A Self-Cooled Lithium Blanket Concept for HAPL

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Presentation Outline

- Introduction and Guidelines
- Chamber Description
- Beam Layout
- Blanket Designs
- Power Cycle Optimization

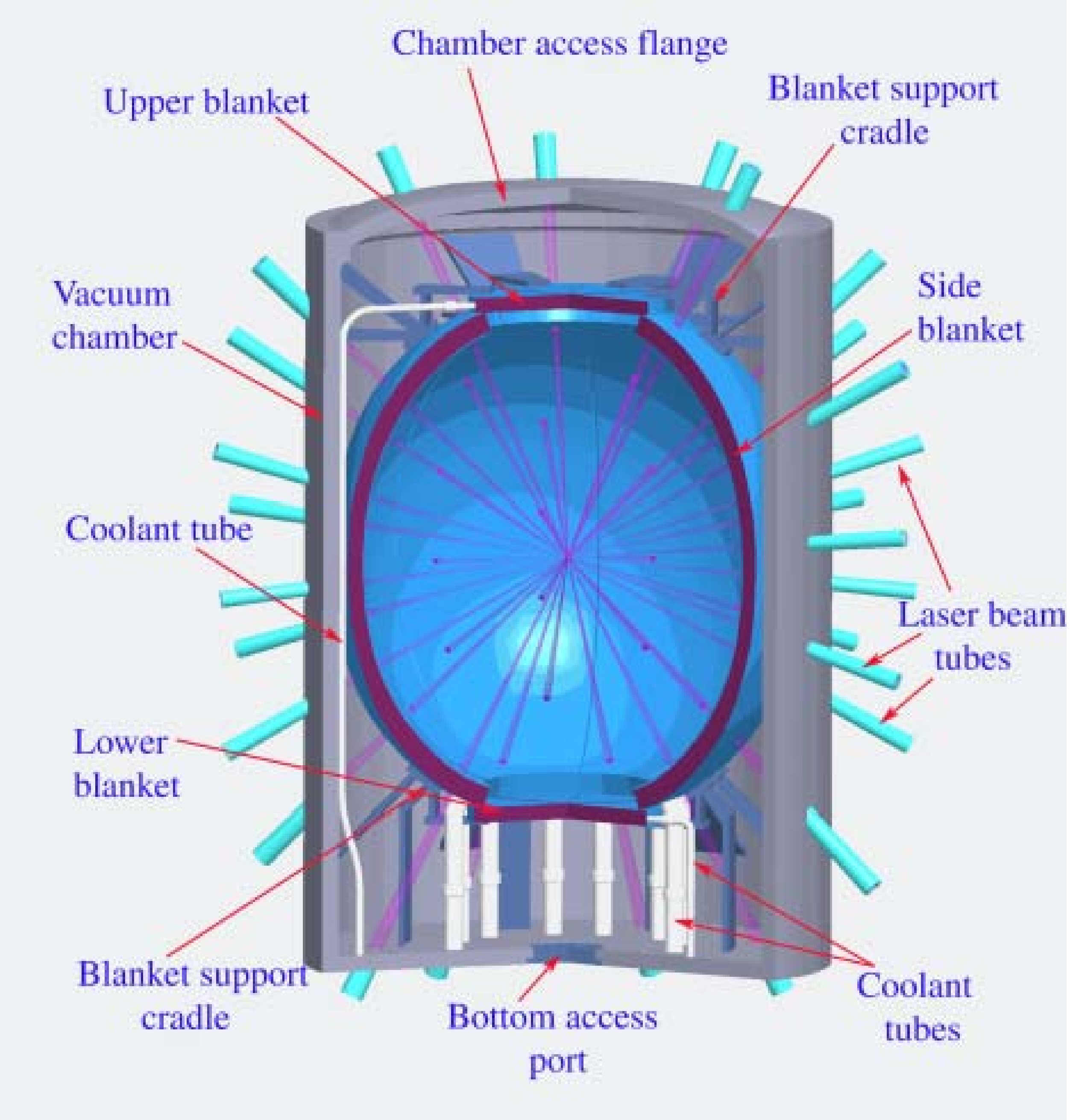
Introduction and Guidelines

- The blanket structure is F82H ferritic steel with max. average temp. at FW of 550°C (700°C for ODS FS).
- Make the blanket compatible with the first wall protection scheme.
- Integrate the beam ports into the blanket and make them compatible with the first wall coolant circuit.
- Arrange the laser beam tubes such that they are unobtrusive to the maintenance of the blanket sectors.
- Make all the coolant connections on the bottom at a common location.
- Maintenance of the blanket sectors is through an upper access port.

Chamber Description

- The chamber is an upright cylinder about 20 m high and 6.5 m radius at the midplane.
- The blanket curves inwards at the upper and lower ends to facilitate the placement of beam ports and help with blanket maintenance.
- There are 12 side blanket modules surrounding the chamber and an upper and lower blanket closing off the ends.
- Each side module has 13 sub-modules connected toroidally.
- The laser beam tubes terminate at the outer surface of the vacuum chamber.
- The vacuum chamber is separately cooled with He gas.

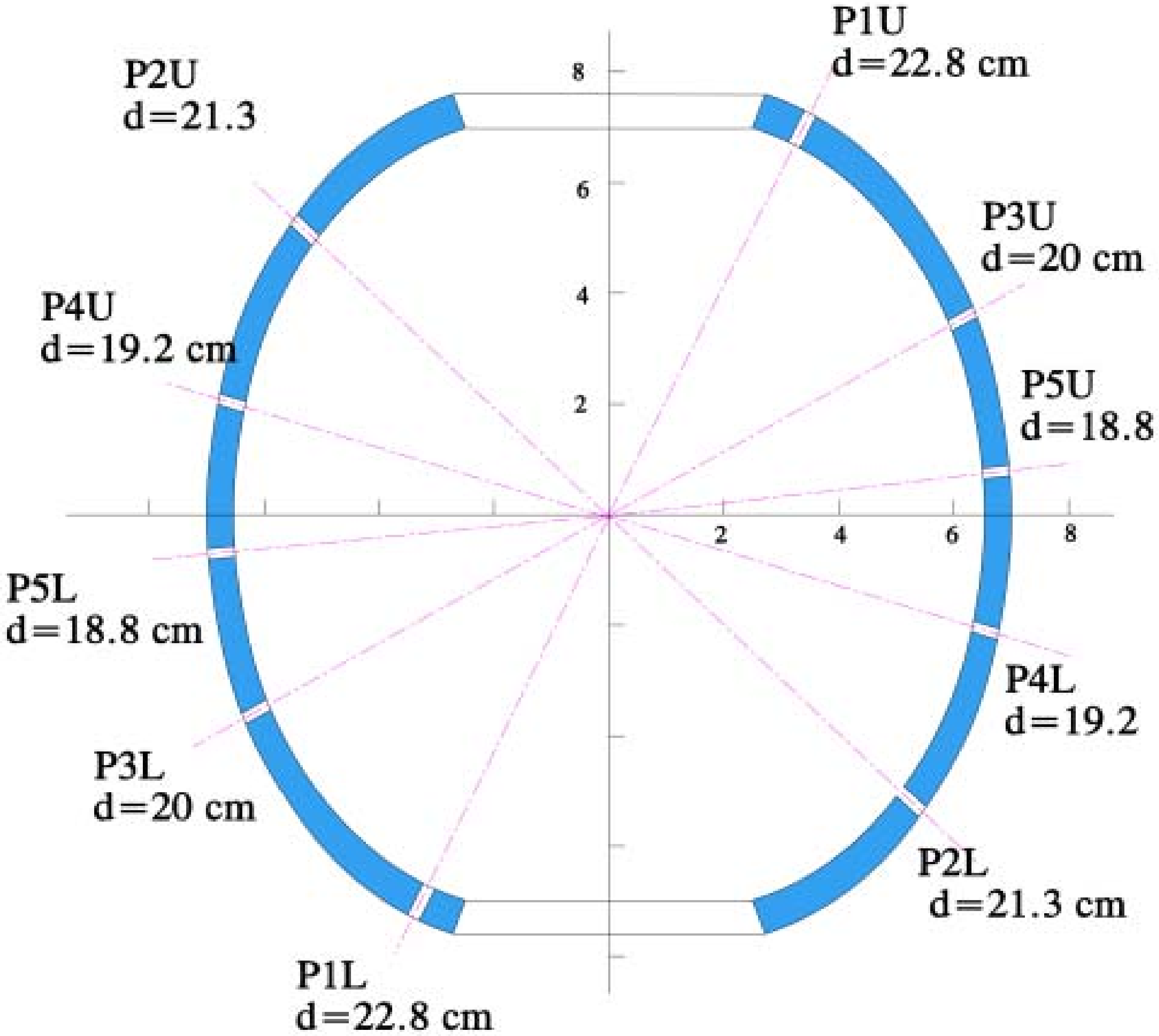
Chamber Cross-Section



Laser Beam Lay-Out

- There are 60 laser beams with an F number of 32 in the reactor arranged to provide near symmetric illumination of the target. (Rochester LLE)
- The beam ports are all located on azimuthal lines which are also in the centers of each blanket module. The ports lie along ten horizontal planes, with six beam ports in each plane forming a cone with the vertex at the chamber center.
- Five cones lie above the mid-plane and five below.
- The sub-module containing the beam ports is of uniform width, top to bottom in order to provide room for the ports without compromising the first wall coolant flow.
- The laser beams on opposite sides do not co-inside such that if there is no target, the beam does not propagate into the opposing beam tube.

Beam Port Lay-Out in Blanket



The F number is 32. Opposing beams do not co-inside, such that if there is no target, the beam does not propagate into the opposite port

Side Blanket Description

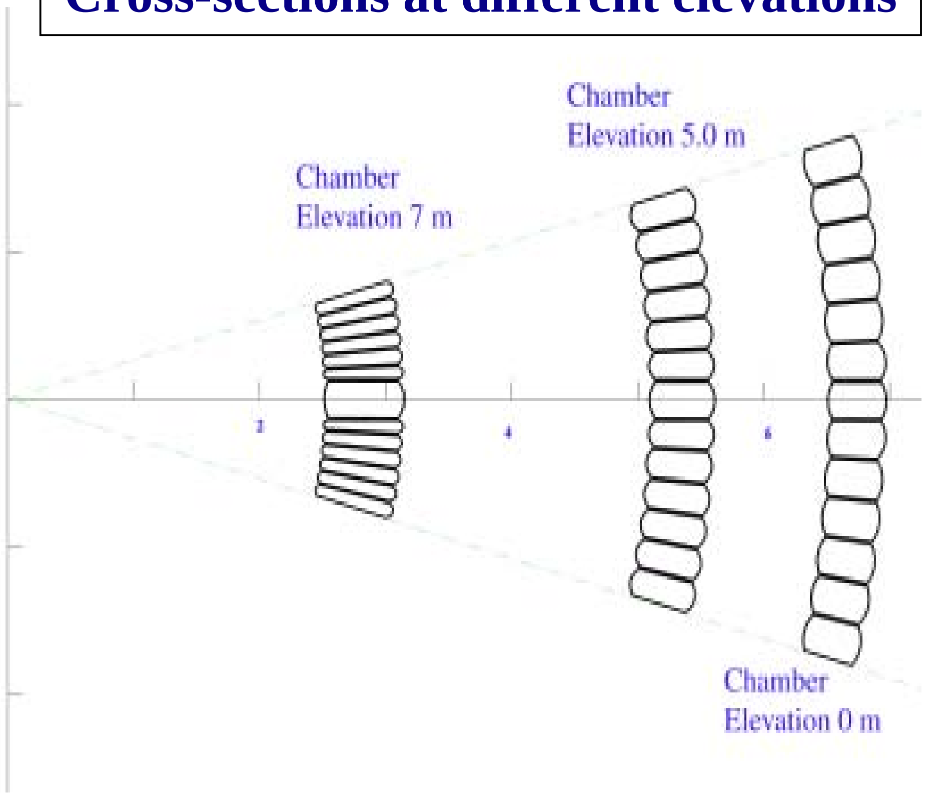
- There are 12 side blanket modules in the reactor each subtending 30 ^{o} of circumference.
- The modules are at a radius of 6.5 m at the mid-plane but taper down to a radius of 2.5 m at the upper/lower ends.
- Each module has 13 sub-modules which vary in width and depth to accommodate the reduction in radius.The sub-modules have a minimum radial depth of 47 cm.
- The sub-modules consist of two concentric rectangular tubes separated by a constant gap. As the shape of the sub-modules changes, the hydraulic diameter is maintained constant.

Side Blanket Description (continued)

- The outer tube is 0.35 cm thick and on the surface facing the target has 0.1 cm thick layer of W diffusion bonded to it for armor.
- Lithium coolant enters the sub-modules at the bottom, then flows at a high velocity in the gap between the tubes to cool the first wall. Vanes are provided to allow the coolant to spiral around the tubes in order to even out the temperature by spending equal amounts of time on each side of the sub-module.
- At the top the coolant makes a 180^{o} turn and travels back at a very low velocity through the large central channel of the inner tube exiting at the bottom (allowing decoupling to some extent of coolant exit temp. and in-reactor max. FS temp.).

Side Blanket Module

Cross-sections at different elevations



Overall view of a side module

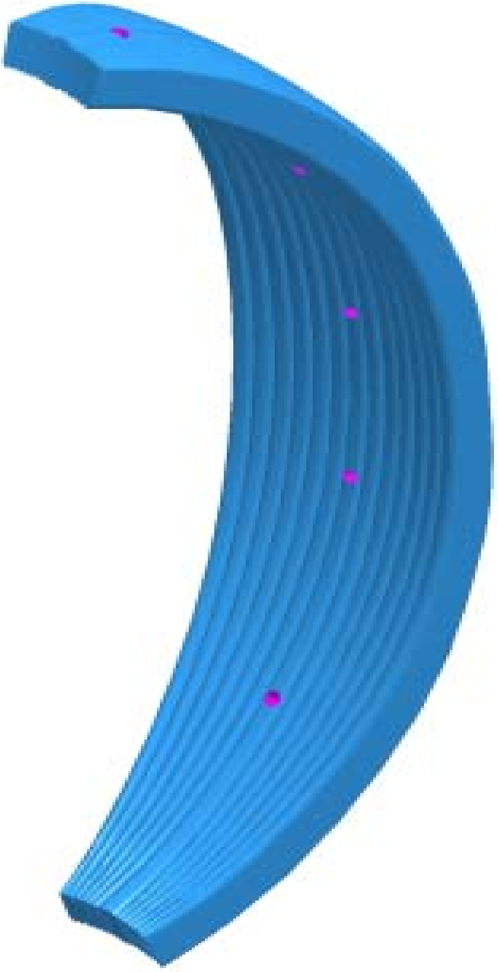
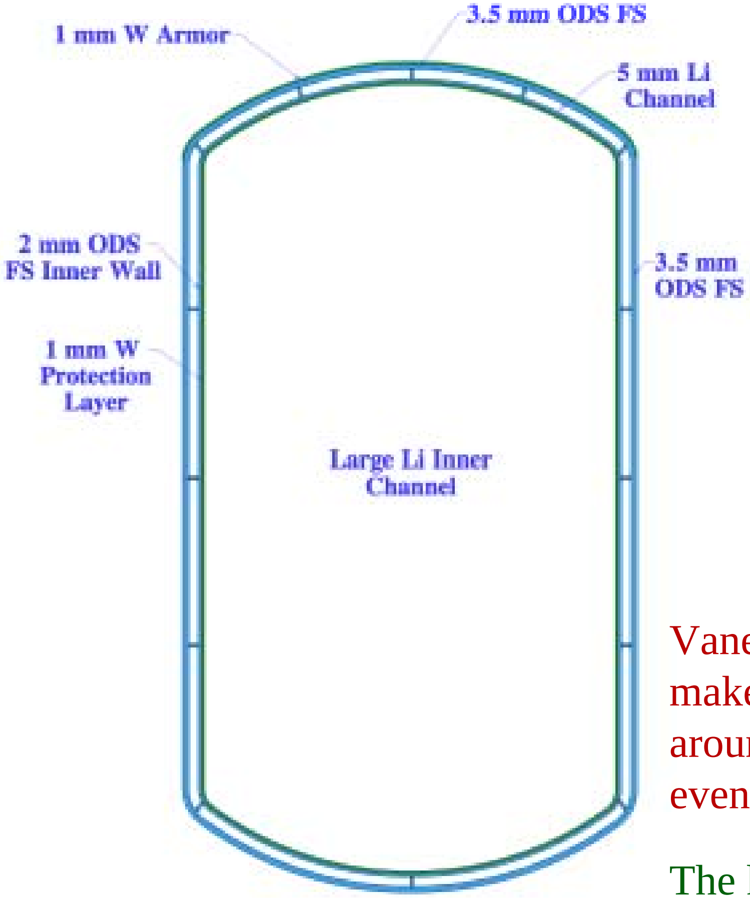


Table of Sub-Module Dimensions

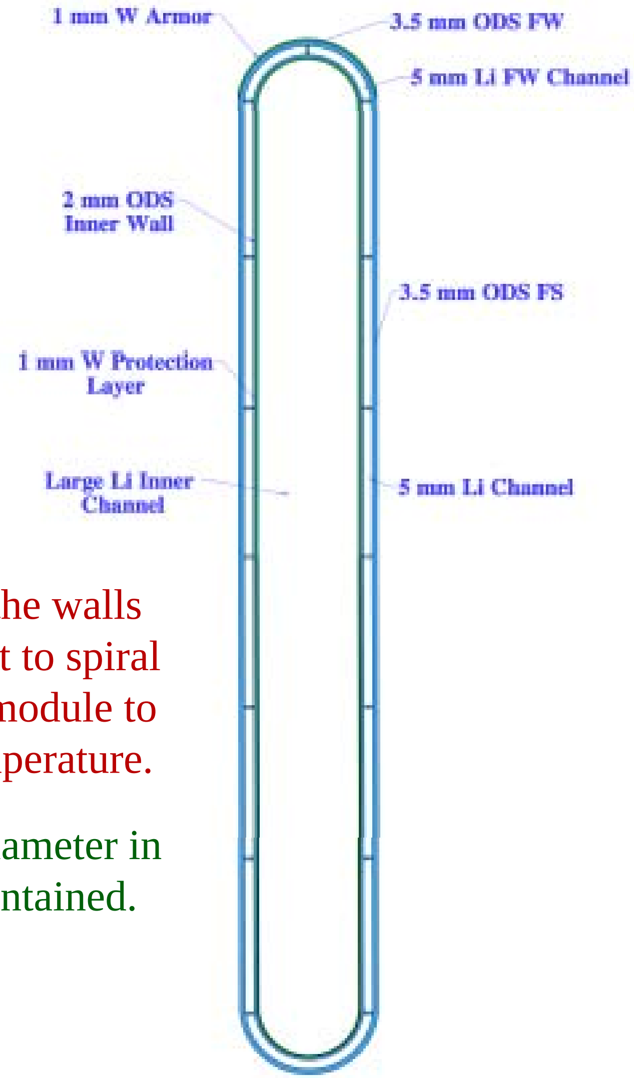
Elevation(m)	Width(cm)	Depth(cm)
0	26.0	47.0
5	19.8	53.2
7	8.6	64.4

Sub-Module Shapes

Mid-plane



Extremity

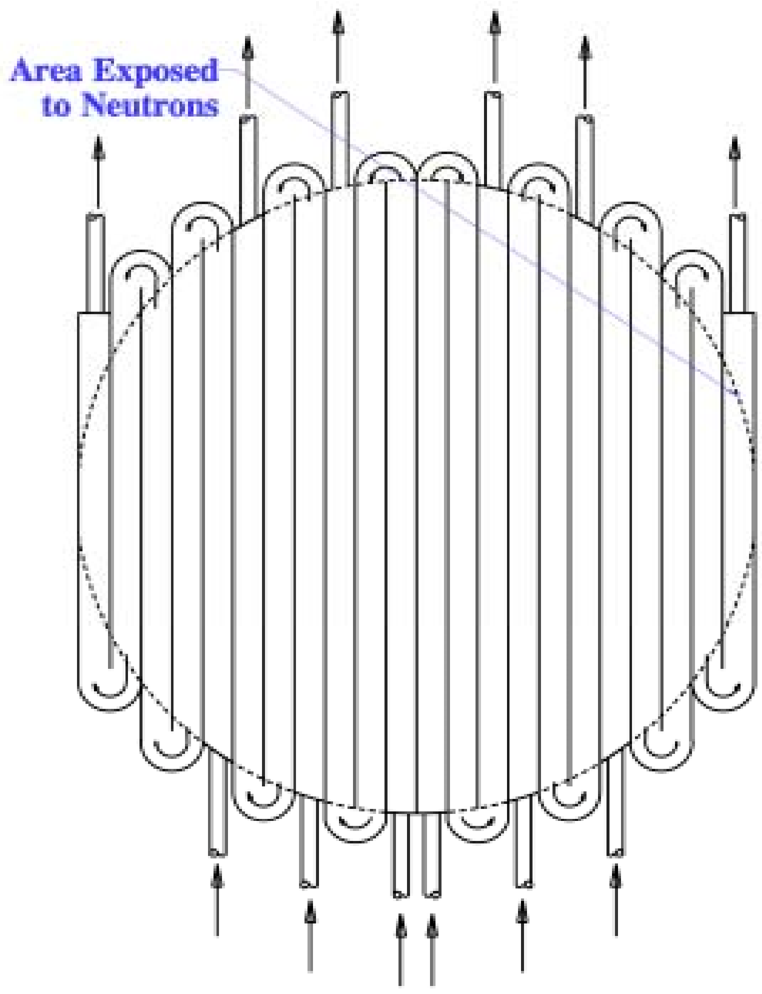


Vanes between the walls make the coolant to spiral around the sub-module to even out the temperature.

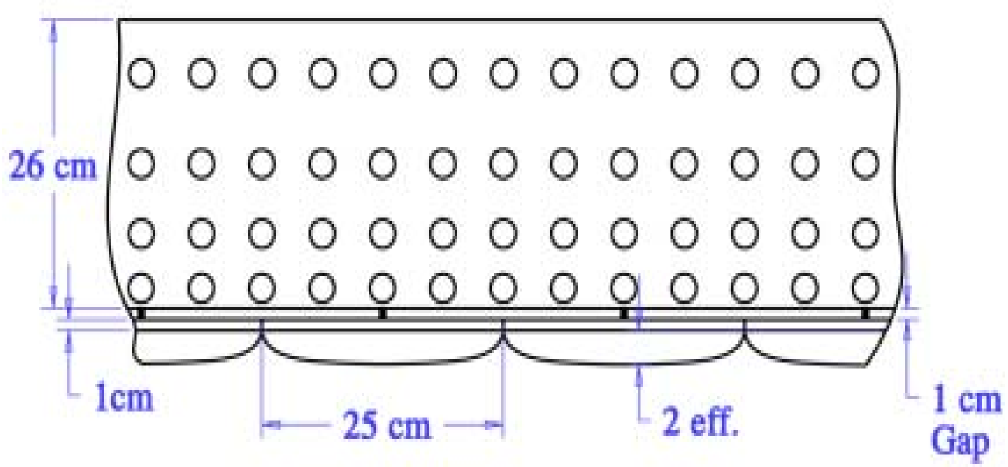
The hydraulic diameter in all shapes is maintained.

Upper/Lower Blanket

As viewed from chamber center



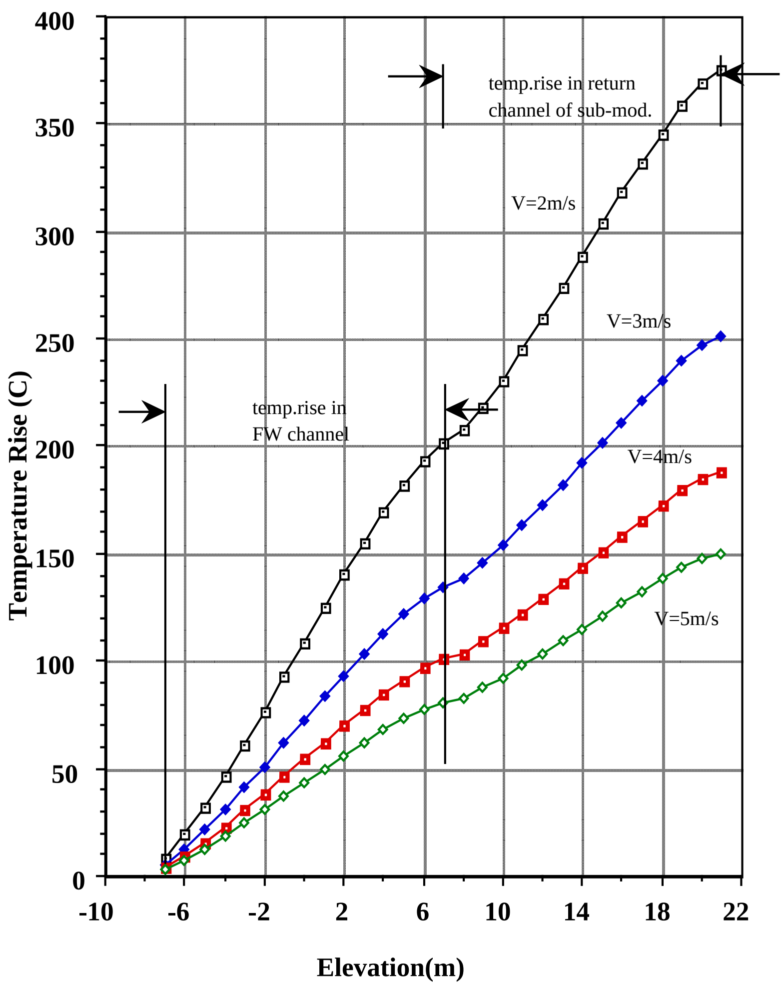
Partial cross-section



The coolant, after going through the first wall channels, is directed into the shield for cooling

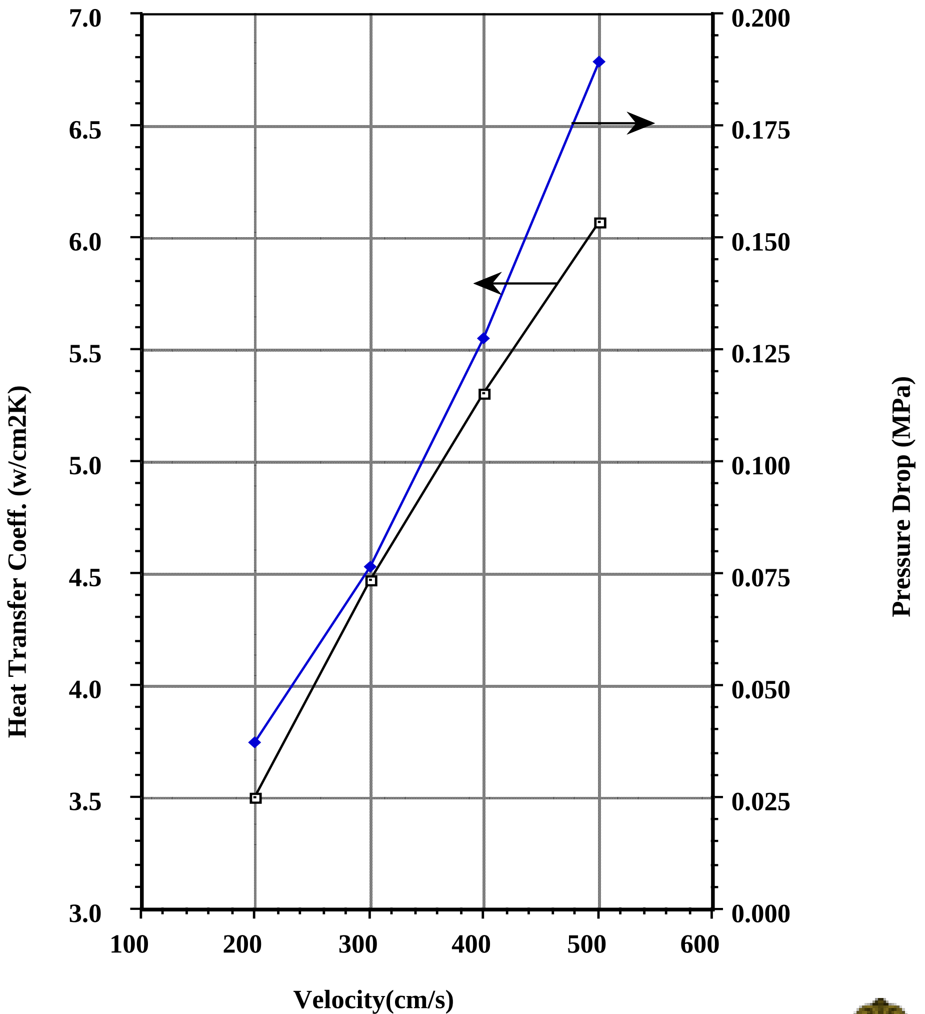
Thermal Hydraulics of the Side Blanket

Coolant Temp. Rise in the Side Blanket as a Function of Velocity from 2-5 m/s and for a 0.5 cm Gap



Elevation from 7m- 21m
is in the return channel

Pressure Drop and Heat Transfer Coefficients for 0.5 cm gap as a Function of Velocity



Parametric Optimization of Power Cycle Coupled with Blanket Under Different Assumed Conditions

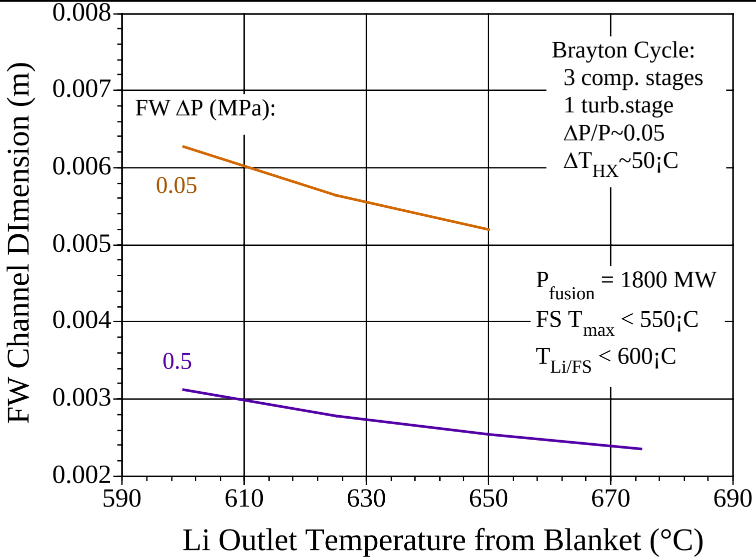
- Two Example Brayton Cycle Configurations:
  - I. **3 Compressor stages (with 2 intercoolers) + 1 turbine stage; $\Delta P/P \sim 0.05$**
  - II. **4 Comp. stages (+ 3 intercoolers) & 4 turb. stages (+ 3 reheats); $\Delta P/P \sim 0.07$: $r_p = 2.87$**
  - **$\Delta T_{HX} \sim 50°C$; $\eta_{comp} = 0.89$; $\eta_{turb} = 0.93$; $\text{Effect.}_{recuperator} = 0.95$**

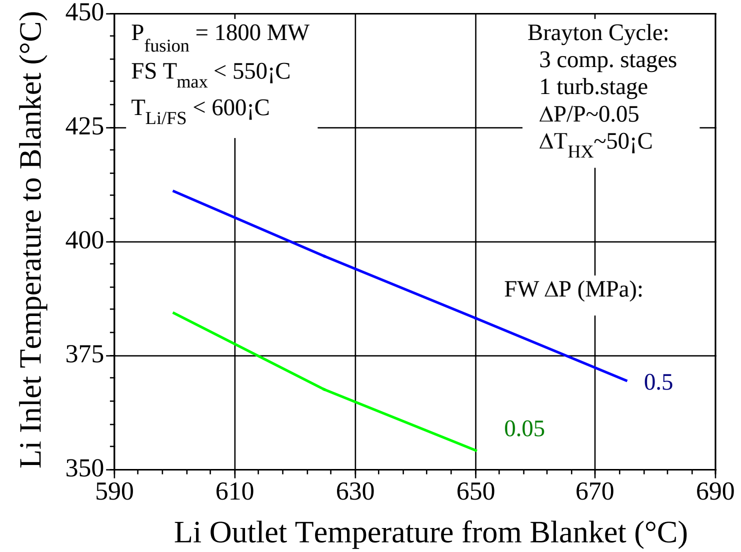
- Two Example Fusion Power
  - **1800 MW and 2400 MW**

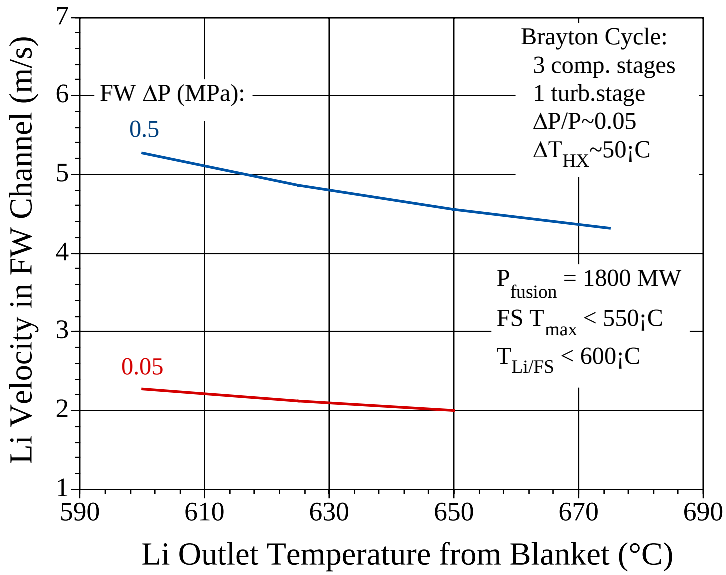
- Two Maximum FS Temp. Limits
  - **Regular Ferritic Steel: ~550°C**
  - **ODS FS: ~ 700°C**

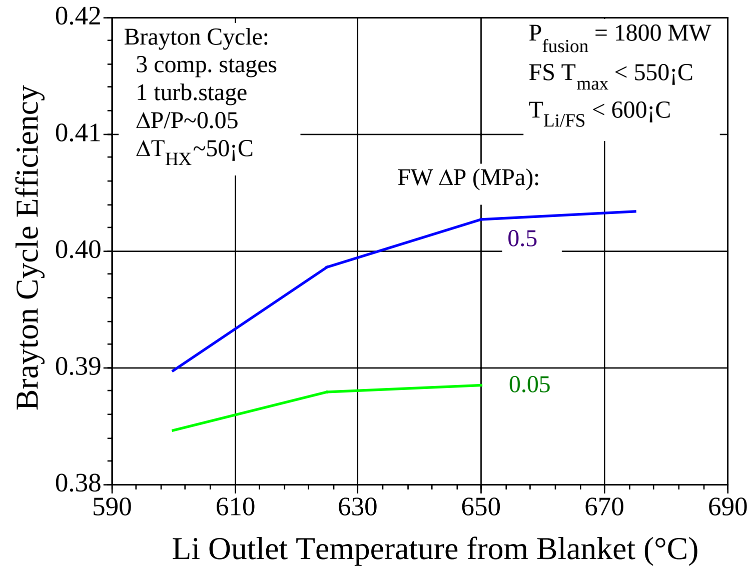
- Two Example Limits on Pressure Drop in FW Channel
  - **0.05 MPa and 0.5 MPa**

Power Cycle Optimization
(1800 MW Fusion, Brayton Cycle I, and FS T_{max} < 550°C)

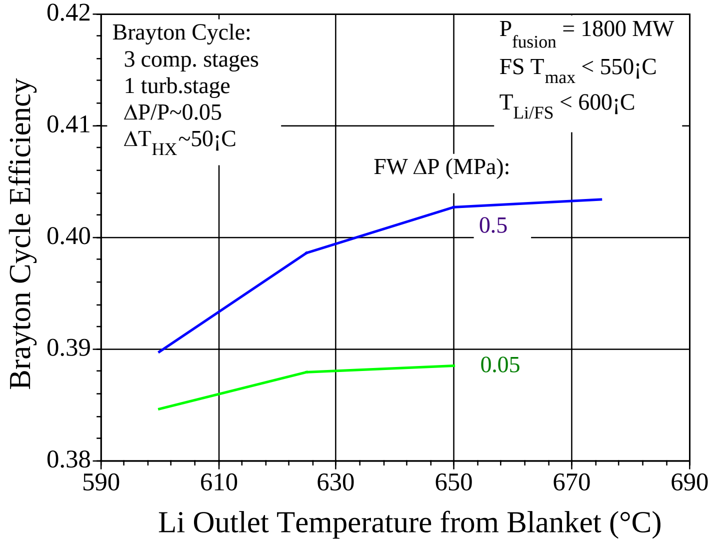


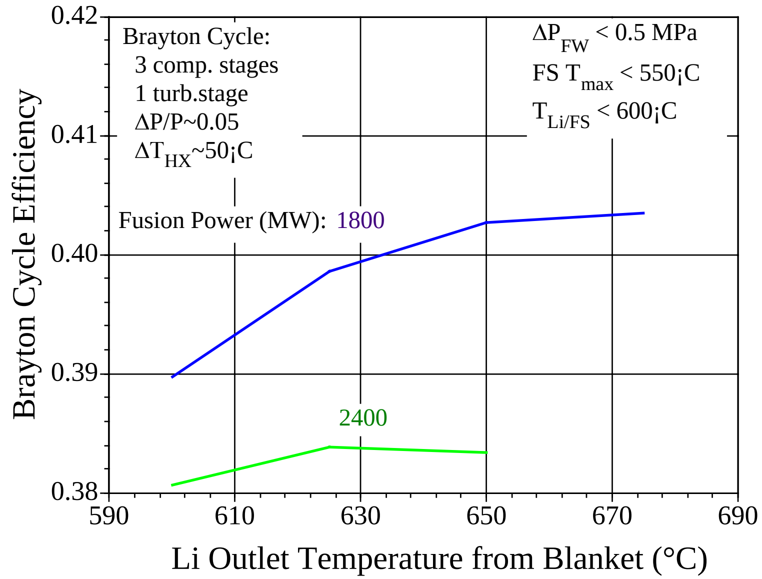


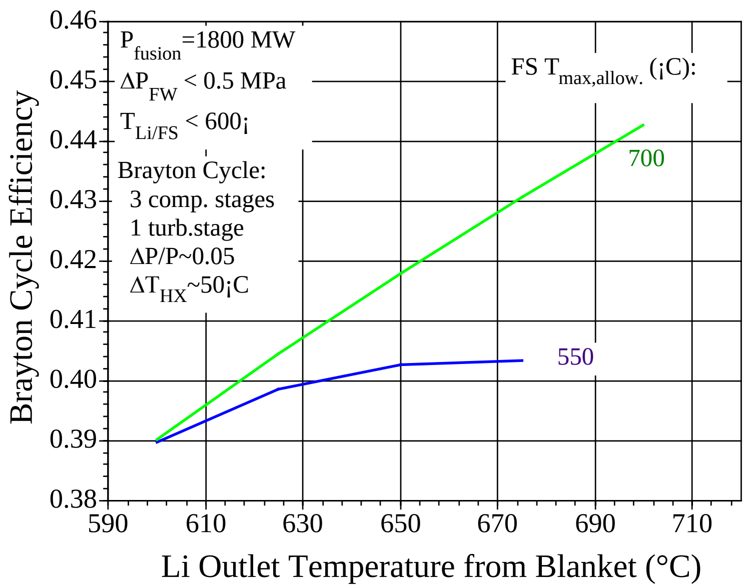


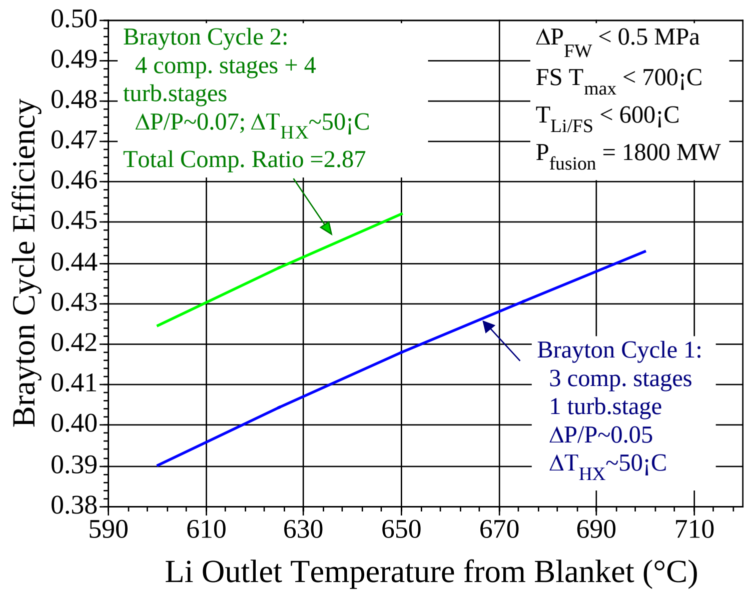


Brayton Power Cycle Efficiency Optimization Under Different Conditions









Conclusions

- A relatively simple self-cooled Li blanket made of ferritic steel F82H structure, operating at a low pressure and accommodating the FS temperature limits has been designed.
- Good geometric compatibility with the laser beam ports has been achieved.
- For a FS average T_{max} < 550°C and a P_{fusion} of 1800 MW, a FW Li velocity of 4.5 m/s and a pressure drop < 0.5 MPa can be achieved with a first wall gap of 0.25 cm. The inlet and outlet Li temperatures are 383°C and 650°C, respectively.
- Under these conditions the $\eta_{Brayton}$ ~ 0.4 assuming that the maximum He gas temperature is 50°C below the maximum Li coolant temperature.
- For an ODS FS average T_{max} < 700°C, $\eta_{Brayton}$ ~ 0.42
- Upgrading to the Brayton Cycle with 4-stage compression and expansion increases $\eta_{Brayton}$ to ~0.44.