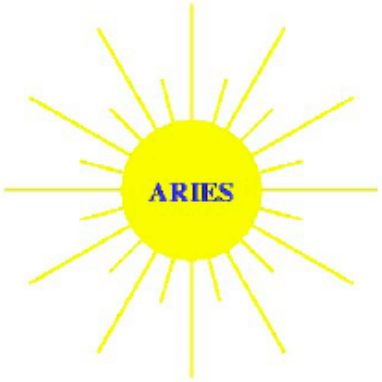

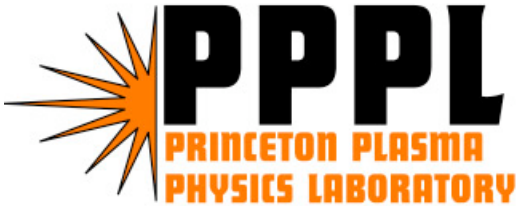

ARIES Systems Analysis: Four Corners Identification

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Systems analysis of the 4 corners

- Scans have been performed by L. Carlson, to produce a large database of viable operating points

- Isolation of lowest COE points in the 4 corners
  - Aggr physics/aggr technology
  - Aggr phys / cons tech
  - Cons phys / aggr tech
  - Cons phys / cons tech

- Aggressive physics is β_N = 0.04-0.06, conservative physics is β_N = 0.03
- Aggressive tech is SiC & η_{th} ~ 58%, conservative tech DCLL and η_{th} ~ 45%

Overall, first look

β_N	R, m	B_T, T	n/n_{Gr}	H_{98}	f_{BS}	P_{aux}, MW	COE, mills
Aggr phys / aggr tech							
0.06	5.0	4.5-5.3	0.9-1.3	1.5-1.9	0.77-0.97	54-79	54-55
0.05	5.0	5.5-6.0	1.0-1.3	1.58-1.74	0.80-0.93	47-65	55-56
0.04	5.0	6.8-7.0	1.0-1.3	1.52-1.65	0.77-0.84	46-79	58-59
Cons phys / aggr tech							
0.03	5.5-6.5	7.0-8.5	0.8-1.3	1.2-1.6	0.56-0.64	95-145	66-70
Aggr phys / cons tech							
0.06	6.5-7.0	4.5-5.0	1.0-1.3	1.47-1.8	0.77-0.92	92-110	79-80
0.05	6.5-7.0	5.5-6.3	1.0-1.3	1.45-1.73	0.76-0.93	89-110	80-82
0.04	6.5-7.0	6.3-7.5	1.1-1.3	1.33-1.57	0.71-0.84	89-110	83-84
Cons phys / cons tech							
0.03	7.0-8.0	7.5-8.5	1.0-1.3	1.1-1.35	0.56-0.64	160-220	93-98

Aggr phys / Aggr tech corner

- COE vs β_N shows a relatively weak dependence
  - β_N = 0.06, COE ~ 54-55 mills/kW-hr
  - β_N = 0.05, COE ~ 55-56 mills/kW-hr
  - β_N = 0.04, COE ~ 58-59 mills/kW-hr
  - Since β_N ~ 4 has been obtained for about 2 seconds, using resistive wall mode feedback, but not sustained, it might make sense to move our target down from 0.054 (AT) to lower values
  - Our original estimates in ARIES-RS & AT were based on the theory of ideal MHD and the resulting "with wall" beta limits
  - Interestingly going down to β_N = 0.03 leads to COE of ~ 66-70 mills/kW-hr, a significant jump, we have a "knee in the curve" which is where we want to be
  - The lowest major radius points (R = 5 m), which are generally also the lowest COE, had n/n_{Gr} = 1.0-1.3, and H_{98} > 1.65, which are too aggressive
  - Restricted to larger major radii (R = 5.5 m), found points at β_N = 0.05-0.055, with n/nGr = 0.8-1.0, and H_{98} = 1.58-1.67, with COE ~ 59-60 mills/kW-hr

More detail on aggr phys / aggr tech points

P_{fusion} ~ 1840-1980 MW
$q_{peak,div}$ < 10.5 MW/m^2
$q_{peak,\ FW}$ < 0.37 MW/m^2
Ip ~ 8.7-9.8 MA

Examine going to larger major radius to reduce n/n_{Gr} and H_{98}

β_N	R, m	B_T, T	n/n_{Gr}	H_{98}	f_{BS}	$P_{aux,}$ MW	COE, mills
0.06	5.0	4.5-5.3	0.9-1.3	1.5-1.9	0.77-0.97	54-79	54-55
0.05	5.0	5.5-6.0	1.0-1.3	1.58-1.74	0.80-0.93	47-65	55-56
0.04	5.0	6.8-7.0	1.0-1.3	1.52-1.65	0.77-0.84	46-79	58-59
Examine R=5.5m, small sample, Ip ~ 10-11 MA							
0.05	5.5	5.0	**0.8-1.0**	1.61-1.67	0.64-0.72	**75-98**	59-60
0.055	5.5	4.5	**1.0**	1.59	0.71	**97**	59

“Thickening” of database provides more results for the aggr phys / aggr tech corner

R = 4.5, 5.0, 5.5, 6.0….
B_T = 4.5, 5.0, 5.5, 6.0,…
Then add
R = 4.25, 4.75, 5.25, ….
B_T = 4.75, 5.25, 5.75,…

P_{fusion} ~ 1880-2050 MW
$q_{peak,div}$ < 12.3 MW/m^2
$q_{peak,\ FW}$ < 0.39 MW/m^2
Ip ~ 9.4-10.4 MA

β_N	R, m	B_T, T	n/n_{Gr}	H_{98}	f_{BS}	$P_{aux,}$ MW	COE, mills
0.055	4.5	5.5	1.0	1.68	0.76	64.5	56.7
0.045	5.0	6.0	1.0	1.57	0.73	77.4	56.9
0.06	5.0	4.75	1.0	1.66	0.77	102	55.5
0.055	5.0	5.25	1.0	1.68	0.80	100	56.7
0.05	5.25	5.25	0.9	1.67	0.71	76.7	56
0.055	5.5	4.5	1.0	1.59	0.71	97	59
0.05	5.0	5.25	1.0	1.50	0.69	100	56.4

Cons phys / aggr tech corner

- Cons phys means $\beta_N = 0.03$
- Major radii range from R = 5.5-6.5 m
- Toroidal fields range from B_T = 7-8.5 T ← higher field to compensate lower β
- Edge safety factor ranges from q_{95} = 4.7-5.3 ← higher to keep f_{BS} high
- Ip = 10.6-12 MA
- COE ranges from 66-70 mills/kW-hr, P_{fusion} = 1900-2200 MW
- Power for auxiliary heating and current drive P_{aux} = 95-145 MW with f_{BS} = 0.56-0.64
- There are some good $n/n_{Gr} < 1.0$ and $H_{98} < 1.7$ combinations, this operating corner should probably have lower n/n_{Gr} and H_{98} than the aggr phys / aggr tech

Aggr phys / cons tech corner

- Aggr phys means β_N = 0.04-0.06
- Major radii range from R = 6.5-7.0 m ← need higher P_{fus} so device is larger
- Toroidal fields range from B_T = 4.5-5.3 T(β_N=0.06), 5.5-6.3 T(β_N=0.05), and 6.3-6.7 T(β_N=0.04)
- Edge safety factor ranges from q_{95} = 3.2-3.8 (β_N=0.06), 3.8-4.6 (β_N=0.05), 4.6-5.2 (β_N=0.04)
- Ip = 12-13.4 MA
- COE ranges from 79-80 (β_N=0.06), 80-82 (β_N=0.05), 83-84 (β_N=0.04) mills/kW-hr, P_{fusion} = 3650-3900 MW, still weak COE effect of β_N
- Power for auxiliary heating and current drive P_{aux} = 89-130 MW with f_{BS} = 71-93%
- Both n/n_{Gr} = 1.0-1.3 and H_{98} = 1.43-1.82 are too aggressive, need to find points with lower values

Cons phys / Cons tech, ugh

- Cons phys means $\beta_N = 0.03$
- Major radii range from R = 7.0-8.0 m ← need higher P_{fus}, and thicker blanket so device is larger
- Toroidal fields range from B_T = 7.5-8.5 T ← larger field to compensate low β
- Edge safety factor ranges from q_{95} = 4.7-5.3
- Ip = 14-16.7 MA
- COE ranges from 92-98 mills/kW-hr, P_{fusion} = 3950-4350 MW
- Power for auxiliary heating and current drive P_{aux} = 159-220 MW with f_{BS} = 56-64%
- Both n/n_{Gr} = 1.0-1.3 and H_{98} = 1.1-1.35, n/nGr is too aggressive, could try to push H98 downward also.

Plasma elongation, 1.8 and 2.2

- All the points that have been identified have κ =2.2
- This value of elongation generally requires a stabilizer in the middle of the breeding blanket, made of tungsten
- This can coincide with the kink stabilizer shell for the higher β_N cases (>0.03)
- Lower elongation, like 1.8, would generally move such a stabilizer shell to behind the blanket
- Is elongation an uncertainty or can it be designed for?

Cases below are for κ =1.8, making it harder to find lower n/n_{Gr} and H_{98}

(#) is ave over κ =2.2 cases

β_N	R, m	B_T, T	n/n_{Gr}	H_{98}	f_{BS}	P_{aux}, MW	COE, mills
Aggr phys – Cons phys / Aggr tech							
0.05-0.055	4.75-5.5	6-7	**1.0**	1.58-1.68	0.65-0.72	75-100(**65**)	59-63(**55**)
0.04-0.045	5.0-5.5	6.5-8.3	**1.0**	1.38-1.68	0.59-0.7	76-137(**65**)	61-64(**58**)
0.035	5.5-6.3	6.5-8.5	**1.0**	1.27-1.64	0.55-0.67	96-140(**99**)	68-73(**64**)
Aggr phys – Cons phys / Cons Tech							
0.05	7.5-8	6.5-7	**1.1**	1.5-1.57	0.66	161-225	92-97(**80**)
0.045	7.5-8	7-8	**1.1**	1.32-1.56	0.58-0.64	218-233	96-101(**82**)
0.04	7.5-8	7-8	**1.1**	1.25-1.36	0.56-59	210-228	97-99(**84**)

Decisions to make on conservative and aggressive

- Physics:
  - Parameters β_N, n/n_{Gr}, H_{98}, q_{95}, and κ
  - Use $\beta_N > 0.045$ for aggressive, < 0.03 for conservative?
  - Use $n/n_{Gr} < 1.0$ always
  - Use $H_{98} < 1.6$ for aggressive, < 1.2 for conservative?
  - Use $\kappa = 2.2$ for aggressive, and 1.8 for conservative?? Maybe 2.0?
  - The q_{95} on experimental plasmas is 5 to 6-ish for AT discharges and probably 4-ish for hybrid stationary discharges ($q > 1$), is this fundamental?
- Technology:
  - Use SiC for aggressive, DCLL for conservative (corresponding η_{th})
  - Use ARIES TF coil for aggressive, and ITER TF coil for conservative, both use LTSC? Does anyone remember what HTSC buys us??
  - Use Fundamenski form for λ_{pow}, or utilize easier values from recent expts?
  - Use different $q_{peak,div}$ and $q_{peak,FW}$ values?
  - What $f_{rad,div}$ values, 0.75 for conservative and 0.9 for aggressive (ITER is 0.7)

- Once we choose these numbers, then thicken database locally to choose the operating points

If I really really had to choose 4 corners right now……

Aggr phys / Aggr tech: β_N = 4.5-5.0, R = 5.5 m (A=4), κ =2.2, H_{98} ~ 1.5-1.6, B_T ~ 5-6 T

Aggr phys / Cons tech: β_N = 4.5-5.0, R = 6.75 m (A=4), κ =2.2, H_{98} ~ 1.5-1.6, B_T ~ 6-6.5 T

Cons Phys / Aggr tech: β_N ~ 3.0, R = 6.0 m (A=4), κ =2.2, H_{98} ~ 1.3, B_T ~ 7-7.5 T

Cons Phys / Cons tech: β_N = 3.0, R = 7.5 m (A=4), κ =2.2, H_{98} ~ 1.3, B_T ~ 8 T