Nuclear Fusion and Plasma Physics - Exercises

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Exercise 1 - Control of plasma burn

In principle, burning plasmas can undergo thermal runaway, which involves an uncontrolled transition to ignited conditions, with an ever increasing temperature. Analyze this possibility in ITER using a simple 0-D model, based on power balance and neglecting bremsstrahlung radiation. Consider a situation in which the density is fixed.

a) Does a burning ITER plasma risk undergoing thermal instability?

b) What measure can you think of to control the burn and prevent instability?

Hints:

1. Start with the energy balance equation close to ignition, neglecting the external power input (why can this be done?). Assuming constant plasma density, find an expression for the plasma temperature change with respect to time (the time derivative of the temperature).
2. Find the equilibrium condition for the temperature from the expression above.
3. Then, consider a perturbation to this equilibrium temperature. Estimate whether such a perturbation will grow or decay with time.
4. Consider for $\langle\sigma v\rangle_{DT}$ the approximation

$$\langle\sigma v\rangle_{DT} \approx 1.1 \times 10^{-24}\, T^2_{[\mathrm{keV}]} \quad (\mathrm{m}^3/\mathrm{s})$$

5. Consider the following ELMy H-mode scaling law for τ_E:

$$\tau_E \propto \tau_B\, \rho_*^{-0.7}\, \beta^{-0.9}\, \nu_*^{-0.01},$$

with

$$\tau_B \approx \frac{a^2 B_T}{T_e} \quad \rho_* \approx \frac{\sqrt{T_e}}{a\, B_T} \quad \nu_* \approx \frac{n_e\, a}{T_e^2} \quad \text{and} \quad \beta \approx \frac{n_e\, T_e}{B_T^2/(2\mu_0)}$$

Exercise 2 - On the use of Tritium in ITER and fusion reactors

Using the definitions and the developments done in the lecture, estimate:

a) The tritium burn up fraction, f_B, in ITER and in a 1 GW electrical fusion reactor.

b) The tritium mass burn rate dM/dt (how many grams of tritium are burnt every day) in the two cases.

   Assume a reasonable value for the efficiency of the conversion from thermal to electrical power.

c) The tritium inventory M_0 (how many kilograms of tritium are need to be present in the plant at any given time) in the two cases.

Reminder:

$$f_B = \frac{1}{1 + \frac{1}{\tau_T n_T <\sigma v>_{DT}}} \tag{1}$$

$$\frac{dM}{dt} \approx 56 \times \text{fusion power}(\text{GW}_{\text{thermal}})\ [\text{kg/year}] \tag{2}$$

$$M_0 \approx \frac{t_p \frac{dM}{dt}}{\eta_f f_B} \tag{3}$$

where τ_T is the particle confinement time (assume $\tau_T = 1$ s for ITER and 2 s for a reactor), n_T is the tritium density (make a reasonable assumption), t_P is the tritium reprocessing time (assume 1 day), $\langle \sigma v \rangle_{DT}$ is the fusion cross section (use the approximation given for ex. 1 with plasma temperature T = 10 keV for ITER and 15 keV for a reactor) and η_f is the tritium fuelling efficiency (take $\eta_f = 20\%$ for ITER and 50% for a reactor).