Zinkle-Nelson Concept of Dual Lithium Stream First Wall/ FliBe blanket for a tokamak-reactor

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OUTLINE

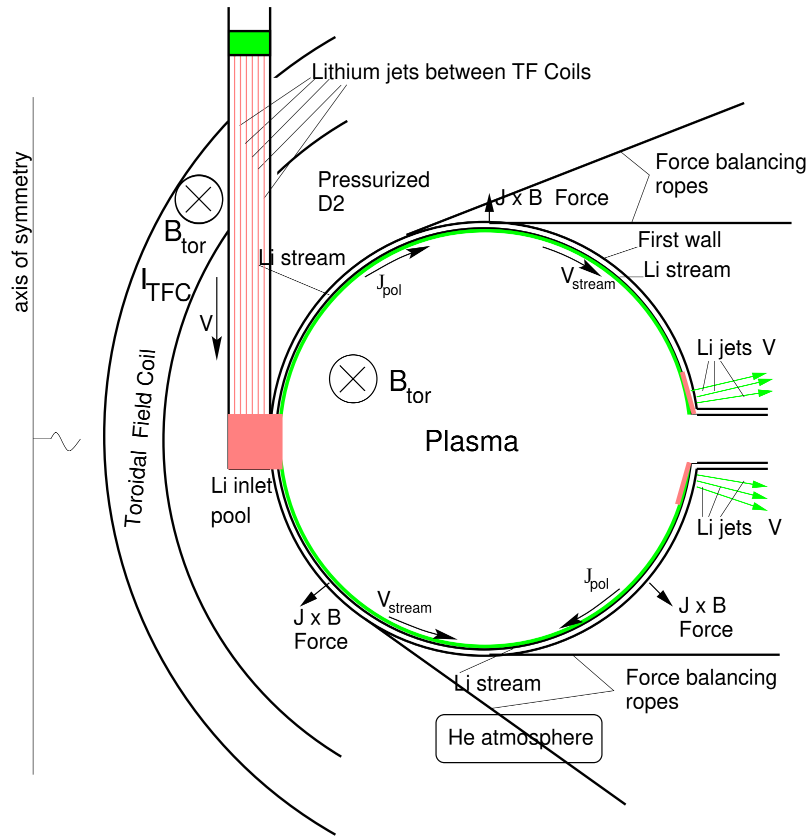
1. Electro-magnetically balanced vacuum chamber.
2. Intense Lithium Streams/FliBe blanket.
3. Heat distribution in the FLiBe flow.
4. Summary

1 Electro-magnetically balanced vacuum chamber

Electro-magnetic pressure exceeds 1 atm everythere

$$\boxed{p_{\mathbf{j}\times\mathbf{B}}|_{inlet} \simeq 2-4\ [atm], \qquad p_{\mathbf{j}\times\mathbf{B}}|_{outlet} \simeq 1-1.5\ [atm]}$$

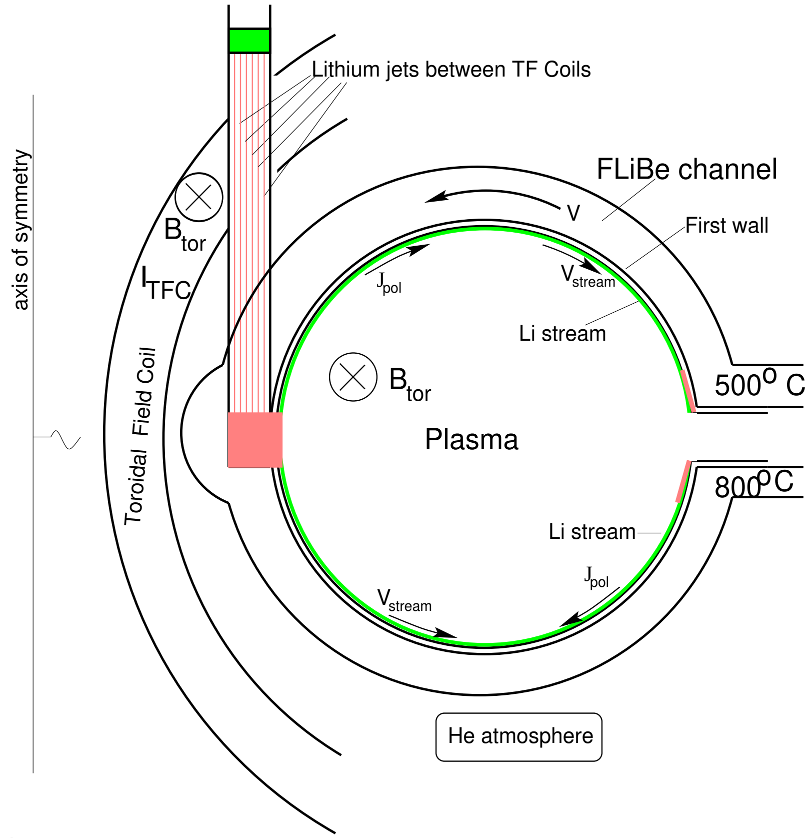
and creates a stable situation for the first wall.



- Guide wall works against expansion $\Longrightarrow$
- Guide wall can be made as a thin shell (like a car tire).
- Toroidal component of the electro-magnetic force can be balanced by the set of external wire ropes.
- Inner surface is sealed by the lithium streams (insensitive to cracks) $\Longrightarrow$
- Vacuum barrier can be moved to the plasma boundary (giving access to the neutron zone).

2 Intense Lithium Streams/FliBe blanket

Intense lithium streams + FLiBe make an excellent FW/blanket combination (S.Zinkle, B.Nelson, ORNL)



Lithium streams keep the wall temperature below melting point of FLiBe

$$\boxed{T_{wall} \simeq 200^o - 250^0 < T_{melt,FLiBe} \simeq 450^o}$$

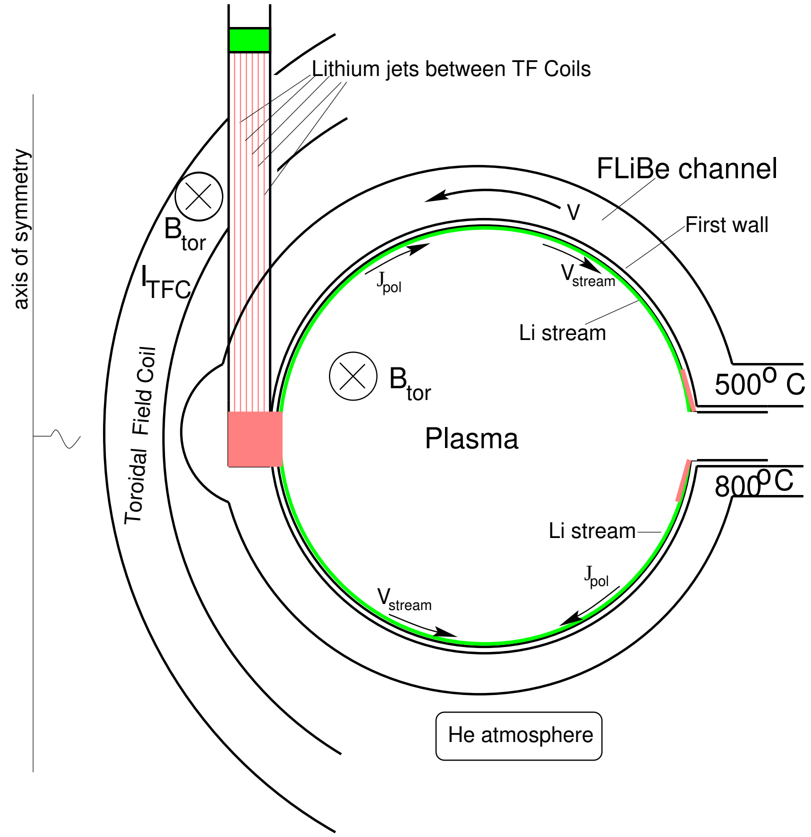
Independent of inner temperature in the chanell FLiBe has a solid boundary layer at the walls.

Even with $\boxed{T_{FLiBe}\big|_{outlet} = 800^o\ C}$ energy losses on the side walls are $\simeq 4\%$.

Small pressure in the FLiBe channel with negligible electro-magnetic drag to the coolant flow.

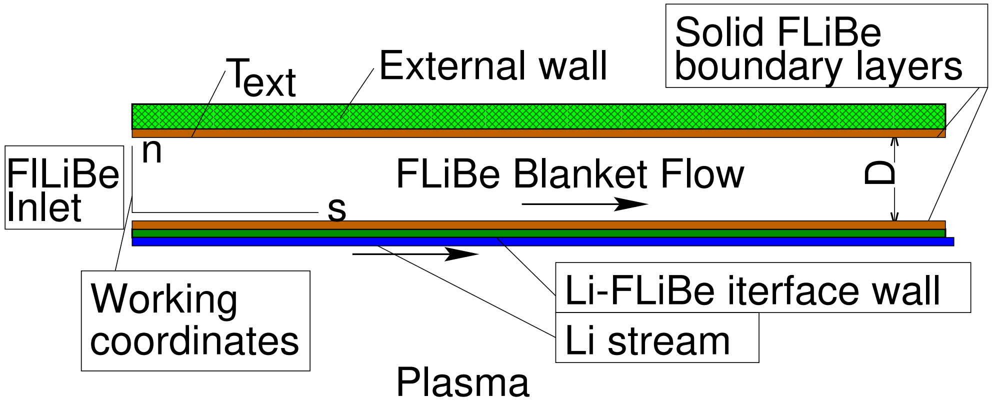
Wall surface is sealed from both sides.

How crazy it would be to think about making the vacuum chamber from the wire mesh



- wall becomes insensitive to thermal deformations $\Longrightarrow$ pulsed regime is acceptable (no high-tech for the current drive);
- deformations of the wall can be corrected on the fly (yacht sail approach);
- wire wall presumably can withstand high neutron flux;
- minimum activation in the neutron zone;
- protection of feedback plates by the FLiBe layer (without loosing their coupling with the plasma);

Stratified geometry of the FLiBe Blanket/Lithium streams



D	m	0.1
L	m	10
V	$\frac{m}{sec}$	0.5
$S(n)$	$\frac{W}{cm^3}$	100-40
$T_{side\ \ wall}$	C^o	200

The radial thickness D of the channel is assumed to be much smaller than the length L of the channel. Plasma side wall temperature is kept constant by a fast Lithium flow.

Heat source S corresponds approximately to 10 MW/m^2 in neutrons.

The walls of the channel are kept below the melting point of FLiBe, so two solid salt layers are formed on the walls of the channel.
The stationary heat diffusion equation

$$\begin{aligned} &\rho c_p V \frac{\partial T}{\partial s} = \kappa T''_{nn} + S, \qquad T > T_{melt}, \\ &0 = \kappa T''_{nn} + S, \qquad T < T_{melt} \end{aligned} \tag{3.1}$$

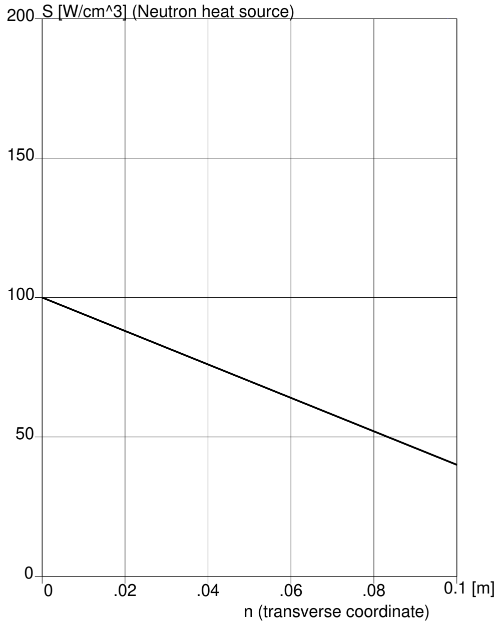
together with the matching conditions determines the temperature distribution in the flow.

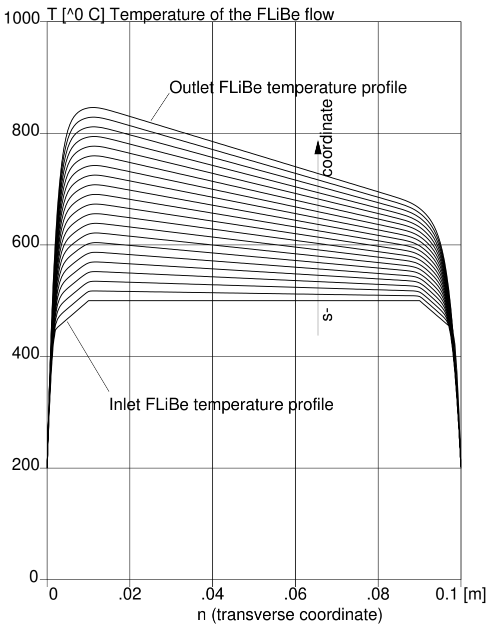
Here, ρ is the mass density of FLiBe, c_p is the heat capacity, V is the velocity of the flow, κ is the thermo-conduction.

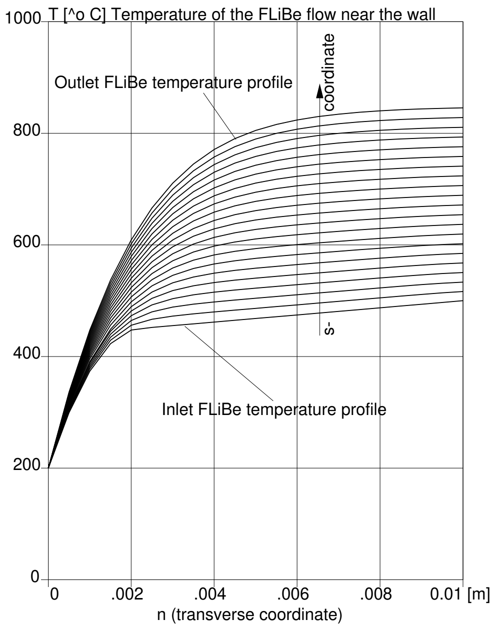
Thickness of the solid layer is determined as an eigenvalue of the problem in a self-consistent way.

FLiBe parameters		
ρ	$\frac{kg}{m^3}$	2240
c_p	$\frac{J}{kg \cdot C^o}$	2380
κ	$\frac{W}{m \cdot C^o}$	1
T_{melt}	C^o	450

Profiles of the (neutron) heat source and T in the FLiBe channel





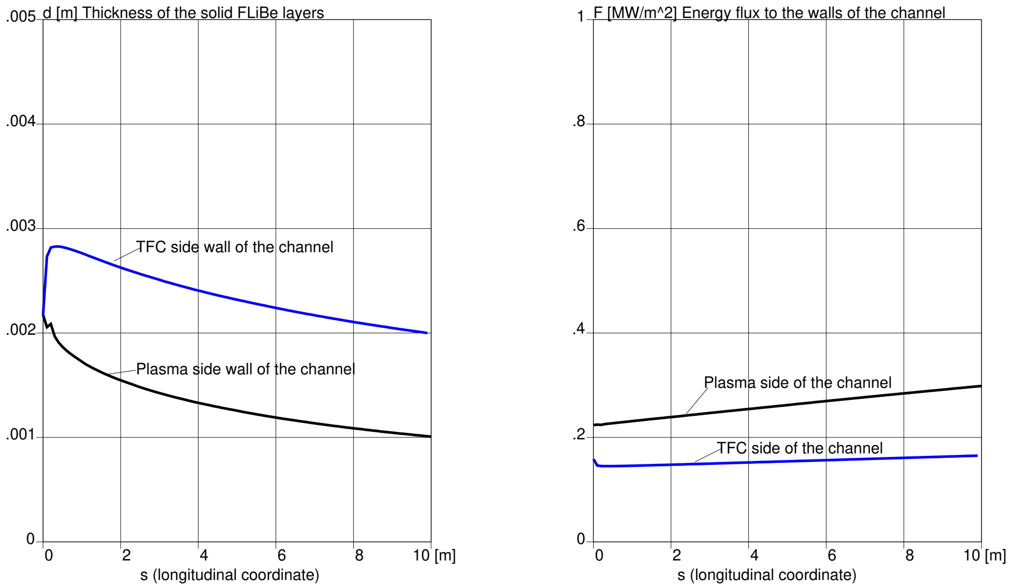


FLiBe thermo-conduction is so small that the temperature inside body of the flow is determined solely by the heat source power

$$\rho c_p V \frac{\partial T}{\partial s} \simeq S, \qquad T > T_{melt}, \tag{3.2}$$

not by thermo-conduction losses.

Two boundary layers of the order of 1-3 mm are formed near walls of the channel. Inside, each of them contains a sublayer of a solid FLiBe.



Thickness of the solid FLiBe layers as a function of a longitudinal coordinate s.
and
Energy losses to the side walls from the FLiBe flow.

In this example the averaged energy losses are $0.26\ MW/m^2$ through the plasma side wall and $0.16\ MW/m^2$ through the Toroidal Field Coil (TFC) side of the wall, which constitute approximately 4 % of the incoming neutron flux energy.

FLiBe seems to be a perfect coolant for the tokamak-reactor

4 Summary

New ideas for the tokamak-reactor design: