1) Aspect ratio scan systems solutions
2) FW and divertor heat flux calculation
3) ELM heat load specification

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UCSD

1) $A = R/a = 2.0, 2.5, 3.0, 4.0$
aggressive physics and aggressive tech

Fixed

A = ??
$\alpha_T = 0.8$
$\alpha_n = 0.3$
$\delta = 0.7$
li = 0.5
$\eta_{CD} = 0.27$
drat = 0
trat = 0
$f_{imp} = 0.002$ (Ar)

Scanned

$n/n_{Gr} = 0.5\text{-}1.1$
Q = 15-40
$\tau_{He}^{*}/\tau_E = 5\text{-}10$

Constraints

$B_{T,max} \leq 18$ T LTSC
$P_{elec} = 970\text{-}1030$ MW

$H_{98} < 1.8$
$n/n_{Gr} < 1$
$q_{div}^{peak} < 5\text{-}15$ MW/m2

SiC blanket build

$f_{div,rad} = 0.9$

<u>A = 4.0</u>
R = 4.0-8.0
$B_T = 4.0\text{-}9.0$ T
$\beta_N = 4.0\text{-}6.0$
$q_{95} = 3.2\text{-}5.4$
$\kappa = 1.8\text{-}2.2$

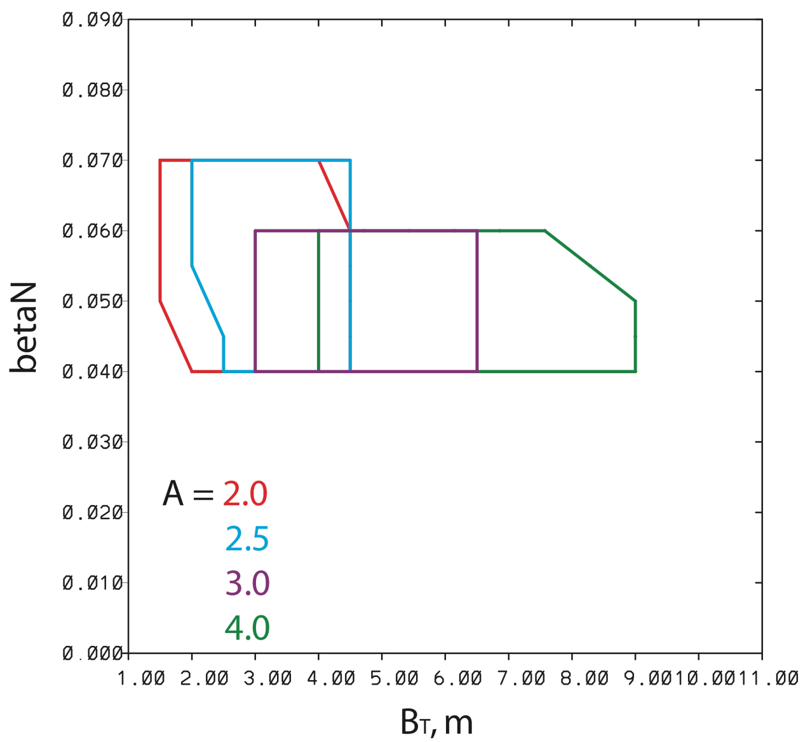
<u>A = 3.0</u>
R = 4.0-8.0
$B_T = 3.0\text{-}6.5$ T
$\beta_N = 4.0\text{-}6.0$
$q_{95} = 3.2\text{-}5.4$
$\kappa = 1.9\text{-}2.3$

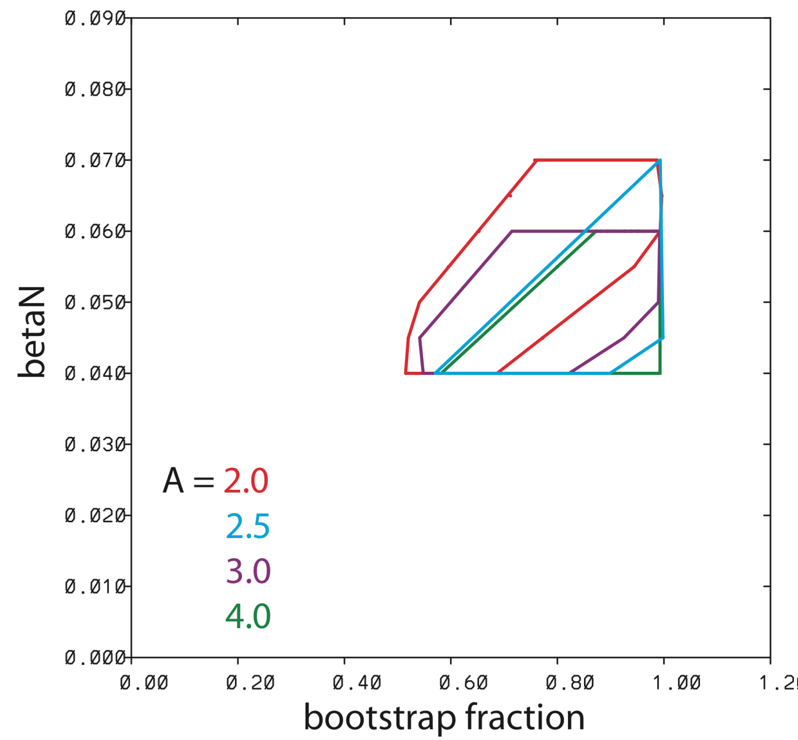
<u>A = 2.5</u>
R =2.5-7.0
$B_T = 1.5\text{-}4.5$ T
$\beta_N = 4.0\text{-}7.0$
$q_{95} = 4.5\text{-}7.0$
$\kappa = 2.1\text{-}2.5$

<u>A = 2.0</u>
R = 2.5-7.0
$B_T = 1.5\text{-}4.5$ T
$\beta_N = 4.0\text{-}7.0$
$q_{95} = 4.5\text{-}7.0$
$\kappa = 2.2\text{-}2.7$

betaN vs B_T betaN vs f_{BS}

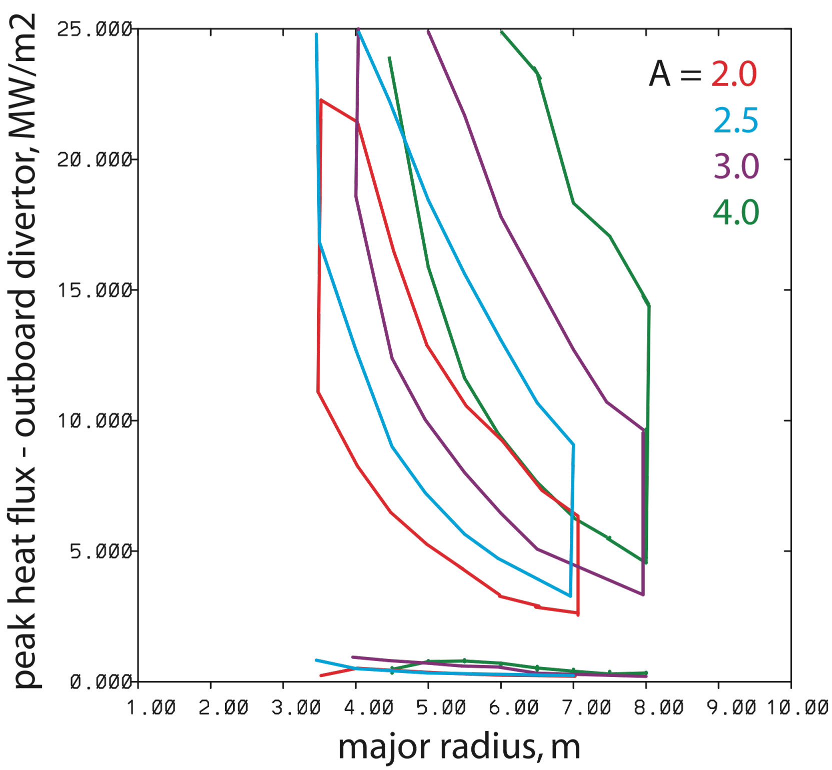
$B_{T,max} \leq 18$ T LTSC
P_{elec} = 970-1030 MW
SiC blanket build
$f_{div,rad} = 0.9$

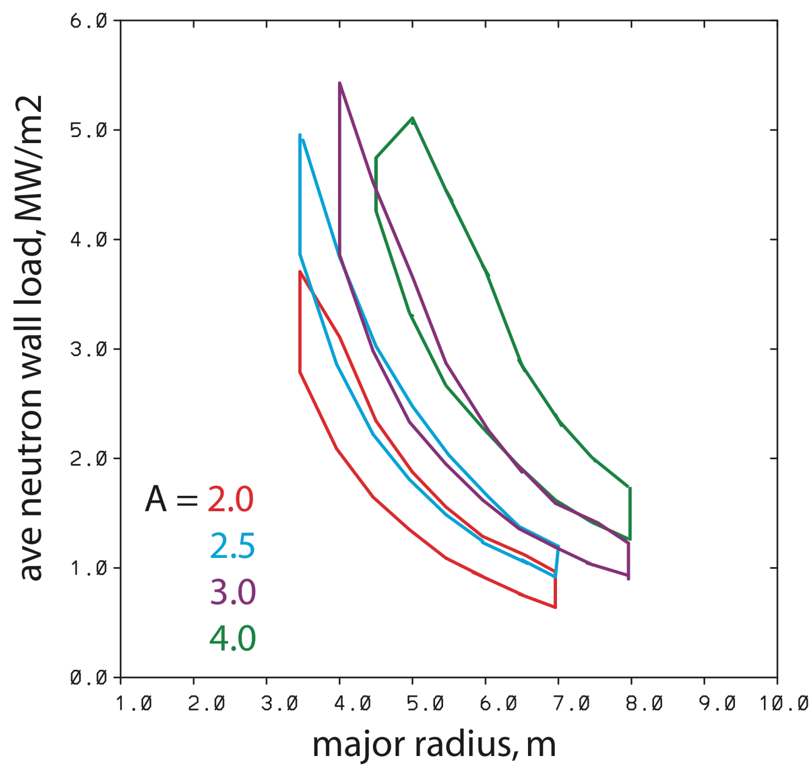




q_{div}^{peak} vs R   <N_w> vs R

$B_{T,max} \leq$ 18 T LTSC
P_{elec} = 970-1030 MW
SiC blanket build
$f_{div,rad}$ = 0.9

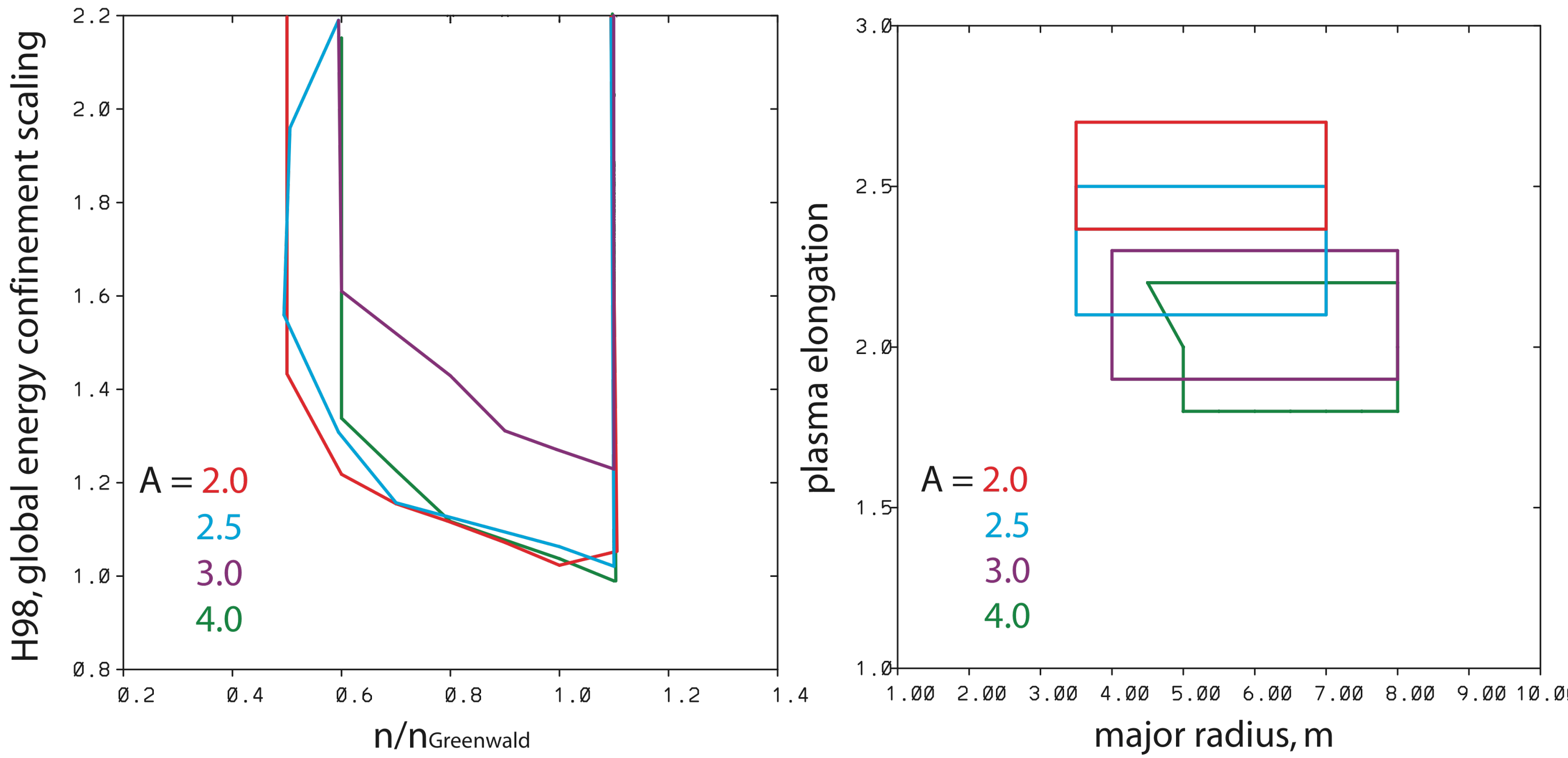




H_{98} vs n/n_{Gr}

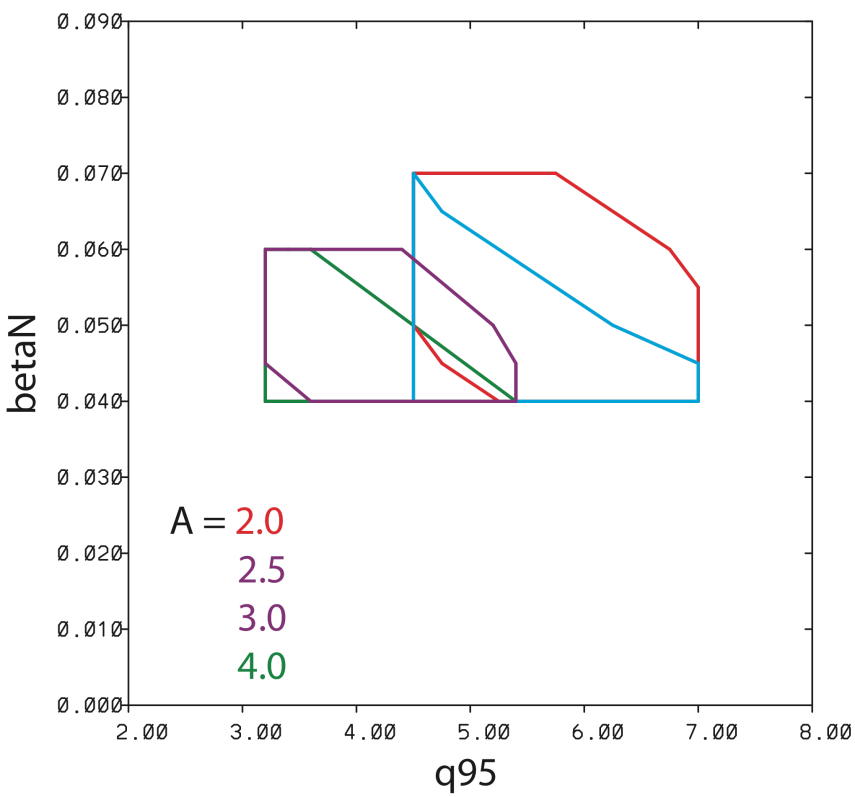
κ vs R

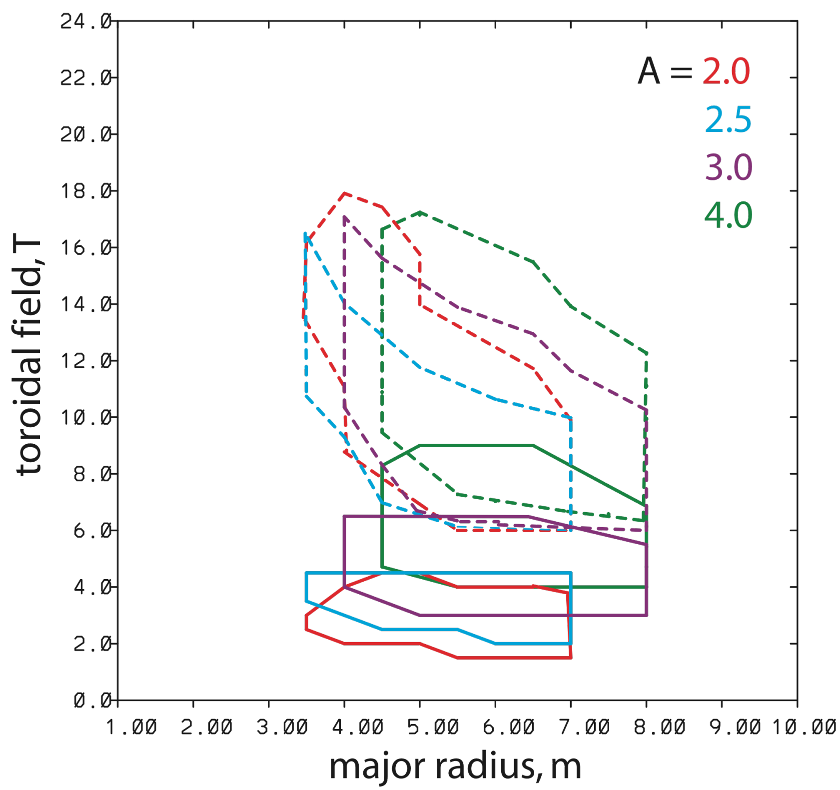
$B_{T,max} \leq 18$ T LTSC
P_{elec} = 970-1030 MW
SiC blanket build
$f_{div,rad}$ = 0.9



betaN vs q_{95} B_T, B_t^{max} vs R

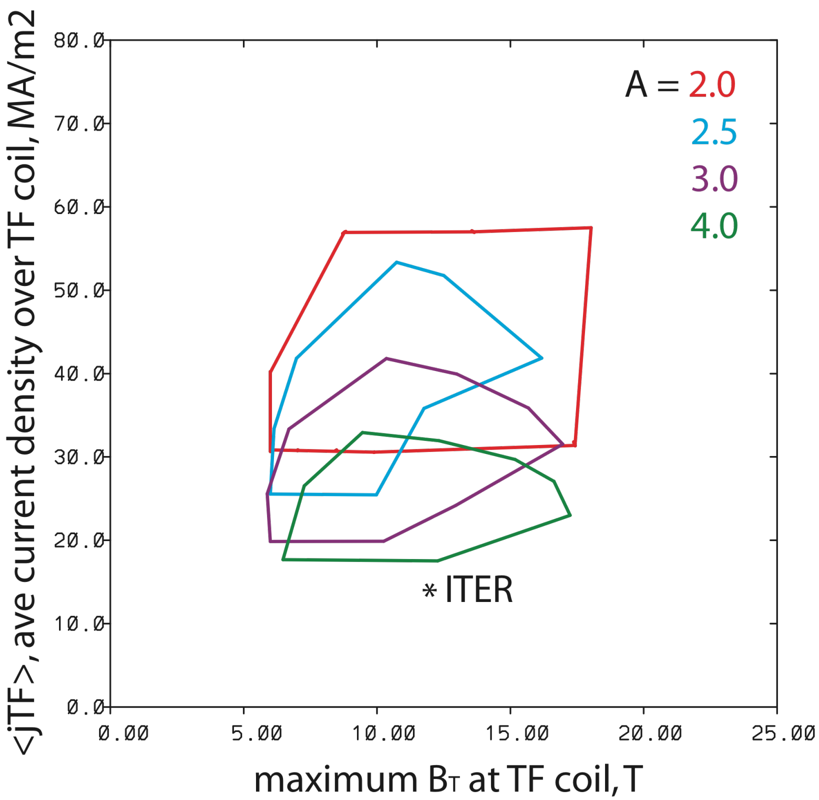
$B_{T,max} \leq 18$ T LTSC
P_{elec} = 970-1030 MW
SiC blanket build
$f_{div,rad}$ = 0.9

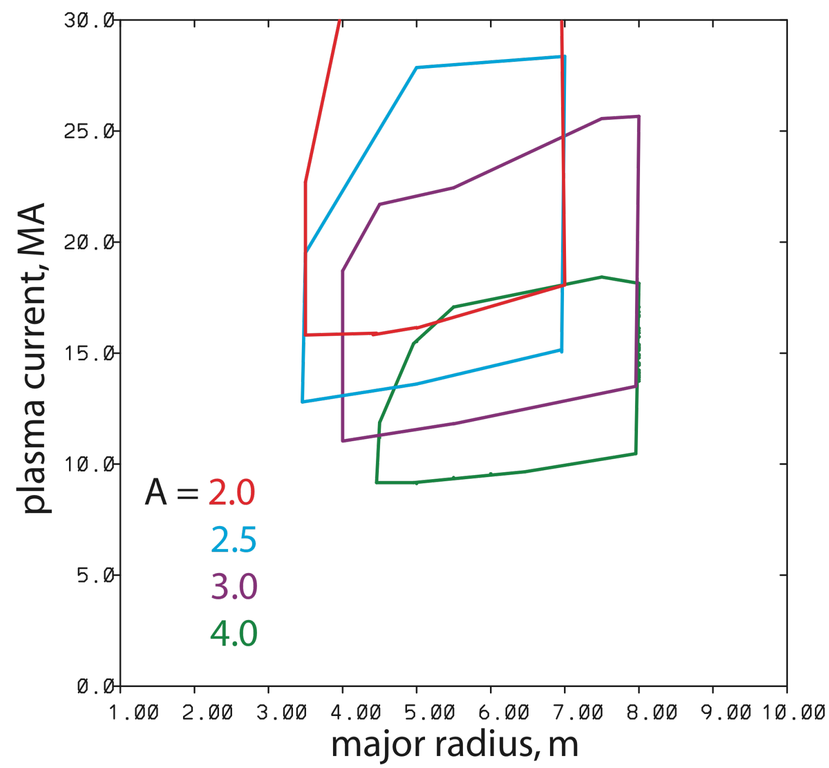




$<j_{TF}>$ vs B_t^{max} Ip vs R

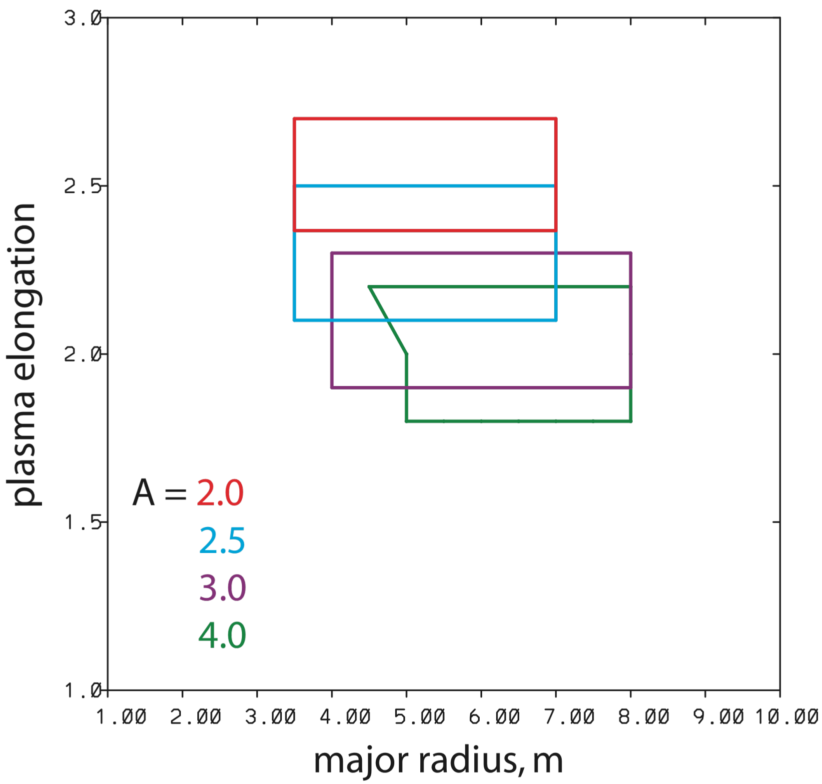
$B_{T,max} \leq 18$ T LTSC
$P_{elec} = 970\text{-}1030$ MW
SiC blanket build
$f_{div,rad} = 0.9$





κ vs R

$B_{T,max} \leq 18$ T LTSC
P_{elec} = 970-1030 MW
SiC blanket build
$f_{div,rad}$ = 0.9

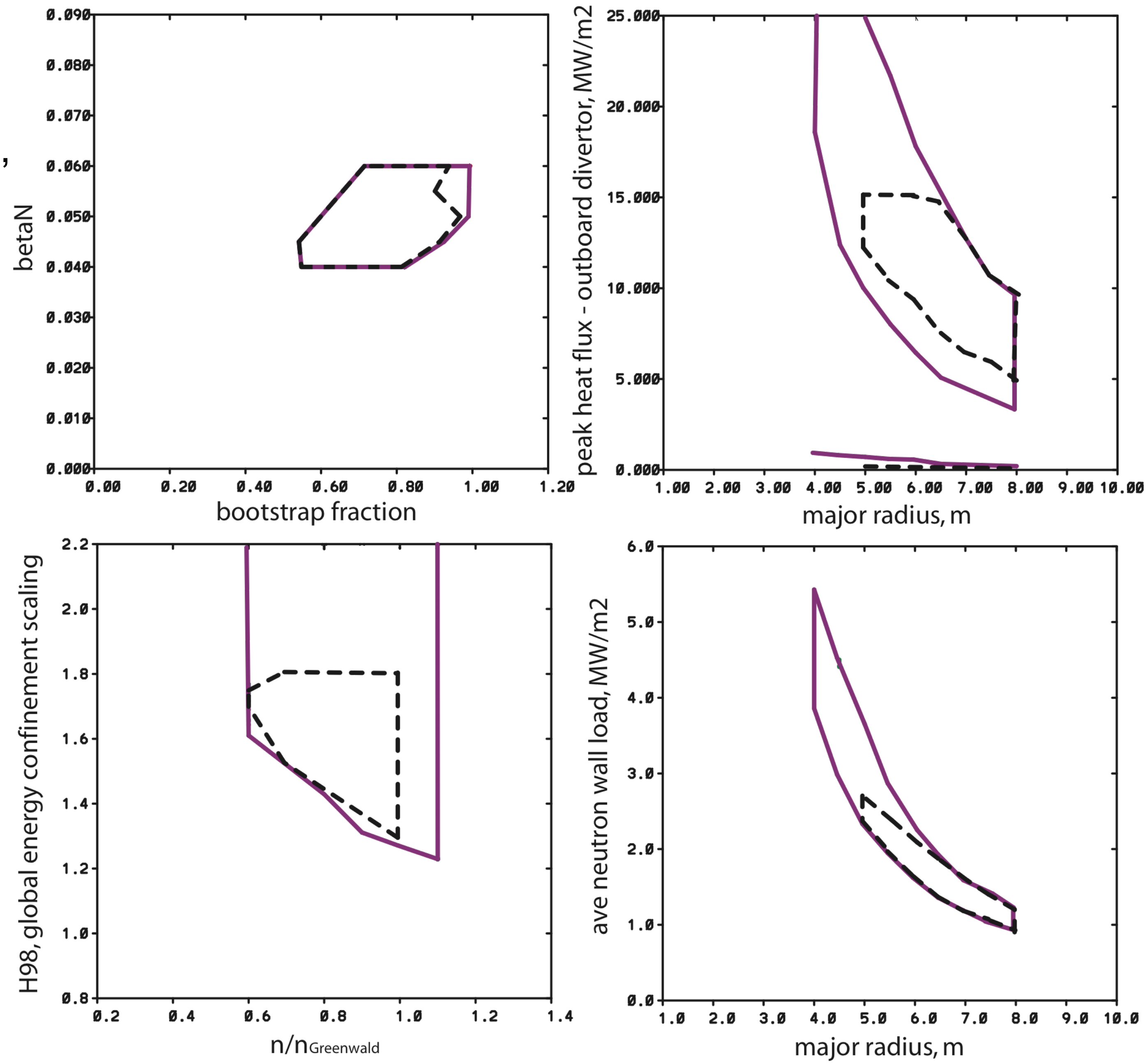


A = 3, SiC, $f_{div,rad}$ = 0.9,q_{div}^{peak} $\leq$ 15 MW/m2, H98 $\leq$ 1.8, n/nGr $\leq$ 1, lowest R solutions

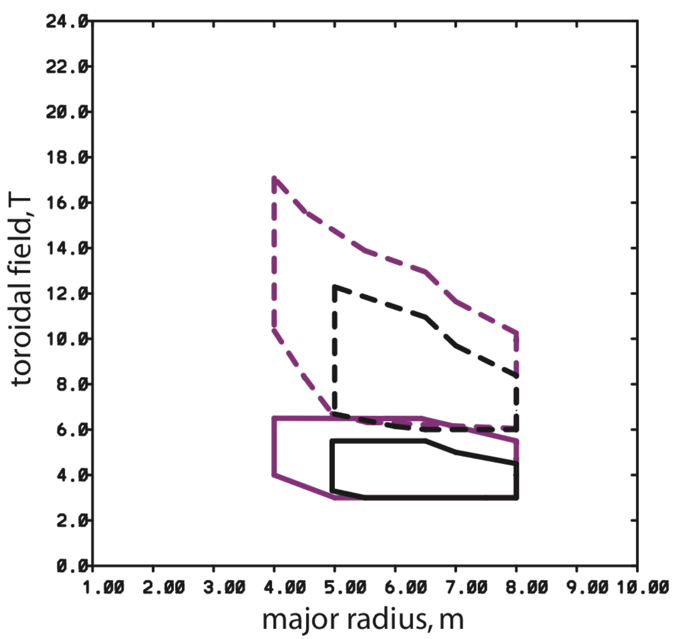
R	B_T	Ip	β_N	q_{95}	n/ nGr	Q	H98	P_{aux}	f_{BS}	κ	<Nw >	B_T^m	<j_{TF}>
5.0	3.0	14.0	**6.0**	3.4	0.9	25	1.7	70	0.76	2.3	2.4	6.7	33
5.0	3.5	14.0	**5.5**	3.8	0.9	25	1.6	71	0.78	2.3	2.4	7.8	33
5.0	4.0	14.0	**4.5**	4.6	1.0	25	1.5	73	0.77	2.3	2.5	8.9	33
5.0	4.0	14.0	**5.0**	4.6	1.0	30	1.7	59	0.86	2.3	2.5	8.9	33
5.0	4.5	13.0	**4.0**	5.2	1.0	25	1.5	72	0.77	2.3	2.5	10.0	33
5.0	4.5	14.0	**4.5**	5.0	0.9	25	1.8	71	0.84	2.3	2.4	10.0	33
5.0	5.0	14.0	**4.0**	5.4	0.9	30	1.7	60	0.80	2.3	2.5	11.0	32
5.0	5.0	13.0	**4.5**	5.0	1.0	30	1.8	58	0.85	2.1	2.6	11.0	32

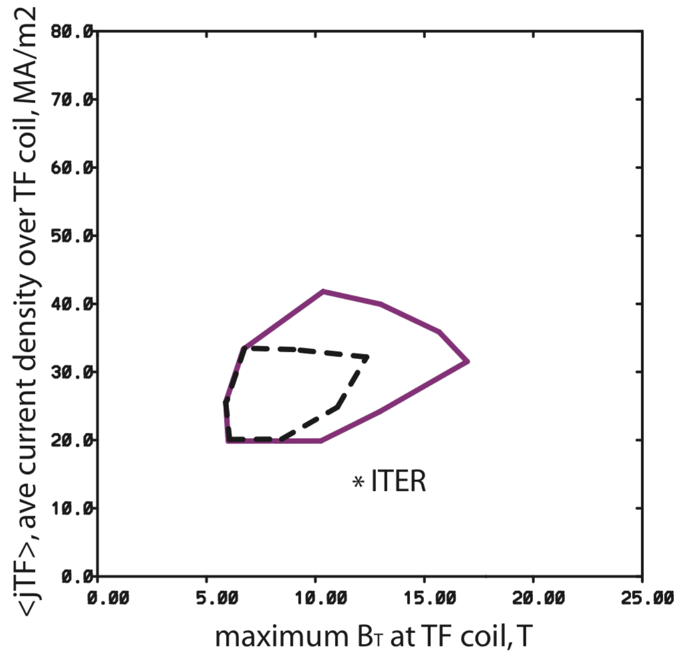
A = 3,
SiC,
$f_{div,rad}$ = 0.9,
$q_{div}^{peak} \leq$ 15 MW/m2,
H98 $\leq$ 1.8,
n/nGr $\leq$ 1

Original scan, A = 3

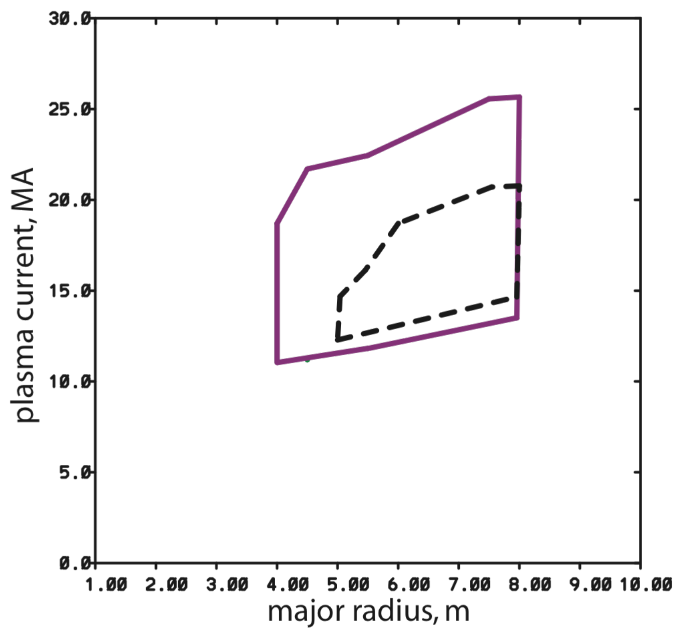


A = 3,
SiC,
$f_{div,rad}$ = 0.9,
$q_{div}^{peak} \leq$ 15 MW/m2,
H98 $\leq$ 1.8,
n/nGr $\leq$ 1





Original scan, A = 3



Leave other constraints/filters the same, now drop $q_{div}^{peak} \leq$ 10 MW/m2, lowest radius pointsare at R = 6.0 m

	R	B_T	Ip	β_N	q_{95}	n/ nGr	Q	H98	P_{aux}	f_{BS}	κ	<Nw >	B_T^m	<j_{TF} >	
	6.0	3.0	16.0	**5.5**	3.6	1.0	20	1.6	89	0.74	2.3	1.7	6.1	27	
	6.0	3.0	15.0	**5.5**	3.8	1.0	25	1.7	71	0.78	2.3	1.7	6.1	27	
	6.0	3.5	14.0	**4.5**	4.6	1.0	25	1.6	71	0.77	2.3	1.7	7.2	27	
	6.0	3.5	14.0	**5.0**	4.6	1.0	25	1.8	70	0.86	2.3	1.7	7.2	27	
	6.0	4.0	16.0	**4.5**	4.8	1.0	25	1.7	73	0.80	2.3	1.7	8.2	27	
	6.0	4.5	16.0	**4.0**	5.4	1.0	25	1.7	71	0.80	2.3	1.7	9.2	27	

Then increase, $f_{div,rad} \leq 0.95$, we recover wide range of R = 5.0 m solutions…..so what values of $f_{div,rad}$ are credible? ITER assumes 0.7 for partial detachment based on B2/Eirene simulations

Dropping $q_{div}^{peak} \leq 7.5$ MW/m2, with $f_{div,rad} \leq 0.95$, leads to minimum radius solutions at R = 5.5 m. This may be reasonable if our max allowed heat load is 15 MW/m2 and we must accommodate ELMs

Systems analysis R/a scan

- Using LTSC coils, and SiC aggressive blanket design, $f_{div,rad}$ = 0.9, A = 2-4 have been examined
  - Basic filters:
    - R_{min}(A=2) = 3.5 m,
    - R_{min}(A=2.5) = 3.5 m,
    - R_{min}(A=3) = 4.0 m,
    - R_{min}(A=4) = 4.5 m
  - H_{98} / n/n_{Gr} / $q_{div}^{peak} \le 15$ MW/m^2 filters:
    - R_{min}(A=2) = 3.5 m
    - R_{min}(A=2.5) = 4.0 m
    - R_{min}(A=3) = 5.0 m
    - R_{min}(A=4) = 5.5 m
  - Lowering q_{div}^{peak} leads to increased R, increased $f_{rad,div}$ allows smaller R

- Input files for varying R/a are established, maybe some tweaking
  - Need to do SiC and DCLL (aggr and cons tech)
  - Need to do betaN = 4-6+ and betaN = 2.5-3.5 (aggr and cons phys)
  - Include new updates to power distribution and so forth from UCSD
  - Are we interested in doing other characteristics to distinguish aggr from cons….<jTF> / B_T, elongation, $f_{div,\,rad}$, or others?

Systems analysis R/a scan, cont'd

- Several parameters need specification from more detailed analysis
  - li, trat, nrat → plasma module, profile matching to 1.5D equilibrium/transport
  - $f_{div,rad}$, radiation dist along divertor, flux expansion, etc → engr module, LLNL modeling
- Need to fix a bug in physics module
- Updates to engineering module, divertor heat flux and some hardwired numbers…..showing on next few VGs

2) Algorithm for calculation of FW and divertor heat loads

Determine plasma power and radiated power from core/ mantle:

$P_{plas} = P_{alpha} + P_{aux}$

$P_{rad} = P_{brem} + P_{cycl} + P_{line}$

Calculate average and peak heat flux on FW:

$f_{peak,FW} = 1.25$

$Q_{peak}^{FW} = P_{rad} \times f_{peak,FW} / A_{FW}$

$Q_{ave}^{FW} = P_{rad}/A_{FW}$

$A_{FW} = 2\pi R \times 2\pi a \times \sqrt{(1+\kappa^2)/2}$

Calculate power to divertor:

$f_{div}^{rad} = 0.9$

$f_{sym} = 0.65$ (DN) and 1.0 (SN)

$f_{outboard} = 0.8$ (DN), 0.67 (SN)

$f_{inboard} = 0.2$ (DN), 0.33 (SN)

$P_{div} = P_{plas} - P_{rad}$

$P_{div}^{rad} = P_{div} \times f_{div}^{rad}$

$P_{outboard}^{cond} = (P_{div} - P_{div}^{rad}) \times f_{outboard} \times f_{sym}$

$P_{inboard}^{cond} = (P_{div} - P_{div}^{rad}) \times f_{inboard} \times f_{sym}$

Algorithm for calculation of FW and divertor heat loads, cont'd

$P_{outboard}^{rad} = P_{div}^{rad} \times f_{outboard} \times f_{sym}$
$P_{inboard}^{rad} = P_{div}^{rad} \times f_{inboard} \times f_{sym}$

$\lambda_{pow} = 0.029 \times 2.5 \times q_{95}^{0.75} \times n_{e,u}^{0.15} / (P_{div}^{0.4} \times B_T)$
$n_{e,u} = 0.35 \times n_{e,L}$
$n_{e,L} = (n/n_{Gr}) \times (I_P/\pi a^2)$
$f_{exp}^{out} = f_{exp}^{in} = 10$

$Q_{peak}^{div,out} = P_{outboard}^{cond} / [2\pi(R-a/2) \times f_{exp}^{out} \times \lambda_{pow}]$

$Q_{peak}^{div,in} = P_{inboard}^{cond} / [2\pi(R-a) \times f_{exp}^{in} \times \lambda_{pow}]$

$Q_{peak}^{div,rad,out} = P_{outboard}^{rad} / [2\pi(R-a/2) \times 2 \times (a/2)]$

$Q_{peak}^{div,rad,in} = P_{inboard}^{rad} / [2\pi(R-a) \times 2 \times (a/4)]$

$Q_{peak}^{out} = Q_{peak}^{div,out} + Q_{peak}^{div,rad,out}$

$Q_{peak}^{in} = Q_{peak}^{div,in} + Q_{peak}^{div,rad,in}$

R = major radius
a = minor radius

Outboard divertor location = R-a/2

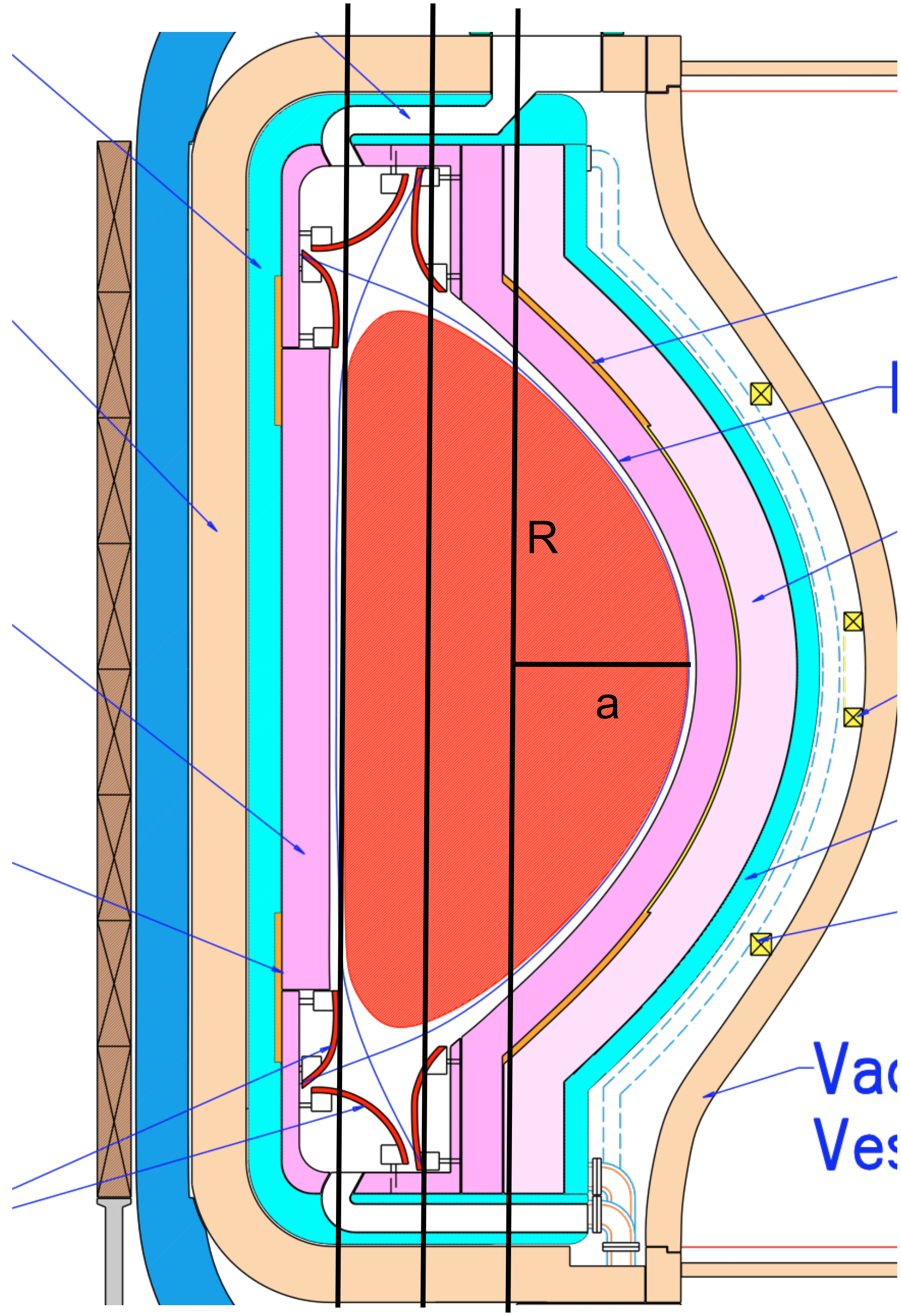
Inboard divertor location = R–a

Area for conducted heat divertor outboard = 2π (R-a/2) x λ_{pow} x f_{exp}

Area for conducted heat divertor outboard = 2π (R-a) x λ_{pow} x f_{exp}

Area for radiation heat flux in outboard divertor = 2π [(R-a/2) x 2 x a/2]

Area for radiation heat flux in inboard divertor = 2π [(R-a) x 2 x a/4]



3) Beginning of specification for heat loads in power plants

FW/heat	nominal	nominal transient	off-normal transient
	P_{rad},core	ELMs	disruption
	CX neutrals		runaway electrons
	stationary core MARFE		fast confinement loss
	stationary X-pt MARFE		fast alpha particles

FW/particle	nominal	nominal transient	off-normal transient
	DT flux	ELMs	disruption
	CX flux		runaway electrons
			fast confinement loss
			fast alpha particles

Beginning of specification for heat loads in power plants

	nominal	nominal transient	off-normal transient
divertor/heat	$P_{SOL(rad+cond)}$	ELMs	disruption
divertor/particle	DT,He,Ar	ELMs	disruption

divertor surface heat load, nominal and ELMs

Nominal heat load to the divertor

- Conducted and radiated powers in divertor ($P_{div} = P_{alpha}+P_{aux}-P_{brem}-P_{cycl}-P_{line}$)
- Conducted power within λ_{power}
- Radiation distributed along divertor "slot" (uniform or other?), ITER assumes 70% radiated

Nominal transient heat load (ELMs) to divertor

- ΔW_{ELM} x f_{ELM} ~ constant = 0.2-0.4 x ($P_{alpha}+P_{aux}-P_{brem}-P_{cycl}-P_{line}$)
- (assumption, $\Delta W_{ELM}/W_{ped}$ function of plasma collisionality)
- f_{ELM} (ITER, worst) = 1-2 Hz & ΔW_{ELM} (ITER, worst) = 20 MJ
- ΔW_{ELM} to divertor 100% for small ELMs and ~ 50% for largest ELMs
- $\tau_{ELM,rise} \sim 2 \times 2\pi Rq_{95}/c_{s,ped}$ for ~ 40% of ΔW_{ELM} to arrive
- $\tau_{ELM,drop} \sim 4\text{-}6 \times 2\pi Rq_{95}/c_{s,ped}$ for remaining ~ 40-50% of ΔW_{ELM} to arrive
- Toroidally symmetric, except in farthest SOL
- λ_{power} remains same during ELM and between ELMs

→ITER is looking for f_{ELM} ~ 30-70 Hz and ΔW_{ELM} ~ 0.6 MJ

→ITER limited by erosion (carbon) or melting (tungsten) of divertor target

FW heat load, nominal and ELMs

Nominal heat load to FW

- Core plasma radiation to FW (P_{brem}+P_{cyc}+P_{line})
- Peaking of 1.5-2

Nominal transient loads (ELMs) to FW

- 5-20% of ΔW_{ELM} (lower for small ELMs and larger for large ELMs)
- all power to outboard
- $\tau_{ELM,rise,FW} \sim 2\pi Rq_{95}/c_{s,ped}$
- $\tau_{ELM\ drop,FW} \sim 2\text{-}3 \times 2\pi Rq_{95}/c_{s,ped}$
- peaking 2-4x, associated with filaments expanding off the plasma
- They do not land in the same place all the time, random