European Fusion Power Plant Conceptual Study - Parameters For Near-term and Advanced Models

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(Presented by Ian Cook)

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Plant Models A, B, C & D.

- All the Plant Models should have **good safety and environmental characteristics**
- All are **1500 MWe**

Models A & B

- Based on **limited extrapolations** in physics and technology: **focus on credibility**

Model C

- **Intermediate**

Model D

- **Advanced** in all respects

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Plant Models A & B

- Limited extrapolations in physics from ITER
- Low-activation martensitic steel

- **Model A: water-cooled lithium-lead blanket (WCLL), ITER-style divertor**

- **Model B: helium-cooled pebble bed blanket (HCPB), helium-cooled tungsten divertor**

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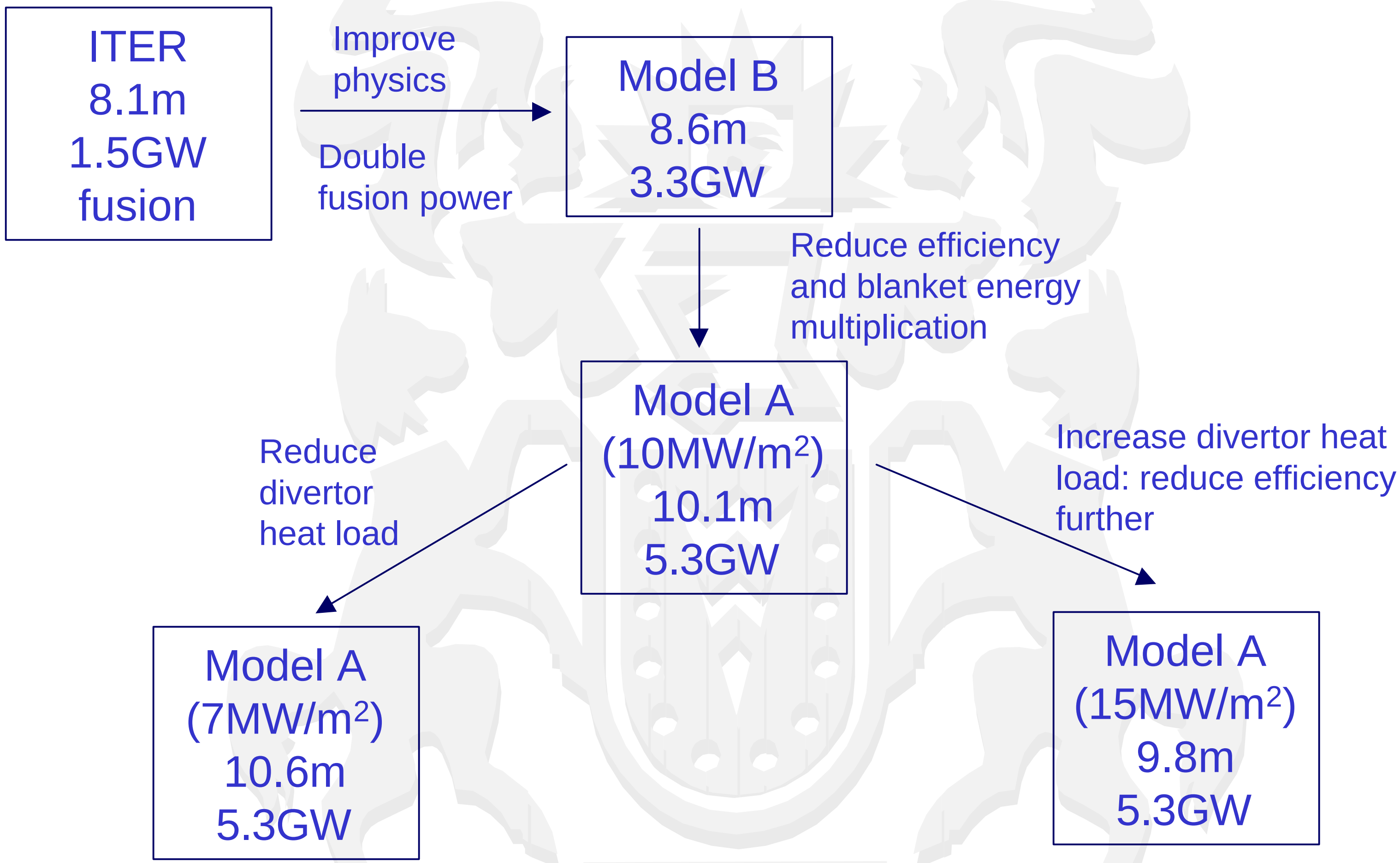
Link Between ITER (98) and PPCS Models A+B



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Plant Parameters

Parameter	WCLL	HCPB
Unit Size (GW_e)	1.5	1.5
Blanket Energy Gain	1.18	1.39
Net Conversion efficiency	0.31	0.42
Fusion Power (GW)	5.5	3.3
Aspect Ratio	3.0	3.0
Elongation (X-point, 95% flux)	1.9, 1.7	1.9, 1.7
Triangularity (95% flux)	0.4, 0.27	0.4, 0.27
Major Radius (m)	9.8	8.6
TF on axis (T)	7.3	6.8
TF on the TF coil conductor (T)	12.9	13.0
Plasma Current (MA)	33.5	27.5
β_N(thermal) ; β(thermal)	2.7	2.7 (3.8%)
Average Temperature (keV)	23	19.6
Temperature peaking factor	1.5	1.5
Average Density ($10^{20}m^{-3}$)	1.1	1.2
Density peaking factor	0.3	0.3
H_H (IPB98y2)	1.2	1.2
Bootstrap Fraction	0.36	0.36
P_{add} (MW)	265	228
n/n_G	1.2	1.2
Q	21	15
Recirculating power fraction	0.27	0.22
Average neutron wall load	2.27	1.8
Divertor Peak load (MW/m^{-2})	**15**	10
Zeff	2.55	2.7

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Parameters for Model A with Varying Divertor Heat Loads

Parameter	WCLL(7)	WCLL(10)	WCLL(15)
Unit Size (GW_e)	1.5	1.5	1.5
Blanket Gain	1.18		
Net Blanket Conversion efficiency	0.33		
Fusion Power (GW)	5.3		
Aspect Ratio	3.0	3.0	3.0
Elongation (95% flux)	1.7		
Triangularity (95% flux)	0.27		
Major Radius (m)	**10.6**	**10.1**	**9.6**
TF on axis (T)	7.1	7.2	7.3
Plasma Current (MA)	35	34	33
β_N(thermal) ; β(thermal)	2.5 (3.5%)		
Average Temperature (keV)	23	23	23
Temperature peaking factor	1.5	1.5	1.5
Average Density ($10^{20}m^{-3}$)	1.0	1.1	1.1
Density peaking factor	0.3	0.3	0.3
H_H (IPB98y2)	1.2	1.2	1.2
Bootstrap Fraction	0.33		
Recirculating power fraction	0.28	0.27	0.26
Average neutron wall load	1.9	2.0	2.2
Divertor Peak load (MW/m^{-2})	**7**	**10**	**15**
Zeff	2.7	2.6	2.5

There remains some scope for optimisation

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Plant Models C & D

Model C

- Intermediate physics
- **Dual-coolant, RAFM/SiC, blanket**
- Divertor concept still open
- **Model D**
- Advanced physics
- **Self-cooled lithium-lead SiC blanket**
- Divertor concept still open

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Underlying Physics

- Assume a combination of an **internal transport barrier and H-mode.**
- High shaping for stability: **$b_N<4.5$**
- Increased safety factor,q, to give higher fraction of current driven by bootstrap effect: **$q=4.5$, $f_{boot} = 75\%$**
- Higher q tends to make limiting density lower so **$n>n_G$**

Blanket and Shield

- **Model C:**

  1.17 blanket energy multiplication

  44% conversion efficiency

- **Model D:**

  1.17 blanket energy multiplication

  59% conversion efficiency

Preliminary Plant Parameters

Parameter	Intermediate (Model C)	Advanced (Model D)
Unit Size (GW_e)	1.5	1.5
Blanket Energy Gain	1.17	1.17
Net Blanket Conversion efficiency	0.44	0.59
Fusion Power (GW)	3.41	2.46
Aspect Ratio	3.0	3.0
Elongation (X-point, 95% flux)	2.1, 1.9	2.1, 1.9
Triangularity (X-point, 95% flux)	0.7, 0.47	0.7, 0.47
Major Radius (m)	7.5	6.1
TF on axis (T)	6.4	5.6
Plasma Current (MA)	20.1	14.1
Safety factor q(95)	4.5	4.5
β_N(thermal, total)	3.4, 4.0	3.7, 4.5
H_H (IPB98y2)	1.3	1.2
Heating Power (MW)	112	71
n/n_G	1.5	1.5
Q	30	35
Average neutron wall load	2.2	2.4

Used as starting point for study.

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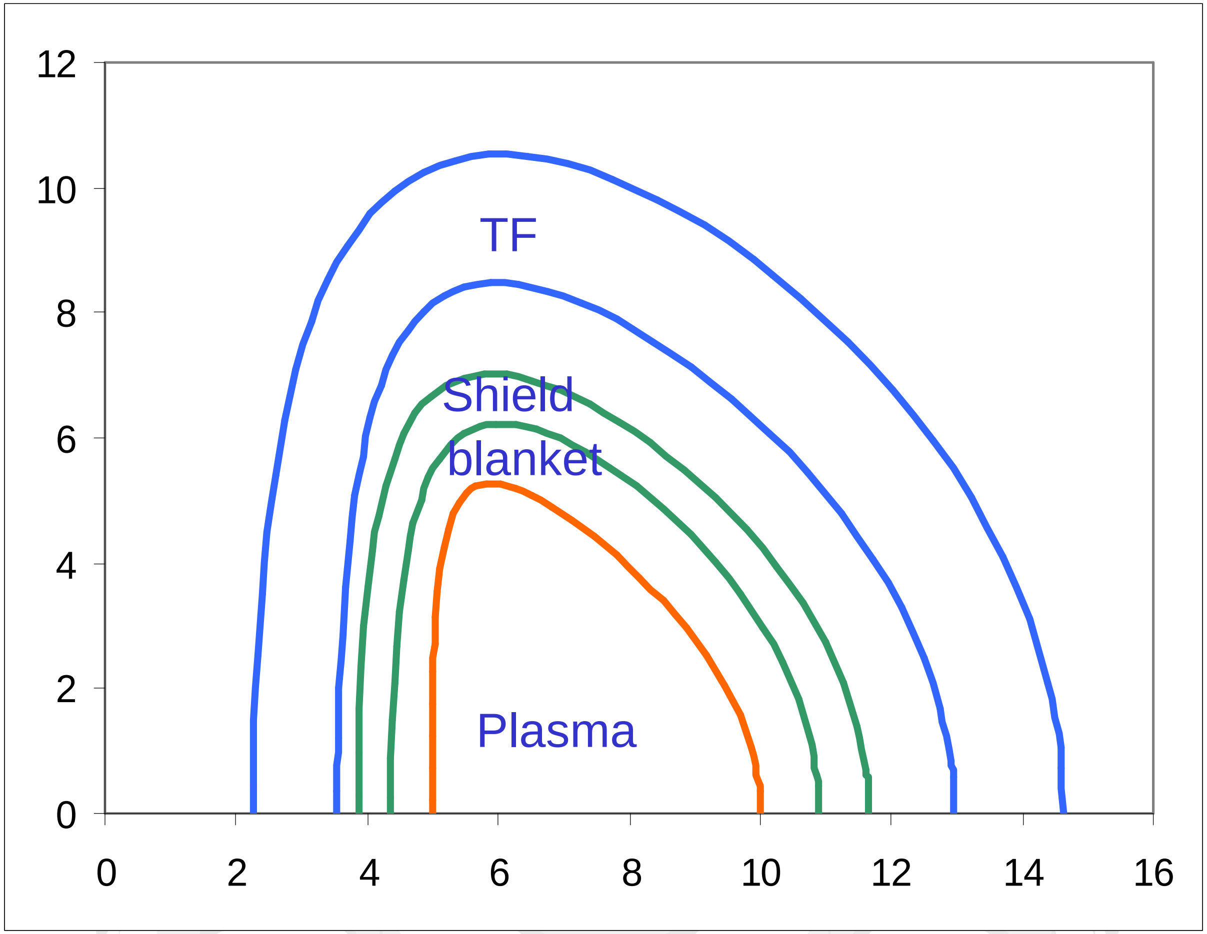
Schematic of Plant Model C



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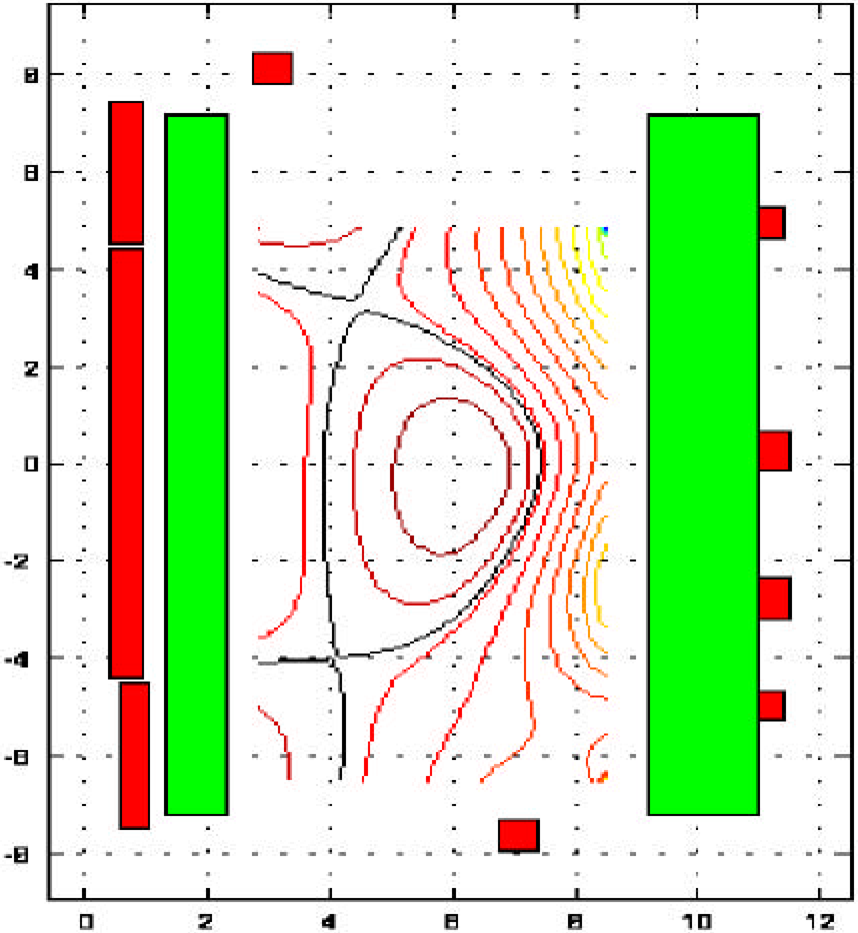
Plasma Shape and Equilibrium

First Attempt at Equilibrium (M. Cavinato)



Ip (MA)	11.6
R0 (m)	5.84
ap (m)	1.78
Rax(m)	6.08
Zax(m)	-0.105
kxp	1.88
k95	1.66
dxp	0.663
d95	0.437
Perim. (m)	17.4
Area (m2)	16.8
Vol. (m3)	640
qaxis	1.27
q95%	4.86
bp(1)	2.44
li(3)	0.807
Lp (mH)	1.81
ΨPF (Wb)	-81
Ψax(Wb)	46.7
Ψb (Wb)	0.00443

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Divertor

- **Model D:**

  Assume **divertor heat load does not impose a penalty on the core plasma**, e.g. radiating mantle outside confinement zone or ergodic divertor…

- **Model C:**

  Intermediate assumption, **core is penalised at a level intermediate between Model B and Model D.**

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Confinement and Density

- With an internal transport barrier combined with H-mode, the confinement requirements should not be difficult.

- Operating at higher safety factor and thus reducing the current drive requirements has the consequence of reducing the density limit, making the density a bigger challenge.

- If necessary, the density and confinement can be traded off against each other to some extent, although at the expense of increased machine size. For instance $n<1.2n_G$ would increase major radius from 6m to 6.3m for Model D.

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Safety Factor and Bootstrap Current

- **Increasing safety factor allows a higher value of b_p (~q/e) and consequently allows a higher bootstrap fraction:**

  Model C 69% bootstrap current

  Model D 76% bootstrap current

- **This reduces concern over the recirculating power needed for the current drive systems and also reduces heat loads.**

First Wall Heat Flux

- As with the nearer term plant models, the advanced models rely on radiating much of the alpha power and additional heating power to the first wall.

- Reducing the current drive power ameliorates this a little.

- The ratio between first wall heat flux and neutron power flux is approximately 20%.

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Comparison with Models A and B

	A	B	C	D	ARIES-AT 1,000MW$_e$
R(m)	9.8	8.6	7.5	6.1	5.2
I(MA)	33.5	27.5	20.1	14.1	12.8
β_N	3.4	3.3	4	4.5	5.4
f_B(%)	36	36	69	76	92
H_H	1.2	1.2	1.3	1.2	1.4
q_{95}	3	3	4.5	4.5	2.8?
η_{th}(%)	31	42	44	59	59
Blanket energy gain	1.18	1.39	1.17	1.17	

Preliminary implications: Models A & B

- Most challenging areas are divertor heat load and need to drive a large fraction of the plasma current with the heating systems
- These constraints tend to drive the designs to a large size, with relatively high recirculating power
- Near-term power stations seem feasible
- Technology of Model B allows a power plant design comparable in size to ITER(98)

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Preliminary implications: Models C & D

- Projected improvements in physics and technology make feasible a plant closer in size to ITER-FEAT, with reduced recirculating power
- Plasmas are more highly shaped: this is a more challenging configuration for the technology integration

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Preliminary Overall Conclusions

- It is becoming apparent that **acceptable power stations can be accessed by a "fast-track" route: through ITER, without major materials advances**
- The potential remains for a more advanced second generation of power stations

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