Systems Code Status

J. F. Lyon, ORNL

ARIES Meeting June 14, 2006

Topics

- Systems code changes since April meeting
  - requested revisions and additions
- Parameters for reference ARE case
  - comparison with parameters for April case
- Effect of parameter variations
- Work in progress, further refinements needed

Les Waganer's Action Items

1. Provide Neutron Source Profile to Mau and Wilson
   L-P Ku & I provided code lines and data to Paul Wilson
   - calculation of neutron production rate on a flux surface
   - data file for VMEC coefficients $r_{m,n}(\psi,\theta,\phi)$, $z_{m,n}(\psi,\theta,\phi)$
   - conversion from ψ,θ,ϕ VMEC coordinates to x,y,z

2. Check Delta-Min Used in Code -- revised

3. Check Power to the Divertor - should include alpha power (~ 41 MW extra) -- was OK, has always been included

Code Changes Since Last Meeting -- 1

(1) Lower neutron flux in the divertor region was used to revise the neutron and radiation flux to the divertor

- calculation that gave 1.52 for peak/average ratio gave 0.737 for the minimum/average ratio (= 1.91 MW/m^2 for ARE ref. case).
- this reduces the *effective* area of the divertor from 15% to 11%

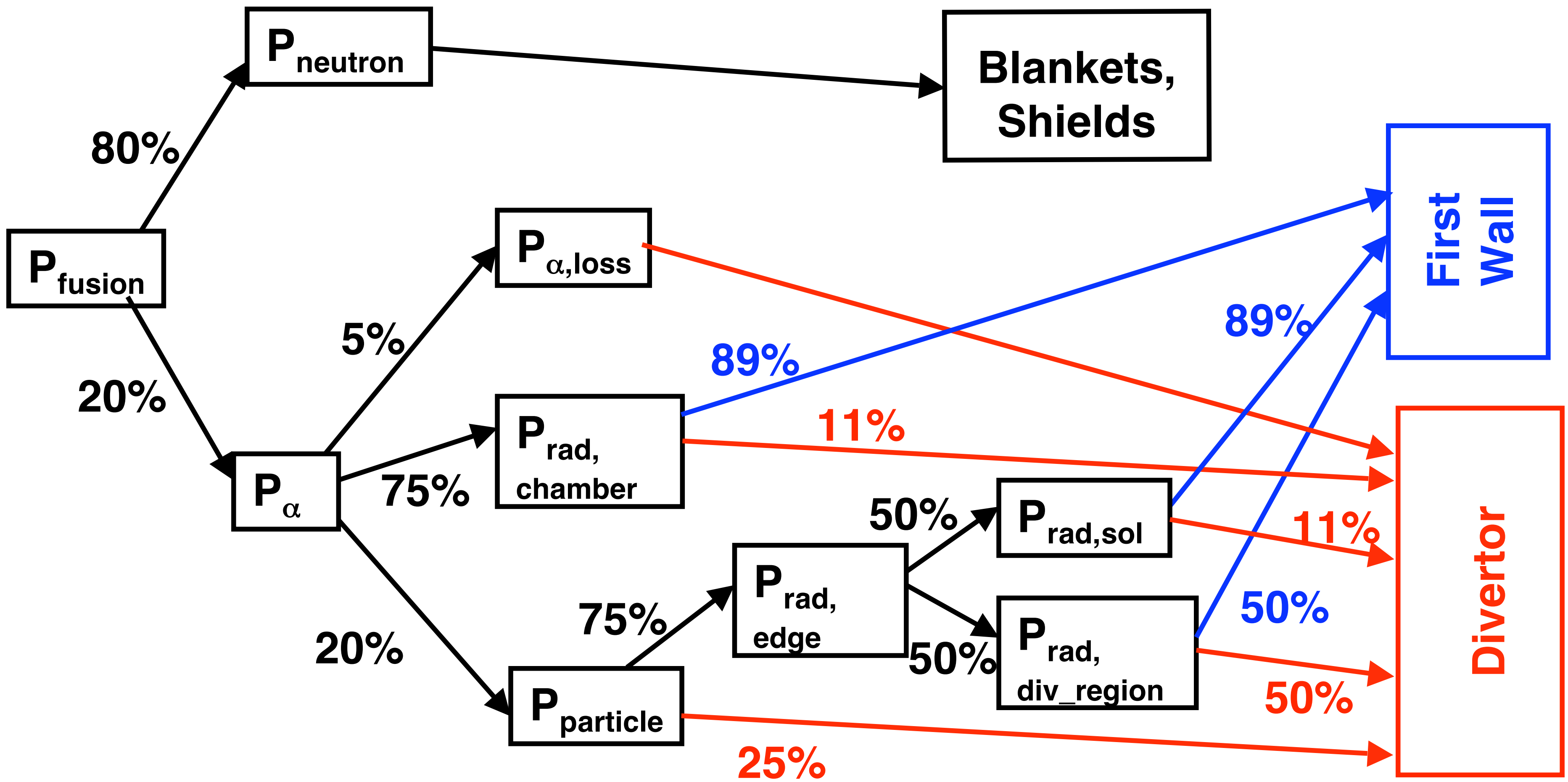
(2) 75% of particle power crossing plasma surface is radiated in the scrapeoff layer (SOL) and divertor vicinity; 25% hits the divertor plate as charged particle power

- of the power radiated in SOL, 1/2 is radiated to the wall and divertor,1/2 in the vicinity of the divertor
- of the power radiated in the vicinity of the divertor, 1/2 goes to the divertor and 1/2 to the wall

pdivert = pdt*floss + prsum*divfract*0.737 + pcond*(1. - fSOLrad)
+ pcond*fSOLrad*(0.5*0.5 + 0.5*divfract*0.737)

pwall = prsum*(1. - divfract*0.737)
+ pcond*fSOLrad*(0.5*0.5 + 0.5*(1. - divfract*0.737))

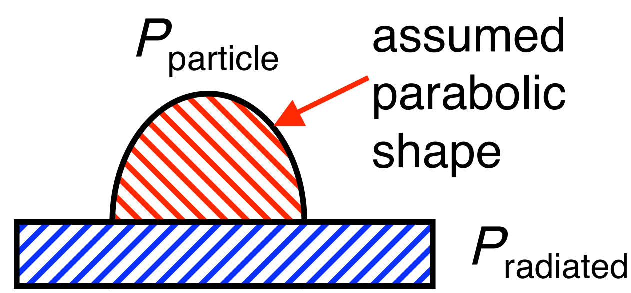
Power Fractions for Reference ARE Case



Reducing Power & Peak Load on Divertor

$$f_{div} = P_{div}/P_\alpha = f_{loss} + f_{part}{}^*(1 - f_{SOLrad}) + f_{rad,core}{}^* f_{div\ area}{}^*0.737$$
$$+ f_{part}{}^* f_{SOLrad}{}^*(0.5^* f_{div\ area}{}^*0.737 + 0.5^*0.5)$$
$$= 0.05 + 0.05 + 0.08 + 0.05 = 0.23$$

- Reduced power to divertor by reducing f_{loss} to 5% (vs 10% before), radiating 75% from core and 75% of the particle power in the SOL
  - this also reduced peaked (particle) power component
  - 0.56 MW/m² radiated power flux on divertor
  - 0.43 MW/m² ave. particle power flux on divertor
  - ⇒ allows 9.44 MW/m² particle power on divertor & peaking factor of 14.6!



Code Changes Since Last Meeting -- 2

(3) Put 90% of electrical (He) pump power back into the thermal power

- decreases P_{fusion} required from 2457 MW to 2355 MW

(4) changed inter-coil shell thickness from 35 cm to 20 cm,
scaled Xueren's penetrations by R^2,
changed strongback thickness from 65 cm to 28 cm

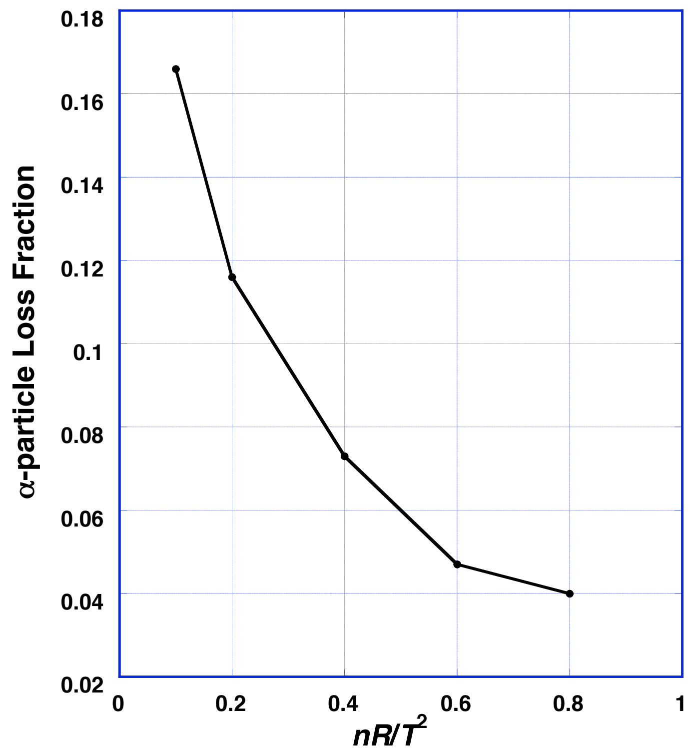
- decreases coil structure from 5730 t to 3420 t

(5) Changed availability from 76% to 85%

(6) Changed cost of coil structure from \$56/kg to \$20/kg (2004 \$)

(7) R_{min} changed to be consistent with Laila's value (Δ = 5 cm)

(8) parametric dependence of α-particle loss fraction on R, B, n and T from Long-Poe's calculation of α-particle loss vs $\nu^* \sim nR/T^2$



Consequences of Fixed α-Particle Loss Rate

(1) the fraction of the power in core radiation was targeted to be ≥75% and the α-particle loss rate was targeted to be ≤5%. However, the code always gave these two limits.

(2) It was not possible to reduce the α-particle loss rate to 5% with the core radiation fraction = 75% for R = 7.5 m. As the α-particle loss rate decreases below 10%, R_{min} increases above 7.5 m.

- B_{max} increases so the current density in the coil pack must decrease and the radial depth of the coil pack increase.

(3) As the α-particle loss rate decreases: the coil pack thickness, B_{axis}, B_{max}, n and n_{DT}/n_e increase; T, %He and % Fe decrease.

- below 4.5% α-particle losses, n is above twice the Sudo limit, which depends on B_{axis} and R.
- nR/T^2 determines the α-particle loss rate; the code selects the lowest value that gives the limiting value.
- nT/B_{axis}^2 is constrained for a fixed β value.
- $n^2 f(T)$ determines the power radiated from the core, and $\sim n^2 T^2$ and fuel dilution determine the fusion power.

Code Changes Since Last Meeting -- 3

(9) Added 1 cm to the coil-coil distance calculation

(10) Scaled TBR and blanket thickness linearly between R = 7.5-8 m rather than polynomial fit over a larger R range that did not give exactly Laila's value at R = 7.5 m

(11) Changed A_{coil} (A_{Δ}) from 5.89 to 5.9385 for the ARE case

(12) Changed EOL fluence from 15 to 15.7 Mwy/m2 & blanket energy mult. From 1.16 to 1.155

(13) $V_{RB} = 1.3 \times 10^5$ m^3 x 1.3 & cost (2004 \$) = (33 + $0.00025V_{RB}$) x LSA

- 21.2: \$151M ⇒ \$67.7M

(14) Used ARIES-AT costing for plasma heating to ignition

- 22.1.4: \$65.9M ⇒ \$28.6M

Code Changes Since Last Meeting -- 4

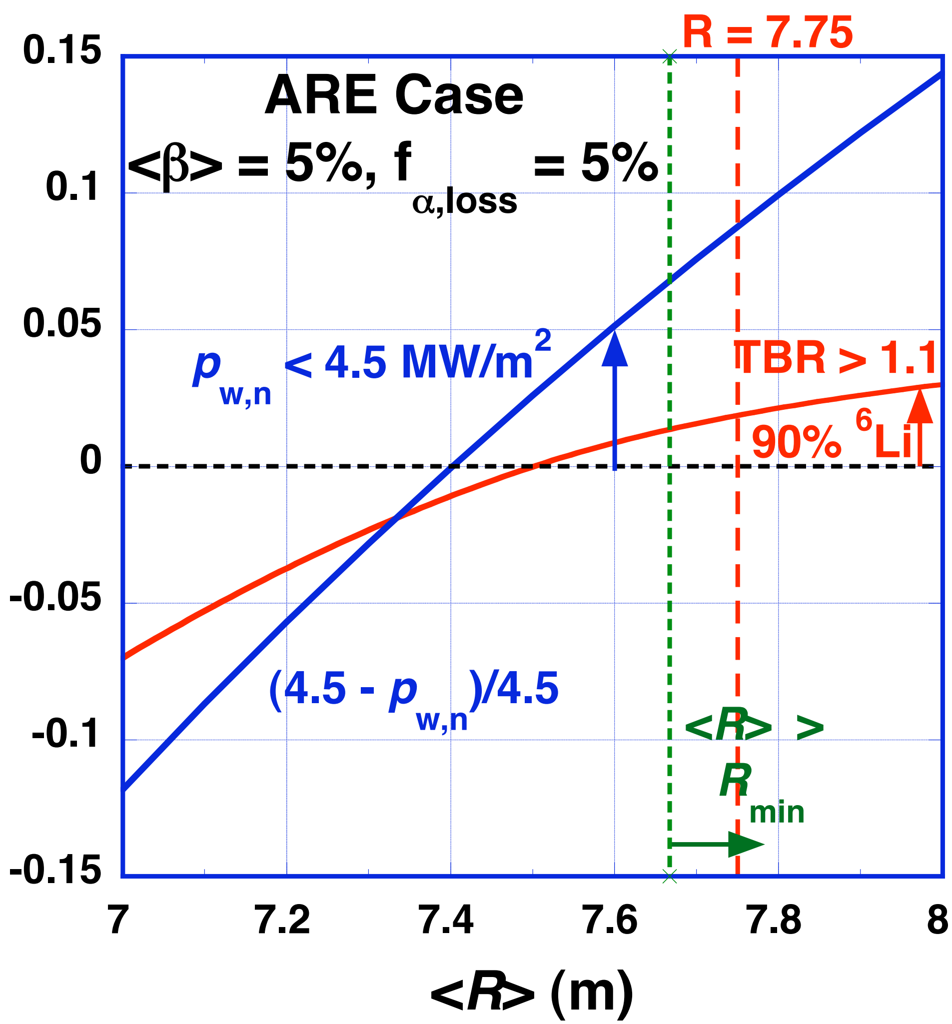
(15) Added more diagnostic output for divertor power and checking

(16) Added new input variables: % power radiated in the scrapeoff and divertor regions; an extra gap space

(17) Added new constraints to avoid negative power components and an undesired divertor solution:

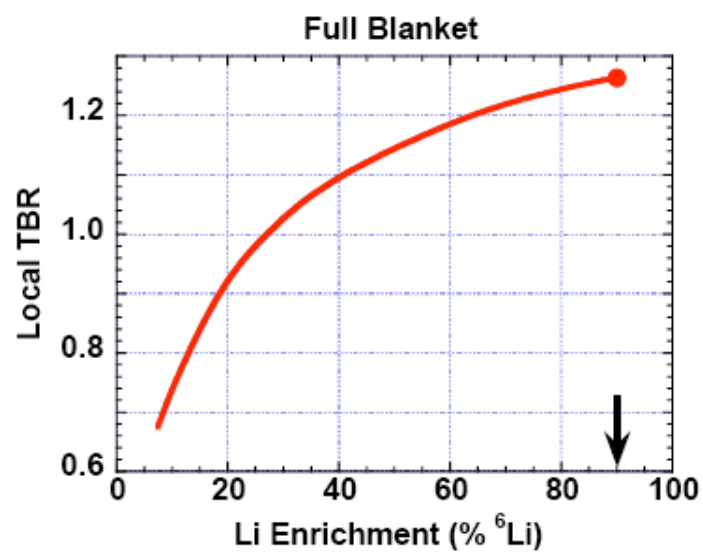
- an upper limit on the calculated α-particle loss fraction
- a lower limit on the conduction power
- a target value for R

$\langle R \rangle$ = 7.75 m chosen to Give Margins on ^{6}Li % for TBR and R_{min} constraint



Not possible to set R = 7.5 m or 7.75 m -- always results in an over-constrained problem; the only way left to minimize the CoE is the value of B_{axis}, but there are too many conflicting constraints.

However, setting the value for $p_{n,wall}$ that gives R = 7.75 m worked



Consequences of Parameter Changes

(1) On divertor power load

- α-particle loss rate reduced from 10% to 5%
- effective divertor area reduced by 26% (from 15% to 11%)
- radiated 75% of particle power in SOL (52% to wall)
- net effect: P_{div} was 178 MW, now 108 MW
  particle power was 123 MW, now 47.2 MW

(2) On cost of coil structure

- changed inter-coil shell thickness from 35 cm to 20 cm
- changed strongback thickness from 65 cm to 28 cm
  $\Rightarrow$ decreased coil structure from 5730 t to 3420 t
- changed cost of coil structure from \$56/kg to \$20/kg (2004 \$)
  $\Rightarrow$ decreased coil structure cost from \$321M to \$68M

(3) On COE

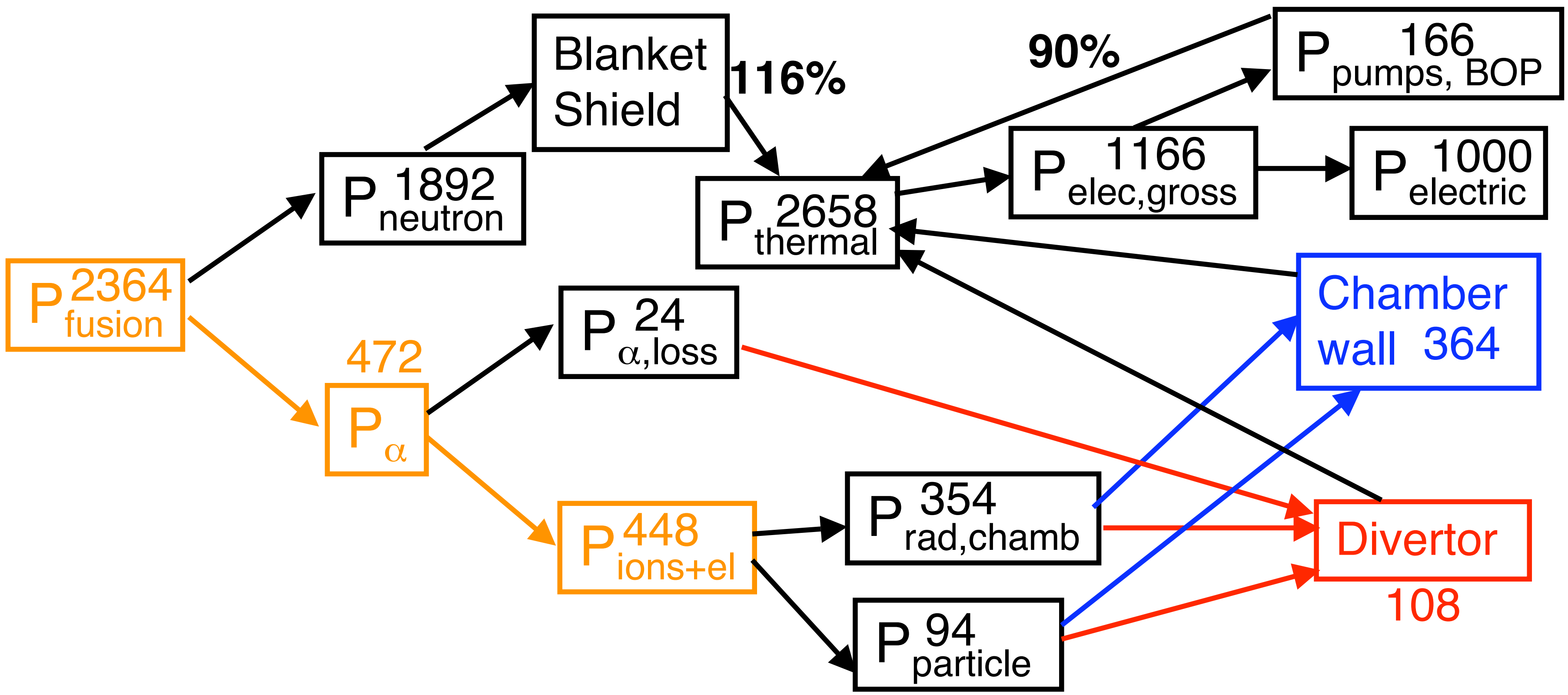
- from 98 mills/kWhr to 79 mills/kWhr in 2004 \$
- from 78 mills/kWhr to 63 mills/kWhr in 1992 \$

Reference vs April ARE Case

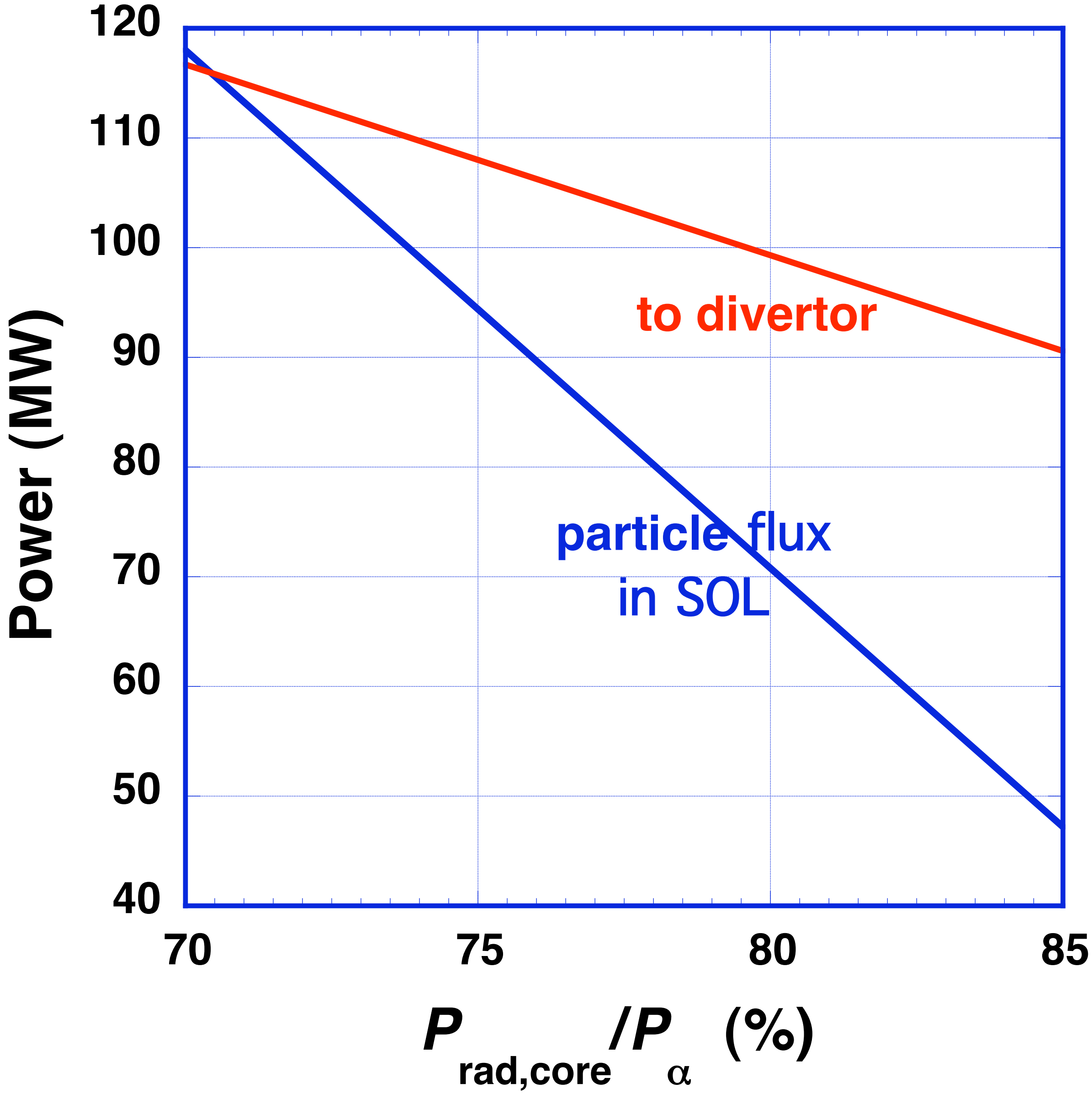
- $P_{\text{rad,core}}/P_{\alpha}$ = 75%

	June	April		June	April
$\langle R \rangle$ (m)	7.75	7.75	R/R_{min}	1.010	1.000
$\langle B_{\text{axis}} \rangle$ (T)	5.70	5.41	COE	79.0	98.3
$\langle n \rangle$ 10^{20}m^{-3}	3.58	2.11	% P_{rad}	75.0	75.0
$\langle T \rangle$ (keV)	5.73	8.88	TBR	1.115	1.128
H-ISS95	1.48	1.83	τ_E (s)	0.96	0.88
$f_{\alpha,\text{loss}}$ %	5	10	$f_{\text{rad,SOL}}$ %	75	0
% Fe	0.008	0.062	P_{rad} (MW)	354	368
$p_{\text{n,max}}$ MW/m^2	3.95	4.11	P_{H} (MW)	240	141
$n/2n_{\text{Sudo}}$	0.94	0.57	P_{Fe} (MW)	113	225
$j_{\text{SC}}/j_{\text{max}}$	1.00	1.00	P_{cond} (MW)	94.4	73.6
B_{max} (T)	15.08	14.71	P_{div} (MW)	108	178
P_{fusion} (MW)	2364	2457	P_{wall} (MW)	364	313

Power Flows (MW) for Reference ARE Case

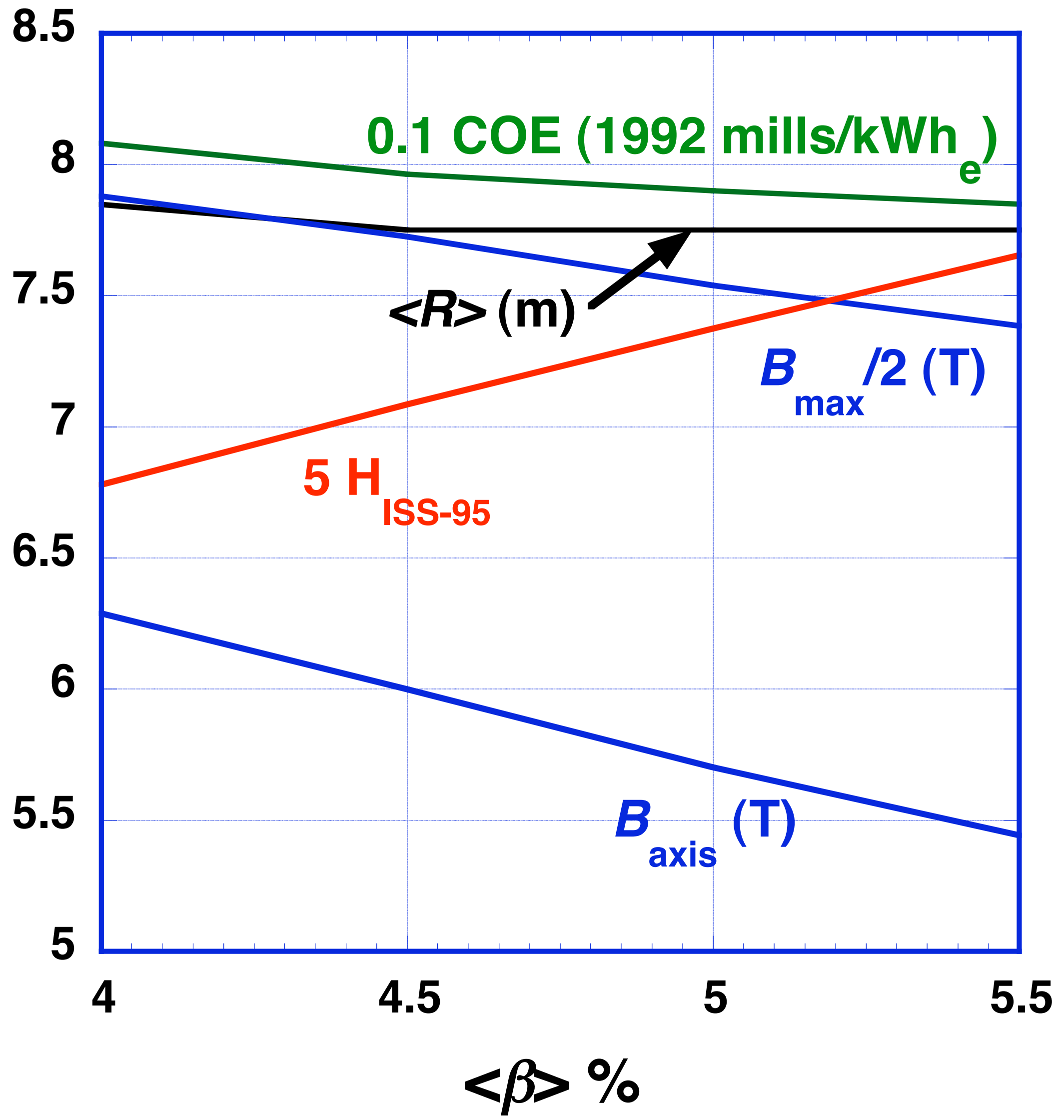


Variation With Radiated Power Faction



Sensitivity to $\langle\beta\rangle$ Limit

- Constraints met for $\langle\beta\rangle < 6\%$



Items in Progress

1. Estimate COE for full blanket coverage as a reference point to justify complexity of a shield only zone
   - $\langle R \rangle$ = 9.81 m (vs 7.75 m) close to meeting most constraints: ignition margin =1.02, $P_{electric}$ = 984 MW) but exceed others (j_{SC})
   - COE = 89.5 vs 79.0 mills/kWhr (2004 $)

2. Generate parameters for MHH2 (K14LA) configuration
   - requires completion of full blanket case convergence

Further Additions, Refinements

Later this summer

- Revise replacement cost, coverage fractions (32% vs 28%)
- Add pumping costs (input from Farrokh) to 22.1.6 account (VV, Cry.)
- Generate parameters for SNS (KJC167) configuration
- Generate parameters for advanced LiPb/SiC design with 58% thermal conversion efficiency (get data from Laila).
- Near end of study, vary $P_{electric}$ up to 1.5 GW or more
- Near end of study, look at NbTi at higher β.
- Calculation/comparison with HSR parameters

Still Needed

- Add VF or control coils to design
- Revision of manifold design?
- Better calculation of $B_{max}/\langle B_{axis}\rangle$?
- Additional divertor costs?
- Geometry for field period maintenance?

Summary

- Addressed most of the revisions and additions requested at April meeting
- Added new features to systems code
- Developed reference ARE case
- Studied effect of parameter variations
- Studied other cases
- Work in progress, refinements needed