Boundary Plasma Issues in Burning Plasma Science

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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^{-2}) steady-state with active cooling, perhaps 20 MW m^{-2} pulsed**
- **divertor plate and magnetic geometry buys factor ~ 100, i.e. q_u ~ 0.5 GW m^{-2} steady-state, q_u ~ 2.0 GW m^{-2} pulsed**
- **c.f. ITER, q_u ~ 1 to 2 GW m^{-2}, C-Mod ~ 0.5 GW m^{-2}, DIII-D ~ 0.2 GW m^{-2}**
- **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_{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):

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

- this is essentially a collisionality parameter:

collisional → develop parallel gradients

(1) Wide Dispersal of Power/(cont)

- most important parameter: power width λ_P

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

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

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

- q_u at high power and especially in H-mode rises strongly: i.e. as $P_{SOL} \uparrow$ and $\chi_\perp \downarrow$, then $\lambda_P \uparrow\uparrow$

- we have very little solid scaling for $\chi_\perp$ amongst different machines ⇒ 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^{-2} (ITER) on divertor plate, significant erosion expected above 1.5 MJ m^{-2}**
- **mitigating factors:**
  - **radiation (non-coronal)**
  - **λ_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. τ_{He} , limited by extraction rate at the edge (maybe not with ITB)**

- **present results are encouraging:** $\tau_{He} < 10\ \tau_E$

- **scaling to reactor is favorable, i.e.** $\tau_{He} \sim a$, $\tau_E \sim a^2$

(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 $Z_{eff} < 1.5 \Rightarrow$ 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_{SOL} (c) confinement degradation**
  2. **divertor – highly desirable**
- **how to have divertor enrichment ($\eta \equiv c_{gas}/c_{plasma}$) for impurities (including helium)?**
- **flow entrainment to fight thermal force:**
  1. **<u>natural:</u> rely on the relative mfp's of the impurity atoms compared with the hydrogenic atoms,**
     - **(a) helium dilution, $0.1 < \eta_{He} < 0.8$**
     - **(b) N, Ne, Ar strong enrichment, $\eta_z = 5$ to 20**
  2. **<u>generate flow:</u> 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….

λ_P, ELMs, main chamber recycling ⇒ we really cannot predict these with any certainty