2nd In-class Exam, Apr. 13

Take home exam (final exam) Apr.27, due May 6.

Reading:

6.5 Global leakage

10.3 Toroidal particle trapping (Bananna orbits → neoclassical D, where $D_\perp \sim \frac{r_{banana}^2}{\tau_s}$ instead of classical $D_\perp \sim \frac{r_g^2}{\tau_s}$.)

P158 Safety factor q

4.5 ICF (Review)

9.3-9.5 Magnetic Mirror

] for subsequent comparison to Tokamaks

HOMEWORK 8

Homework = ~~30%~~ 50% of exam, turn in Apr. 13.

NOTE change 4/6/10

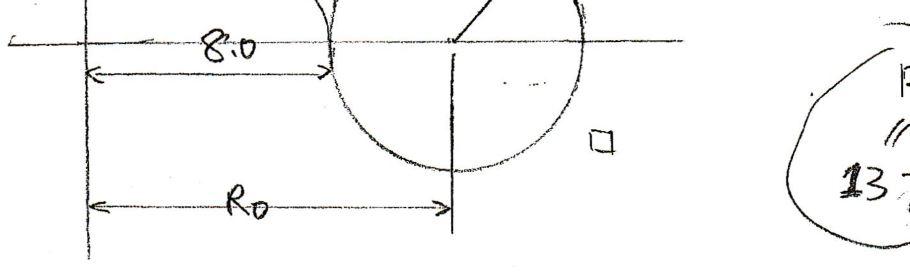
ITER (see ITER ~~internal~~ international website) http://www.iter.org/default.aspx

1) What is the goal of ITER? (Hint: Engineering and Physics goal) What needs to be done then to make it a power plant?

(Physics: , such as the energy balance. Eng: Blanket, etc.)

2) Make a table of specs of ITER: R_0, a, B_T, $B_\theta(a)$, P_{in}(plasma & auxiliary), Fueling rate, Fusion power level P_f. Assume an equivalent circle cross section as shown below.

(In "The Machine" drawdown menu, a lot of info is provided.)



$B_T \sim \frac{1}{R}$, $a = 5.5$m.

$R_0 = (8 + 5.5)$m

$A_S = \frac{R_0}{a} = \frac{8+5.5}{5.5}$

$B_T \sim \frac{1}{R} \sim \frac{1}{R_0 + r\cos\theta}$ — B_T = 13T

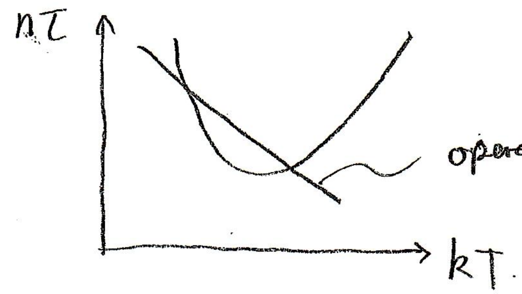
$\theta = 0 \rightarrow \frac{1}{R_0 + a}$

$\theta = \pi \rightarrow \frac{1}{R_0 - a}$

3). Plot $n\tau_{ig}$ vs. kT for an ITER plasma.

(Hint: p132-133). To get rid of N, $N = \frac{\beta B_0^2}{4\mu kT}$

Assume $\beta = 5\%$ max, ...

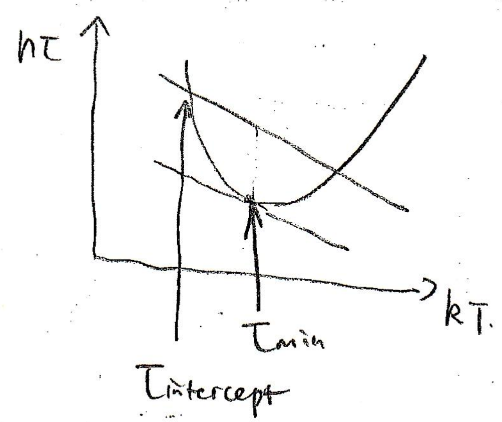


4) Add ITER operating line to graph, i.e. $n\tau_{IER}$ vs. kT.

(classical $D_\perp \sim \frac{r_g^2}{\tau} \sim$ constant. $\frac{1}{B^2\sqrt{kT}}$)

$n\tau = K n_0 B_0^2 \sqrt{kT}$

5). Calculate confine time margin $\equiv \frac{\tau_{min}}{\tau_{intercept}}$ we calculate.



HW #8 [Continued] (plus discussion)

4/6/10

6) Wall ~~loading~~ loading: Plasma and Radiation heating present wall cooling challenge. Keep < few MW/m². Neutron material damage sets limit on neutron "power" loading (actually power associated with neutrons passing through wall) of ≈ 1 MW/m².

Assume ITER uses 50/50 DT and operates at the $n\tau - kT$ intercept you found in 5) (or if not found, used min $n\tau - kT$ on energy balance curve of 3)); calculate the corresponding "heating" and "neutron" wall loading in MW/m². Do they fall in allowed limits. If not, suggest how to change the design to adjust the loadings.

7) "Ash" issue: The α particles from fusion are generally contained in the plasma. They provided the needed "ignition" heating but as they slow down + thermalize, they become a useless diluent or "ash" in the plasma, i.e., $n_{TOTAL} = n_D + n_T + n_\alpha^{\text{"ash"}}$. Assume that the confinement times for all ions are equal ($\tau_D = \tau_T = \tau_\alpha$). Find the equilibrium % of ash in the ITER plasma. (Hint: use $\frac{dn_\alpha}{dt} = S_\alpha - L_\alpha = 0$)

Evaluate the resulting change in fusion power and radiation emission in ITER. Could this cause ITER to fall below ignition (= "sub-ignited"). Discuss your answer — include discussion of the possibility the $\tau_\alpha > \tau_{D,T}$ — indicate a rough limit on the allowed τ_α.

8) Ohmic heating of plasma.

Ohmic heating comes from the plasma current, J_P, which also creates B_θ. A first approximation of the plasma resistivity η is:

$$\eta \sim \frac{9.6 \times 10^{-6}}{(kT)^{3/2}} \text{ ohm-cm} \quad \left(\begin{array}{c}\text{Ref. } G+ \\ PP\ 103 \\ \text{in text Eq 10.15}\end{array}\right)$$

where $\eta \equiv E / j_p$: E = electric field around torus. [note; $E = I_p \frac{R_p}{\ell} = \frac{I_p}{A}\frac{(R_p A)}{\ell} = j_p \eta$].

We can find I_p from $B_\theta(a) = \frac{\mu I_p}{2\pi a}$

and requiring that $q(a) \gtrsim 2.5$

since $q \equiv \frac{1}{A}\frac{B_T}{B_\theta}$

Evaluate the ohmic heating power in ITER: P_Ω MW/m^3. Compute the % of the total plasma heating that is due to ohmic power when the ITER plasma is ignited. Is the term "ignited" still applicable?

For our text, pp 161-62, we see that E comes from transformer action, i.e. $d\psi/dt$. Evaluate the flux rate $d\psi/dt$ needed for ITER. Does this agree with data from the web site? How would you prevent the vacuum vessel wall from shorting out E? [note E is $E_{toroidal}$ and wall materials are generally conductors]. Does your suggestion agree with the web-site? [if nothing is said about these pts on web, note that]

(9) The "vertical field" (B_V) prevents up-down motion of the plasma. Field ordering is $B_T > B_\theta \gg B_V$. Make a sketch showing the location of the vertical field coils in an ITER like device. Estimate the strength (Tesla) of B_V. Could B_V affect particle orbits in the plasma? - discuss your answer.

(10) Consider the divertor on ITER. Is a single or double poloidal divertor used on ITER (see web site)? Assume 2/3's of the plasma leakage power enters the divertor (1/3 goes to wall). Estimate the heat load assuming a divertor "dump" plate is ~ 0.3a high. Does this

fit into loading limits stated in 6)? If not suggest how to modify the design to handle the load.

The 1/3 of the plasma flux going to the wall causes sputtering. Assume a sputtering rate of 0.01 atoms Fe per ion hitting. Assume $\tau_{Fe} = \tau_{DT}$. What would the concentration (%) of the Fe in the plasma be? How much would the radiation power be changed by sputtering?

(11) <u>Extra credit</u>: Estimate the fueling rate required for ITER. Estimate the power required to heating injected ions up to the plasma temperature, assuming they begin at room temperature ≈ 0.063 eV.

[hint: note $\frac{dN_T}{dt} = \frac{N_T}{\tau}$. Also

$$P_{\substack{heating \\ needed}} \simeq \frac{N}{\tau}\left(kT - kT_{Room}\right)$$]

How does ITER inject (and heat) fuel? Do your estimates agree with the web site? - discuss.

(12) <u>Extra credit #2</u>: Find a recent "ITER scaling law" agreed to by the ITER Council. Compare it to our classical one using plots of the two on $n\tau$ vs kT graph. Discuss differences.