General information

The exercise sessions will be held as blackboard sessions, where the participants will present their solutions to the group. As such, the problems should be set up and solved before the session. The focus of the exercises lies on analyzing and discussing the task at hand together with the group: thus, a perfect solution is not required to be awarded points. A point will be awarded for each question, and a person will be chosen to present their solution from the pool.

Exercise 1.

Power exhaust in tokamaks Consider an ITER-sized tokamak of $R = 6$ m and $r = 2$ m with 50 MW of external heating power supplied, operating at steady-state with $Q \approx 10$ using D-T fusion. According to conservation of energy all power must me exhausted from the device while remaining within the material limitations of the plasma facing components, taken to be ~ 10 MW m^{-2}.

a) What are the heat loads on the vessel walls, assuming the power to be exhausted isotropically. How does this value compare to the material limitations.

b) Next, consider the realistic situation in a diverted device where only the fusion power carried by the neutrons is exhausted isotropically. Approximate the heat loads on the divertor target as the sum of the α-power and the auxiliary heating power. Assume $v_\perp \approx 10$ ms^{-1}, $v_\parallel \approx c_s \approx 10^5$ ms^{-1} and $L \approx 100$m, where $v_\perp$ is the effective cross-field velocity, $v_\parallel$ is the velocity along the field lines - assumed to be sonic speed c_s, and L is the distance from the plasma source to the divertor targets along the field lines (Fig. 1). How does this value compare to the material limitations?

Exercise 2.

Challenges in power exhaust

a) What additional caveats regarding power exhaust and the material limitations can you think of?

b) Based on these caveats and exercise 1, what can you say about the operation and PWI of reactor-size tokamaks?

c) How can the divertor heat loads be decreased?

Exercise 3.

The two-point model Here we derive a simple analytic expression relating the divertor target conditions to those at the upstream location. On lecture slide 44 the basic equations are presented, assuming conductive transport, particle, pressure, and momentum conservation along the parallel distance. Using this slide, derive the following as functions of upstream density (n_u) and heat flux density ($q_\parallel$), assuming significant temperature gradients along the parallel distance L ($T_t \ll T_u$). You will need to use $c_{st} = (2kT_t/m_i)^{1/2}$.

a) An expression for upstream temperature (T_u).

b) An expression for target temperature (T_t).

c) An expression for target density (n_t).

d) An expression for target plasma particle flux density ($\Gamma_t = q_\parallel/(\gamma e T_t)$).

Exercise 4.

The extended two-point model and detachment Now, we no longer assume the quantities to be conserved and introduce *ad hoc* conservation factors (lecture slide 45). Now f_{mom} describes the fraction of momentum conserved, f_{cond} the fraction of the heat flux which is conducted, and f_{power} the power lost in the flux tube.

a) Now, repeat task 3 in order to find the scaling factors of the target parameters. Note that the formula for the target particle flux is now modified: $\Gamma_t = (1 - f_{pow})q_\parallel/(\gamma e T_t))$

b) Detachment is crucial in alleviating the heat loads incident on the targets. Detachment occurs when the target temperatures are sufficiently low ($T_t \approx 1$ eV) for volumetric recombination to occur. This reduces the plasma flux incident on the wall. Using the extended two-point model, describe which process drive detachment.