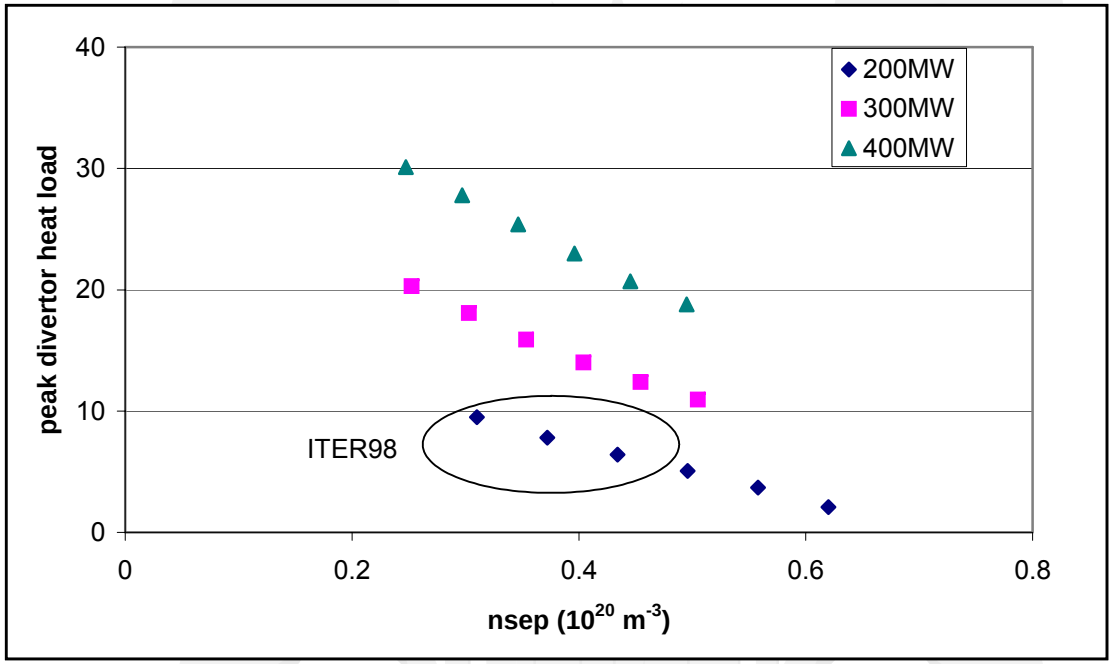
What Power Across the Separatrix Can be Handled?



R=8.2m

300 MW looks to be the highest possible P_{sep} in an ITER(98) sized machine, even allowing for impurity seeding of the divertor.

If this were a DEMO, producing 3GW fusion power, this would require ~60% radiation from the core

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Power Exhaust Couples to Other Plasma Areas

- Divertor heat load:
  - Assumed to be moderated by impurity seeding of both divertor and core plasma
  - Core radiation degrades confinement, increasing machine size, current and current drive power
- This complex interplay between divertor, core confinement and current drive power was one of the key issues in the PPCS.
- It needs more detailed study and this is ongoing.

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PPCS Near-Term Plant Models A and B

- Water cooled steel (A) and helium cooled steel (B)
- Divertor protection penalises main plasma, making the plants substantially larger than they would be due to other constraints (by more than 1m major radius)
- Need for high radiation, penalises confinement and increases current drive power.
- Different from existing machines in many ways, e.g. high temperature, high synchrotron power.
- Require more careful analysis of each area separately. Still need to combine outcomes in a systems study, where power balance, including net electrical power, is included.

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PPCS More Advanced Plant Model C

- Dual coolant (He and LiPb)
- Assumed more advanced physics (constraint for divertor protection relaxed by a divertor equivalent of an H factor)
- Higher safety factor, higher shaping, higher bootstrap current, reduced recirculating power.

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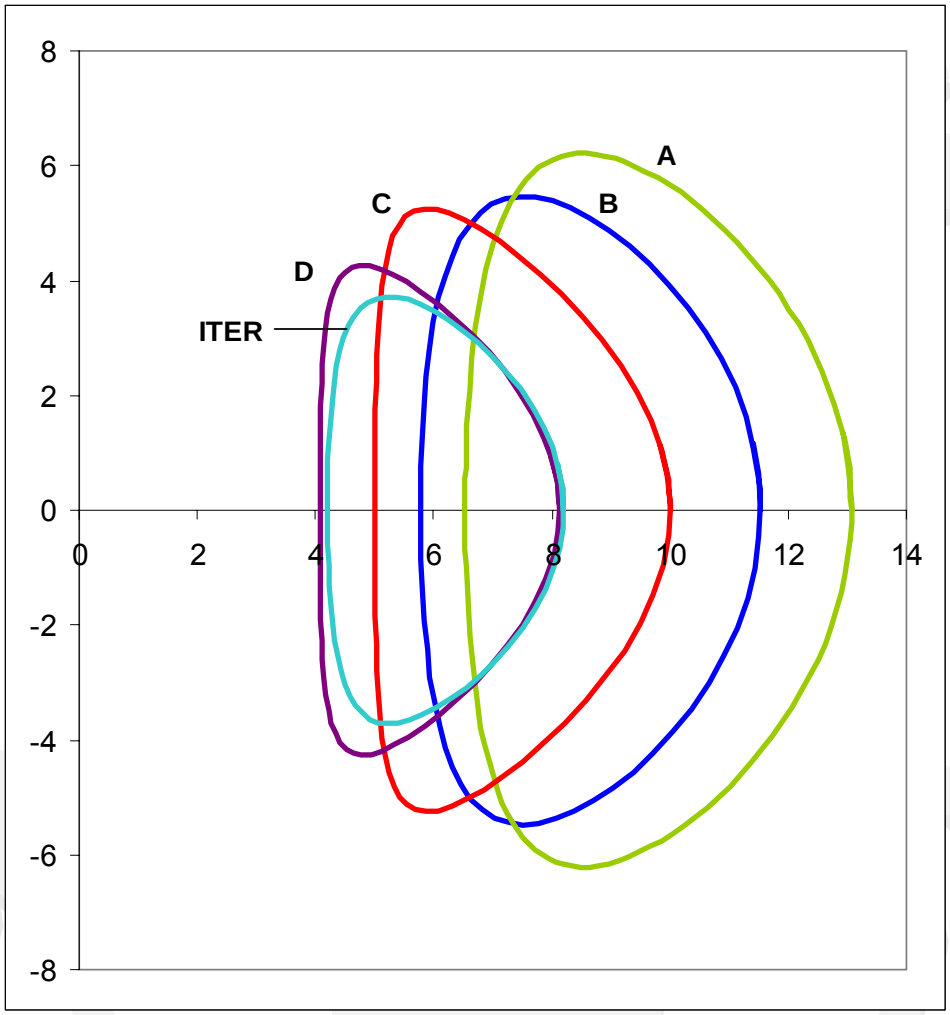
Range of PPCS Plant Model Sizes



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PPCS Main Parameters – Models A to C

	Model A	Model B	Model C
R(m)	9.55	8.6	7.5
P_e,P_{fus}(GW)	1.55, 5.0	1.33, 3.6	1.45, 3.4
I (MA)	30.5	28	18.6
β_N(thermal)	2.8	2.7	3.4
P_{CD}(MW)	246	270	112
Q	20	13.5	30
Avge. neutron wall load	2.2	2	2.2
H factor	1.2	1.2	1.3
Divertor peak load	15	10	10

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Major Physics Questions from PPCS

- Are the effects of higher temperature operation valid, particularly current drive efficiency, fast particles and synchrotron radiation?
- Are the levels of current drive needed for Models A and B feasible? Does the implied increase in efficiency with temperature hold?
- Is the divertor protection sufficient or excessive? Can other techniques relax the problem?
- Is the radiation model adequate, both for impurities and synchrotron/bremsstrahlung (especially at high temperature where synchrotron can become large)?
- Is the H-factor (assumed 1.2 in Models A and B) appropriate. (Cordey et al IAEA 2004 implies this is conservative). Role of density peaking?
- What role do the fast ions play in affecting the limiting beta? Power plants at high temperature can have high non-thermal components. What is their contribution to stability?

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More Specific Physics Questions

- β_N: PPCS values of fast alpha pressure seem excessive giving too high a value for total β. This is being reappraised (with CEA).

- Zeff: PPCS assumed a range of impurities but this has not been optimised. The design could be improved by a more careful selection of seeded impurity giving same radiation without such strong dilution.

- These will be revisited in the light of the present DEMO study.

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How does the divertor constraint impact on the plant parameters?

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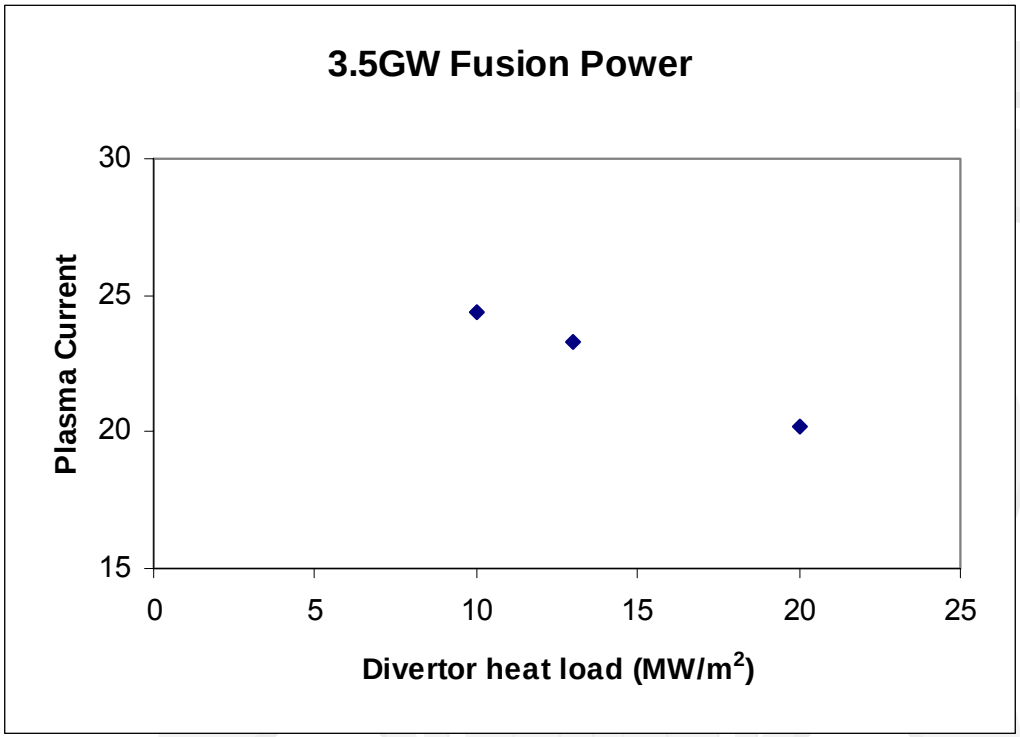
Divertor Constraint Drives up Plasma Current



High Radiation increase fuel dilution and reduces effective heating, consequently challenging confinement. Drives up plasma current and current drive power. How can this be relaxed?

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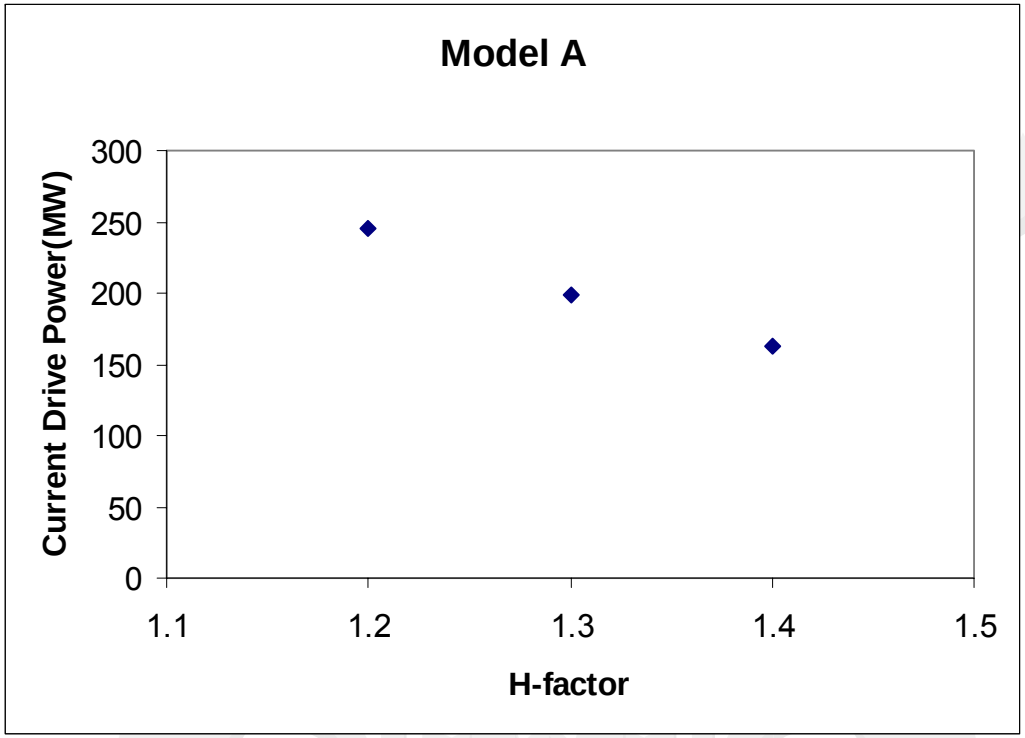
Increase H-factor to Relax Constraint



Cordey et al, higher beta suggest H=1.4 may be more consistent with present data. ITER will clear this up but what value should be assumed for DEMO study?

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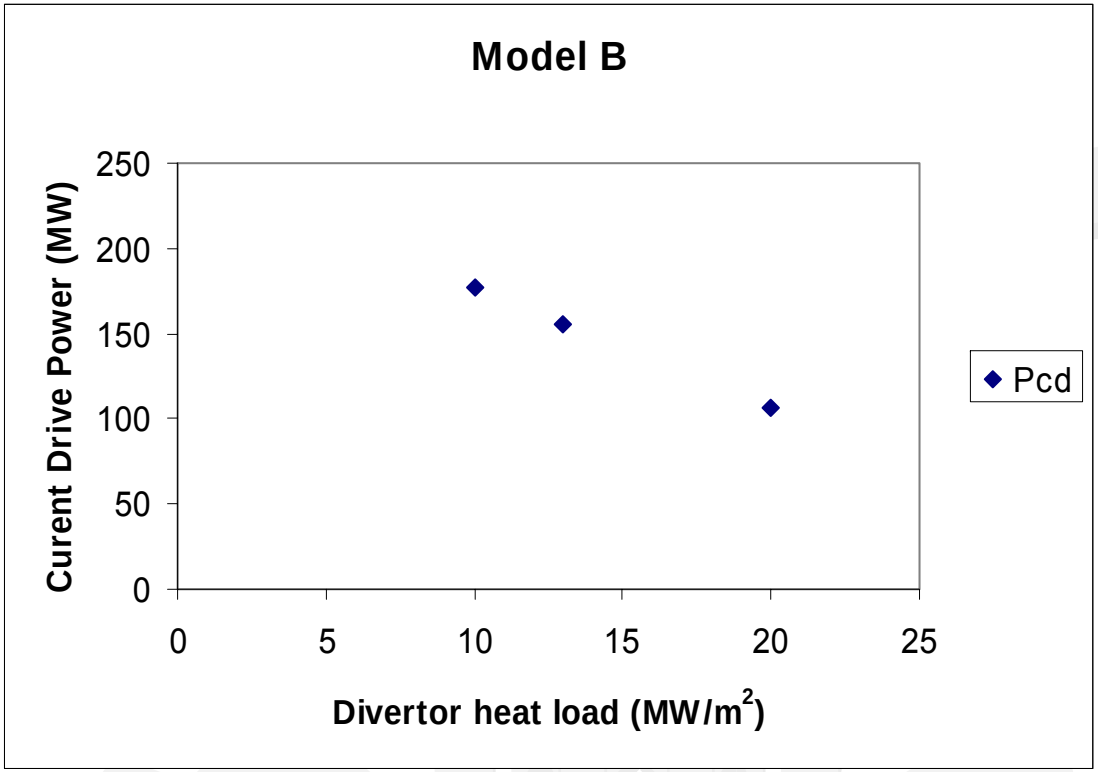
Increase the Tolerable Divertor Heat Flux



Increase the tolerable divertor heat flux

H-factor 1.3, R fixed at 8.6m

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Optimise the Impurity Seeding

- To achieve a given level of radiation requires a given Z_{eff} largely independent of the impurity Z.
- But a higher Z gives a lower dilution at the same radiation, so more fusion power from the same plasma. This can be very beneficial.
- In this example, 1.5GW_e plant with protected divertor, needs high core radiation.
- High Z radiator allows lower density, current and field, and hence lower current drive power

	Low Z	High Z
B (T)	6.8	5.5
I(MA)	27.5	22.4
Zeff	2.7	2.7
Ne	1.20	0.97
Padd (MW)	250	167
Div heat load	10	10

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What might serve as the base line for a DEMO design?

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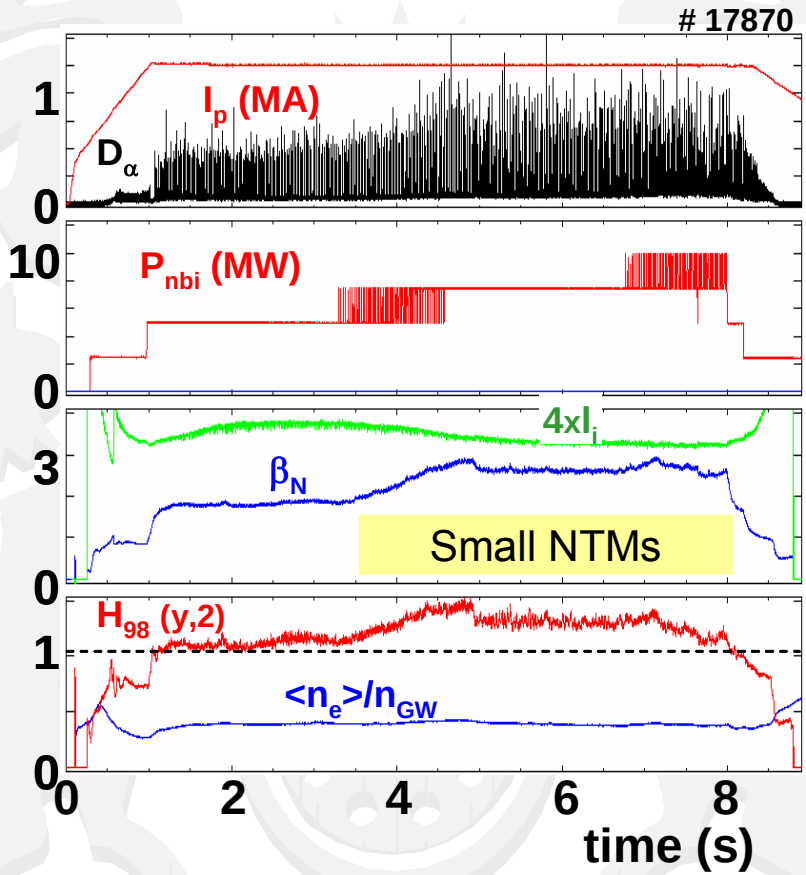
Hybrid Mode - ASDEX Upgrade



Sips et al

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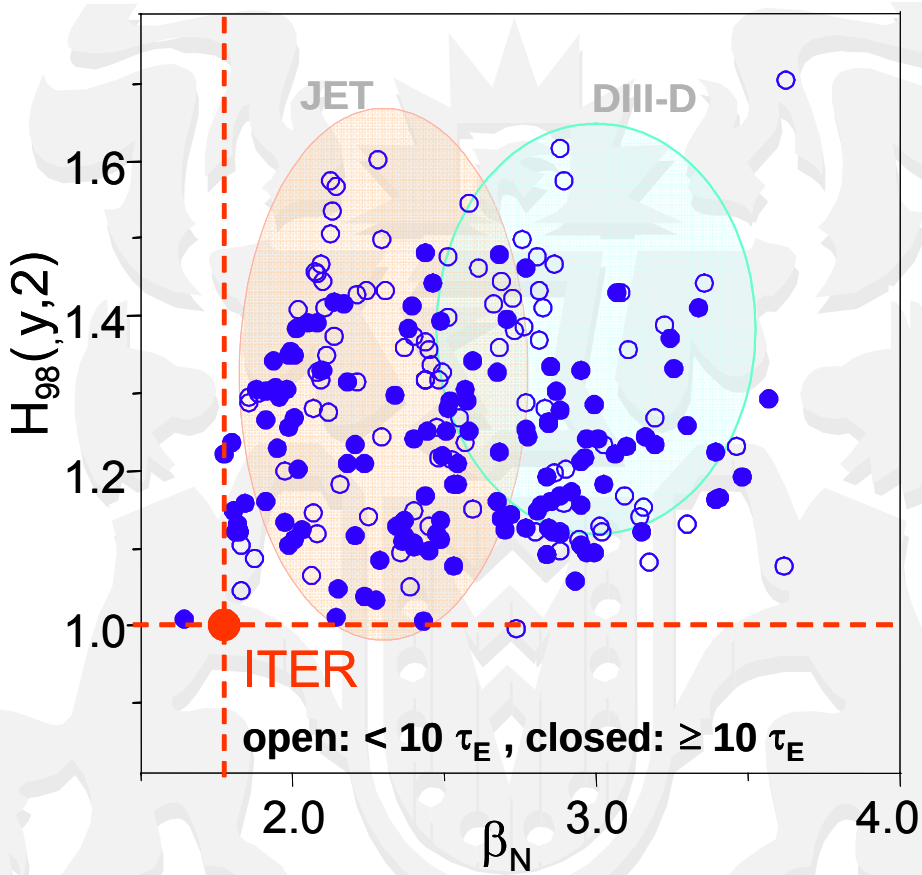
Conditions Achieved in Hybrid Operation



Sips et al

Improved H-modes. Similar to conditions assumed for PPCS Models A and B

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What could a 1GW version of a hybrid plasma with Model C technology look like, assuming high Z radiator?

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Hybrid with Model C Technology

R (m)	7.5
I (MA)	17.6
B (T)	6.1
P_{add} (MW)	137
β_N (thermal)	3
H factor	1.28
P_e, P_{fus} (GW)	1.0, 2.55
Divertor heat load	10

Illustrative results with protected divertor

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What are the implications of applying similar assumptions to an ITER sized device?

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ITER Sized Plant with the Same Assumptions

	ITER-NI	ITER/DEMO
R (m)	6.35	6.2
I (MA)	9	17.7
B (T)	5.18	4.5
P_{add} (MW)	59	178
β_N (thermal)	2.95	3
H factor	1.57	1.1
P_e, P_{fus} (GW)	0, 0.356	0.4, 1.39
Divertor heat load(MW/m^2)	10	10

(Lower B due to thicker blanket, shield and vessel)

ITER sized plant produces 1.4GW fusion power with the same assumptions as the DEMO model. ITER-NI relies on higher q, higher bootstrap fraction, higher H.

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Pulsed vs Steady State

- The issue of a pulsed DEMO is being discussed again.
- This is an option within PROCESS but is being used for the first time.
- Pulsed:
  - Long pulse length, larger solenoid, larger R (larger aspect ratio?)
  - Pulsed heat and stresses
  - Energy storage
  - Power supplies
- Steady state
  - Current drive efficiency and reliability
  - Ports, neutron streaming
- Hybrid design?

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First Attempt to Benchmark Pulsed PROCESS

- Compare with the earlier pulsed power plant study, PULSAR (haven't matched blanket/shield thicknesses)
- New constraints and variables to track: flux swing, pulse length, fatigue life etc.
- First attempt looks quite good but some issues remain, particularly PF supplies, TF stresses.
- Overall, reduced power density compared to steady state device because higher aspect ratio and higher safety factor (both needed for pulse length).
- Divertor less of a problem because of reduced power density.
- First results show that the costs are higher than for a steady-state device in spite of the higher assumed conversion efficiency.

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First Attempt to Benchmark Pulsed PROCESS

	Pulsar I	PROCESS I
R(m)	9.2	9.65
Aspect Ratio	4	4
Burn time (hours)	2.5	8.1
P_e,$P_{thermal}$ (GW)	1, 2.31	1, 2.28
I(MA)	14.2	15.4
B(T)	6.65	7.4
Neutron wall load	1.1	1.1
q	3.5	3.5
Total cost (B92$)	6.36	7.9

First use of Pulsed PROCESS using PULSAR-like assumptions

Provisional results intended to check PROCESS running in pulsed mode.

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Pulsed PROCESS Unresolved/Uncertain Areas

- Includes energy storage costs, options based on Pulsed Fusion Reactor Study (1992 Electrowatt). Cost probably too small in above table as only allows 100s down time.

- Needs further refinement as present inconsistency between PF power supply and assumed fast recharge of OH coil (likely to increase cost).

- PROCESS estimates FW fatigue life, not included as a constraint at present.

- For approximate consistency with PULSAR, TF case stress reduced - compared to steady state models - by 12% (although field in the plasma is higher). Overall (provisional) cost of electricity around 20% higher than a steady state model.

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Initial Pulsed Version of DEMO

- Work is ongoing to move from a PULSAR-like device to an equivalent with Model C technology (lower thermodynamic efficiency etc) and physics comparable to the steady state DEMO.

R(m)	9.4
B(T)	7.4
I(MA)	15.0
P_e,P_{fus}(GW)	1, 2.48
β_N (thermal)	2.7
H factor (IPB98y2)	1.3
Div heat load (MW/m^2)	6.6

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Conclusions

- The largest uncertainties in the PPCS physics relate to the linkage between divertor heat flux, radiation, confinement and current drive.
- In a pulsed machine the issues are entirely different: flux swing, pulse length, fatigue life and power density become most important.
- These need more careful study individually, then improved representation in a systems study to put it all together in a coherent design.
- A possible way ahead is to develop a 1GW steady state DEMO based on Model C technology combined with a hybrid mode of operation. Benchmark a pulsed conceptual design to serve as a comparison.

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