CHALLENGE A

managing power exhaust from the plasma, while controlling impurities.

Power Balance

assumption:

- steady state
- zero dimensional

- P_α, alpha particle power, will be confined by the magnetic field, is what we need to exhaust. composed by two terms, radiation (isotropic) and conduction + advection (anisotropic).

- P_{rad}, radiation term, isotropic; no problem for PEX but for plasma if it occurs where I should like to keep plasma hot is beneficial in plasma edges where it is already cold. his wetted area coincide with first wall ones, less problem

- $P_{cond} + P_{adv}$, anisotropic term, his wetted area is less bigger than the first wall one, so it is more difficult get rid of this power in that small area.

- P_n, neutron not confined that goes out, leaving the reactor, taking care from breeding blanket.

$$P_\alpha = P_{rad} + (P_{cond} + P_{adv}) + P_n$$

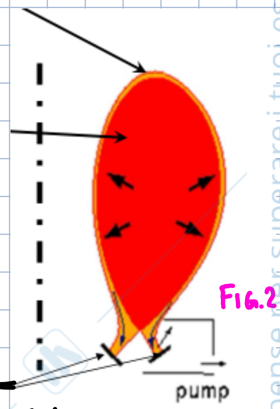


FIG.2

TOKAMAK GEOMETRY

PSI, Plasma Surface Interaction

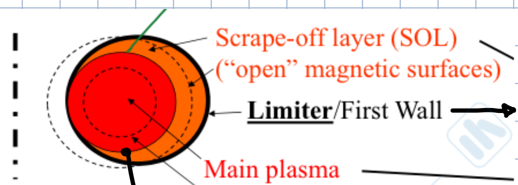


FIG 1

⊙ magnetic surfaces in poloidal section

Limiter/First Wall → limits the boundary of core plasma identifying the SOL

→ first magnetic surface which touch the first wall, called SEPARATRIX or Last Closed (last magnetic surface, close on it self without touching the first wall) to separate two diff. region in plasma domain, RED (mag surface not touching FW, called core plasma); ORANGE region is the SOL, region where magnetic surface intersect with FW)

in red region fast motion has no impact, lead to a uniform condition
entering orange region, due to diffusion, particles are scraped away, wall perfect sinks in which particle enter anon; getting absorbed by it.

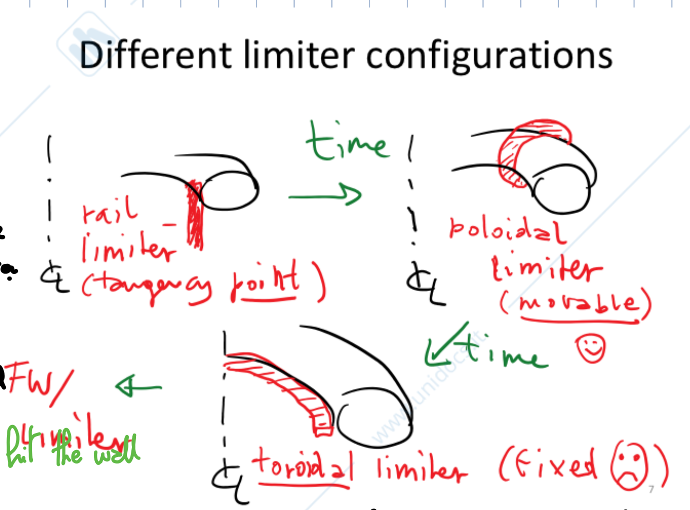
Both in red and orange there is plasma but the spatial distribution is different.

points of FW in which is zero the distance from core plasma, so region that can create impurities that are near the core; location of the source of impurities is too close to the main plasma

DIVERTOR, trying to have a magnetic configuration with magnetic lines that divert away from the main plasma. generating a point in which magnetic poloidal field is equal to zero X-POINT.
river of plasma towards the target at sound speed velocity (Bohm Criterion) FIG.2

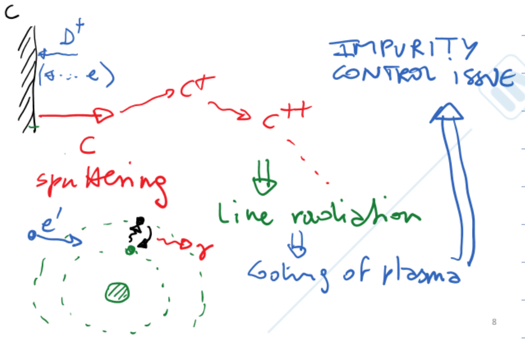
advantage of the divertor is to dedicate that volume also to pump, responsable to pump away α particle which if thermalize are only ash impurities (otherwise help maintaining hot T the plasma).
Or helping pumping fuel inside. T low in boundaries, so fuel it not burn, so feeding continuously our fuel not all is burn but can aggregate in boundaries creating a pedalto. Greenwald limit says max value of fuels deposit and do not burn in boundaries over which system present problems.
so pump help eliminate also that not burnt fuel.

FIG 1
1 dimensional in space but coexistence of fast transport in radial but in azimutal so in red region.
in orange I expect gradients both in radial and azimutal
2 time scale in red
in orange 1 time scale 'cause when I'm diffusing out, slow motion it will travell radially only for the time to reach the wall.
time scale of fast scale to wall FW/limiter



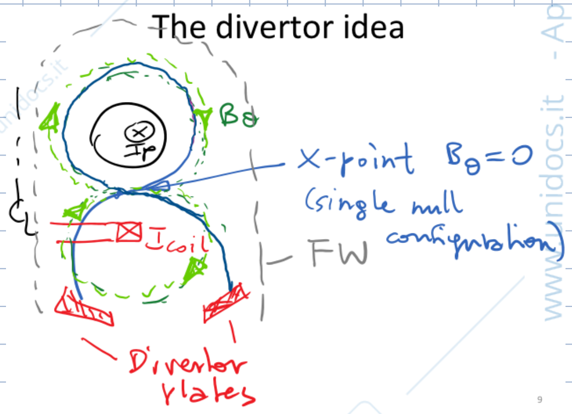
what happens when particle hit the wall

Deuterium and electron goes out reaching the wall, hitting it giving particle of surface sufficient momentum to over come the bonding energy. then they start ionizing (multispecies problem)



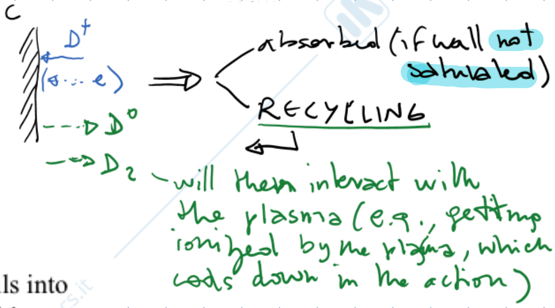
SPUTTERING PROBLEM.
they can lead to line radiation:
have the impurity, that interact with e^- in plasma; that can exitate an electron going up to another orbit generating photon so loosing energy and so cooling down the plasma.

so I need to control them

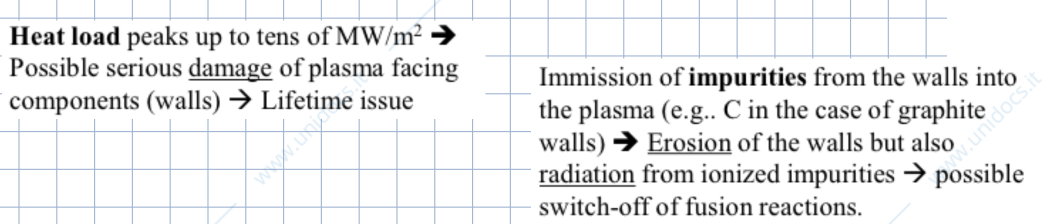


what happens to fuel?

D^+ hitting the wall, saturate and became neutral pumping them away, so the wall receive charge particle resulting neutral one.
there can be both atoms or molecules, themselves are entering the domain having a strong interaction with hot plasma with possibility to ionize, starting interacting now creating same problem as impurity recalling them back to the wall reinitiating the process RECYCLING



plasma confinement is never perfect due to dissipation, plasma interact with the solid wall

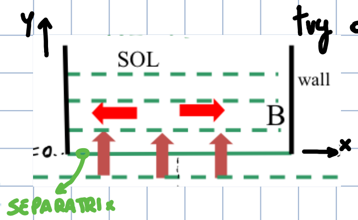


Plasma-Boundary Electrostatic Sheat

dirty region where plasma is not fully ionized, due to the presence of neutrals which come from the recycling process. (electrostat sheat) region with strong electric field which try to pull ions, unbipolar flow

quasi-neutrality is violated when I have sheat < λ_D

SOL thickness



try and get an extimate on how thick the sol is, due to the fact that if thick then also welted Area is longer instead if is thin also the welted Area is smaller.
how thick the sol is from the POV of the heat flux.
considering a simplify geometry, cutting the torus, preserving his 2-Dimensionality.
Only one time scale, fast motion along x bring particle to the wall.

'causes a separation of land scales, differs by order of magnitude

Y radial direction across magnetic surfaces

I need to write an equation for plasma density.

assumption:

- steady-state
- 2D
- no sinks/sources (no recycling)
- plasma flux in radial is diffusive nature.

from continuity: $\frac{\partial \Gamma_x}{\partial x} + \frac{\partial \Gamma_y}{\partial y} = 0$; (divergence)

I know SOL is at least 2D, I now is a PDE so I need to find a right way to simplify (I'm expecially interested in Y direction, thickness)

$$\frac{\partial \Gamma_x}{\partial x} = -\frac{\partial \Gamma_y}{\partial y};$$

$\rightarrow n = n(0)e^{-y/\lambda_n}$

I want to model it, approximating with finite different:

$$\frac{\partial \Gamma_x}{\partial x} = \frac{nC_s}{L} \quad \rightarrow \quad \Gamma_y = -D\frac{\partial n}{\partial y};$$ diffusion type

L, connection lenght, distance between two walls.

Γ_x in $x=0$, mid plane, since I have contribution from left and right, macroscopically I should say $\Gamma_x = 0$;

$$\frac{\partial \Gamma_x}{\partial x} = -\frac{\partial \Gamma_y}{\partial y}; \rightarrow D\frac{\partial^2 n}{\partial y^2} - \frac{C_s}{L}n = 0;$$

BC)

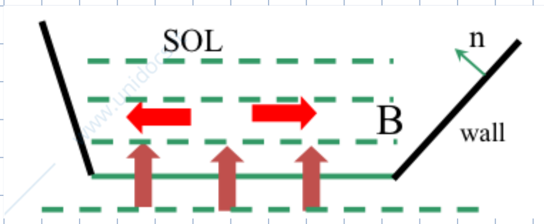
Dirichlet $\quad n$ in $y=0 = n(y)$

$n \to 0$, as $y \to \infty$

SOL thickness $\quad \lambda_n^2 \equiv DL/C_s; \quad \leq 1\,mm$!!

$\lambda_n \ll L$;

Removing one of the assumption we can reach good general results, estimating thickness for the heat flux.



writing the energy balance: $T = T(0)e^{-y/\lambda_T}$;

$\lambda_T = f(D, L, c_s, x)$;

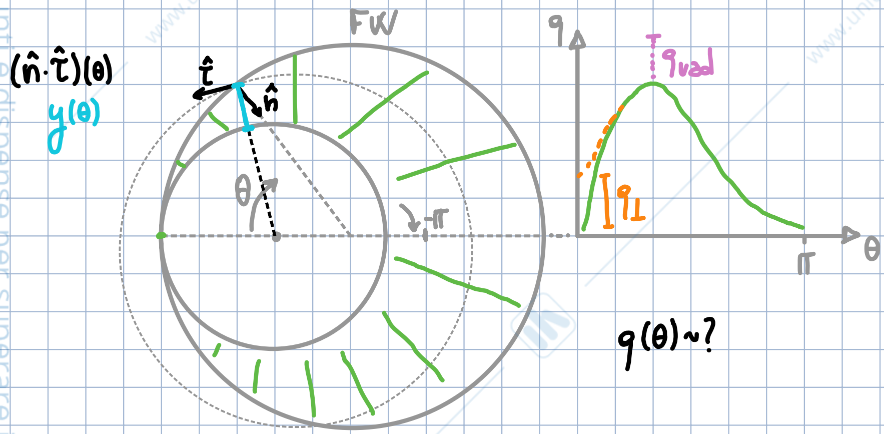
$q_{\parallel} = n c_s T \sim n T^{3/2} \sim q_{\parallel 0} e^{-y/\lambda_q}$; $\longrightarrow$ $1/\lambda_q = 1/\lambda_n + 3/2 \, 1/\lambda_T$;

so $\lambda_q < \lambda_n < \lambda_T$

extend the previous model including a not ⊥ magnetic field to the wall, so an inclined wall

Heat flux on the wall making a finite angle with B: $q = q_0 e^{-y/\lambda_q} \cos(B, \hat{n})$ COSINE MODEL

EQ.1



$q(\theta) \sim ?$

the only terms dependent on θ are the cosine and the value of y due to the fact the SOL represent the thickness.

can we use EQ.1 to qualitatively sketch the profile of heat flux of this simple model.

q in zero is zero due to the fact that here the separatrix touch the first wall, here y=0 'cause $\hat{n}\cdot\hat{\tau} = 0$;

then is an heaven function since we have a symmetry plane

$\theta \to \infty$, $y/\lambda_q > 0$ is exponential so $q \to 0$

the zero at contact point, is because of a reasone hiding in our derivation due to our assumption. we assume that only the ∥ component of the flux is responsible for q where instead near zero has to be a influenced by $q_{\perp}$

than there another influence, another function that goes to pull up our graph and is related to q_{rad}

problem gives us λ_q

where do I get q_0 from?....

EXPERIMENTAL CORRELATION → MULTI MACHINE SCALING;

λ_q scale, obtain from T. Eich correlation, empirical.

$$\lambda = 0.73(B_T)^{-0.78}(q_{cyl})^{1.20}(P_{SOL}(MW))^{0.10}(R_{geo})^{0.02}$$

POWER BALANCE CONSIDERATION introducing power losses from impurity.

LAWSON CRITERION with impurity

Losses: $P_{out} = P_L + P_R$;

P_L, conduction/convection $= 3nT/\tau_E$

P_R, impurity radiation losses $= n n_z L_z(T)$

Limit relative concentration of impurity overwhich I have no ignition.

High Z material, the max concentration that I can afford is much more lower than the low Z material but if I consider also the SPUTTERING YIELDS the situation is viceversa, the sputtering is a treshold process

material more potentially damaging are those more difficult to be seen in plasma.
No going under the treshold level