

# Boundary Plasma Issues in Burning Plasma Science

C S Pitcher, MIT PSFC

---

**Issues present in any magnetic fusion configuration:**

- 1. wide dispersal of power**
- 2. high divertor gas pressures**
- 3. eliminate impurity production**
- 4. screening of impurities**
- 5. burning plasma experiment?**

## (1) Wide Dispersal of Power

- parallel power density ( $q_u$ ) flowing in the SOL in next-step devices is a serious issue
- material surfaces can handle (5 MW m<sup>-2</sup>) steady-state with active cooling, perhaps 20 MW m<sup>-2</sup> pulsed
- divertor plate and magnetic geometry buys factor ~ 100, i.e.  $q_u \sim 0.5$  GW m<sup>-2</sup> steady-state,  $q_u \sim 2.0$  GW m<sup>-2</sup> pulsed
- c.f. ITER,  $q_u \sim 1$  to 2 GW m<sup>-2</sup>, C-Mod  $\sim 0.5$  GW m<sup>-2</sup>, DIII-D  $\sim 0.2$  GW m<sup>-2</sup>
- in steady-state (> secs), reduce  $q_u$  by ~ 4 by divertor radiation processes (detached or partially detached), i.e. impurities needed (at least in the divertor → screening)
- pulsed (~ secs), can handle power, particularly if strike points are swept (BPX), but  $T_t$  will be high → impurity production, high  $Z_{\text{eff}}$  (not desirable mode of operation )
- we know a lot more now than during the BPX design!

## (1) Wide Dispersal of Power/(cont)

- high recycling or detached regimes essential:
  - elevated divertor radiation
  - results in high divertor plasma/neutral densities
- criterion for high recycling and cold divertor,  $T_t \sim 5$  eV (a prerequisite for detachment):

$$\frac{L^{4/7} n_u^2}{q_u^{10/7}} > 3 \times 10^{29} \quad (\text{SI units})$$

- this is essentially a collisionality parameter:

collisional  $\rightarrow$  develop parallel gradients

## (1) Wide Dispersal of Power/(cont)

- most important parameter: power width  $\lambda_P$

$$q_u \sim \frac{P_{\text{SOL}}}{\lambda_P}$$

- $\lambda_P$  determined by relative rates of cross-field ( $\chi_{\perp}$ ) and parallel heat transport (Spitzer conductivity):

$$\lambda_P \sim \frac{(n_u \chi_{\perp})^{7/9}}{P_{\text{SOL}}^{5/9}}$$

- $q_u$  at high power and especially in H-mode rises strongly:  
i.e. as  $P_{\text{SOL}} \uparrow$  and  $\chi_{\perp} \downarrow$ , then  $\lambda_P \uparrow\uparrow$
- we have very little solid scaling for  $\chi_{\perp}$  amongst different machines  $\Rightarrow$  a real need from present experiments!

## **(1) Wide Dispersal of Power/(cont)**

### **ELMs**

- **ELMs exhaust power in short periods of time (< 1 ms)**
- **Type I:  $\Delta E/E = 0.02$  to  $0.06$ , gives 2 to 6 MJ m<sup>-2</sup> (ITER) on divertor plate, significant erosion expected above 1.5 MJ m<sup>-2</sup>**
- **mitigating factors:**
  - **radiation (non-coronal)**
  - **$\lambda_P$  broadening**
- **probably depends on details, particularly density, impurity content, etc  $\Rightarrow$  research on present experiments needed**

## (2) High Divertor Gas Pressures

- while maintaining low main chamber pressure for H-modes (tight baffling??)
- allows efficient pumping to:
  - remove helium ash
  - induce SOL flow towards divertor
  - control density
- helium exhaust time, i.e.  $\tau_{\text{He}}$ , limited by extraction rate at the edge (maybe not with ITB)
- present results are encouraging:  $\tau_{\text{He}} < 10 \tau_{\text{E}}$
- scaling to reactor is favorable, i.e.  $\tau_{\text{He}} \sim a$ ,  $\tau_{\text{E}} \sim a^2$

### (3) Eliminate Impurity Production

- high recycling or detached regime ( $T_t < 5$  eV) will ensure target plate physical sputtering is small
- chemical sputtering of carbon a serious issue (no energy threshold), existing graphite machines rarely have  $Z_{\text{eff}} < 1.5 \Rightarrow$  avoid graphite (also essential to avoid tritium inventory problems through co-deposition)
- throat region is interface between energetic plasma and neutrals  $\Rightarrow$  potential for CX sputtering (perhaps use high Z material here, has high energy threshold)
- interaction at walls of tenuous plasma:
  1. how does plasma reach wall? (rapid  $\perp$  transport?)
  2. can dominate core impurity contamination
  3. volatile impurity gases reduced with boronization

## (4) Screening of Impurities

- we need impurities to radiate power:
  1. mantle (~ 10% to 50% in present machines) – not desirable since this means (a) core contamination (b) reduction of  $P_{\text{SOL}}$  (c) confinement degradation
  2. divertor – highly desirable
- how to have divertor enrichment ( $\eta \equiv c_{\text{gas}}/c_{\text{plasma}}$ ) for impurities (including helium)?
- flow entrainment to fight thermal force:
  1. natural: rely on the relative mfp's of the impurity atoms compared with the hydrogenic atoms,
    - (a) helium dilution,  $0.1 < \eta_{\text{He}} < 0.8$
    - (b) N, Ne, Ar strong enrichment,  $\eta_z = 5$  to 20
  2. generate flow: into the divertor,
    - (a) strong divertor pumping with main chamber fuel puffing
    - (b) neutral gas manipulation, e.g. plate/baffle geometry, by-passes
- validate present codes for application to the Next-Step

## (5) Why do we need a Burning Plasma Experiment?

because....

$\lambda_P$ , ELMs, main chamber recycling  $\Rightarrow$  we really cannot predict these with any certainty