A HELICAL COOLANT CHANNEL DESIGN FOR THE SOLID WALL BLANKET

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ABSTRACT

A helical coolant channel scheme is proposed for the APEX solid wall blanket module. The self-coolant breeder in this system is FLIBE (LiF)2(BeF2). The structural material is the nanocomposited alloy 12YWT. The neutron multiplier used in the current design is either stationary or slow moving liquid lead. The purpose of this study is to design a blanket that can handle a high wall loading (5MW/m^2). In the mean time the design provides means to attain the maximum possible blanket outlet temperature and meet all engineering limits on temperature of structural material and liquids. An important issue for such a design is to optimize the system for minimum pressure loss. For advanced ferritic steel (12YWT) an upper temperature limit of 800°C, and a limit of 700°C at the steel/FlIBE interface are recommended.

The blanket module is composed of two main continuous routes. The first route is three helical rectangular channels side–by-side that are surround a central box. The helical channels are fed from the bottom and exit at the top to feed the central channels in the central box. The coolant helical channels have a cross sectional area with a length of about10 cm and a width that changes according to the position around the central box. For instance: the width of the coolant channels facing the plasma is the narrowest while it is the widest in the back (farthest from the plasma).

In this design the coolant runs around the central box for only 5 turns to cover the total height of the first wall (6.8 m). The design is optimized with the FW channel width as a parameter with the heat transfer requirements at the first wall as the constraints.

INTRODUCTION

A helical coolant channel scheme is proposed for the APEX solid wall blanket module. The self-coolant breeder in this design is FLIBE (LiF)2(BeF2). The structural material is the nanocomposited alloy 12YWT and is chosen for its superiority in mechanical properties and compatibility with FLIBE and lead at elevated temperatures. A neutron multiplier such as beryllium or lead should be used to enhance FLIBE capability of tritium breeding. Both multipliers have their own problems. For example, beryllium has problems such as swelling, large tritium inventory and toxicity, while lead produces bismuth which generates polonium and the effectiveness of this multiplier decreases with increasing distance from the first wall. However, a system can be engineered to avoid and deal with such a problem. Presently, liquid lead is used as the neutron multiplier. The development philosophy is to design a blanket that can handle a high wall loading (5MW/m^2). In the mean time the design provides means to attain the maximum possible blanket outlet temperature and meet all engineering limits on temperature of structural material and liquid coolants. The design also aims at optimizing the coolant system to minimize the pressure loss. For advanced ferritic steel an upper temperature limit of 800°C, and a limit of 700°C at the steel/FLIBE interface are recommended. At the first wall we have the highest thermal load, namely: the surface heat flux and the maximum volumetric heating. Thereby the first wall thermal condition requires the highest heat transfer coefficient. In this design the highest coolant velocity flows in the narrowest channels in the first wall. This combination results in the highest heat transfer coefficient in the system where it is needed. Figure 1 shows a sketch of a cross-section view at mid-plane and also shows the coolant flow direction.

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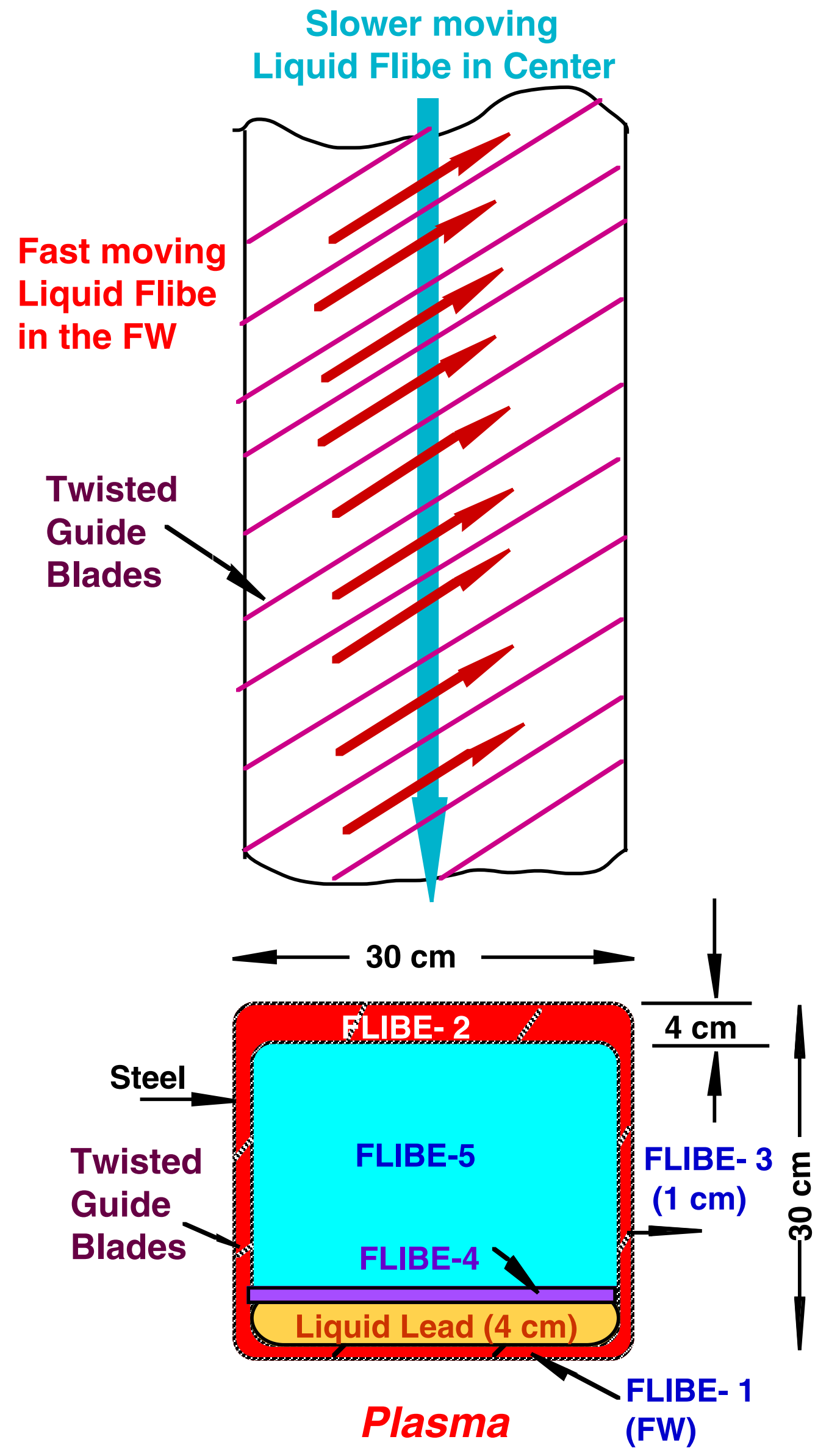
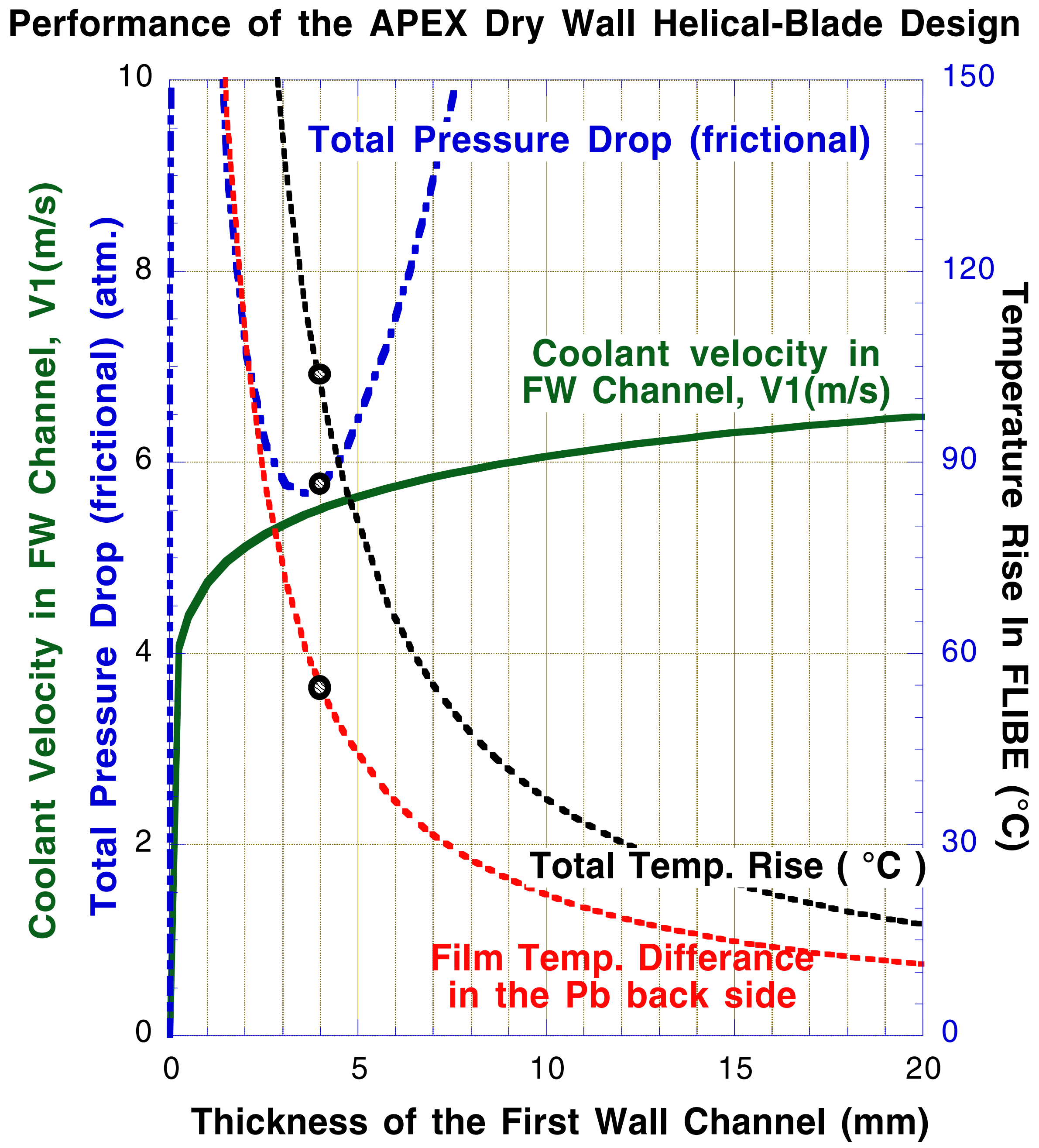
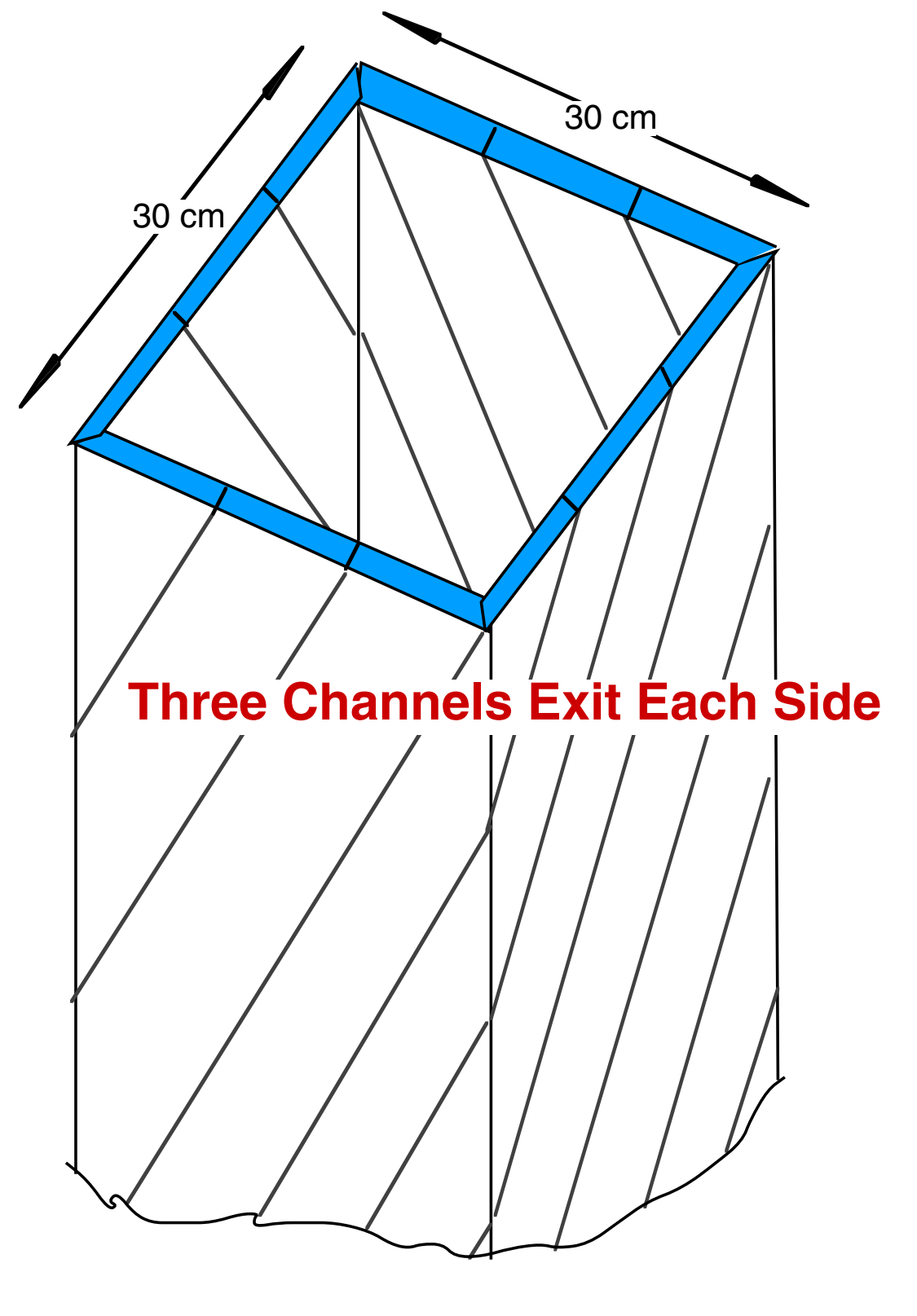


The flat-helical FLIBE/liquid lead/dry wall design



Coolant performance curves in the dry wall helical design.



Twelve helical coolant channels surround the central box.

Input Data

The average reactor neutron wall loading	3.84 MW/m^2
The OB average neutron wall loading	4.61 MW/m^2
The peak OB surface heat flux	1.0 MW/m^2
OB average surface heat flux	0.9 MW/m^2

The thermal loads

FW power	7.00 MW
Central channel power	4.88 MW
Side/back wall power	1.45 MW

Design Requirements

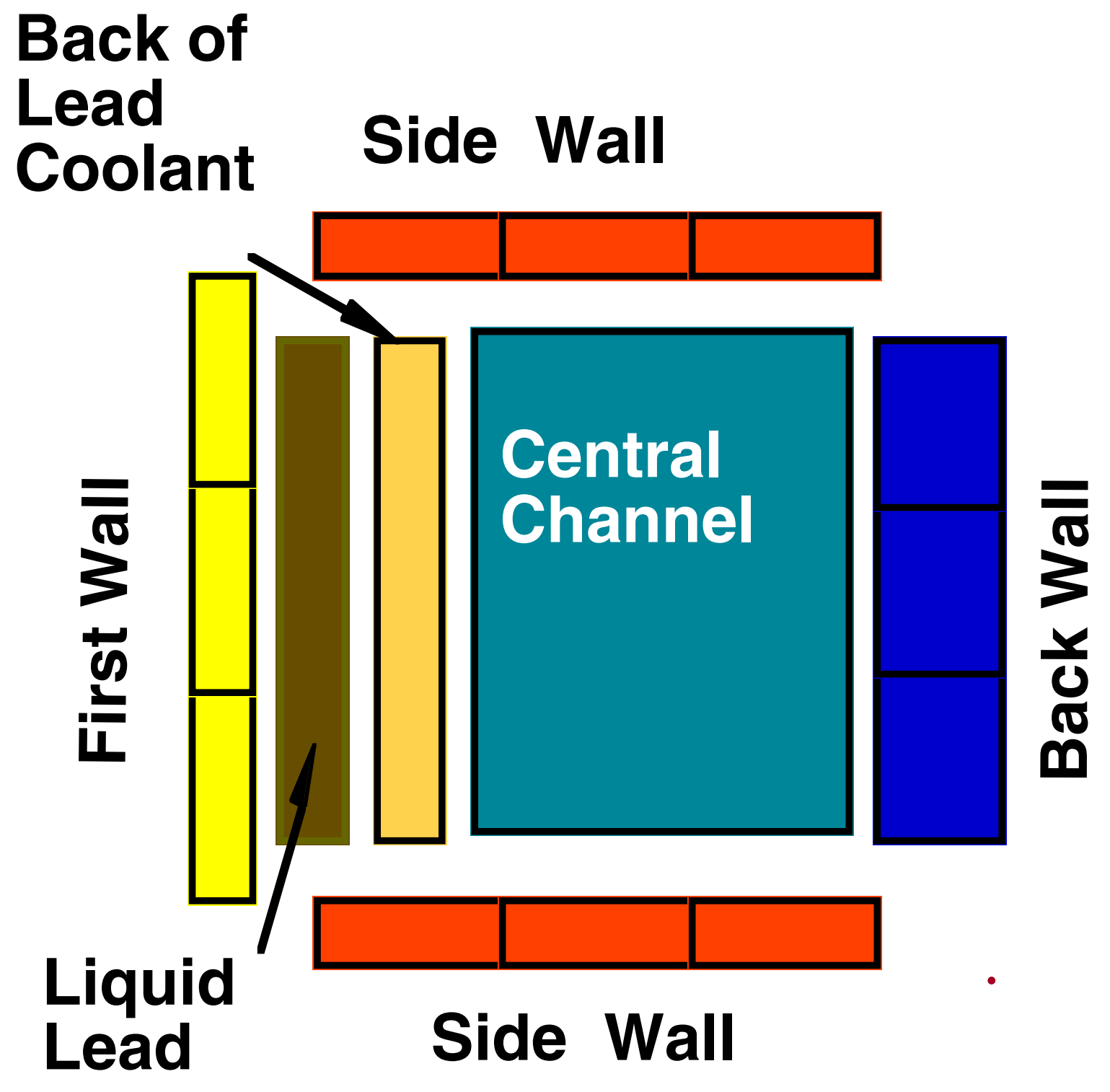
The maximum steel temperature < 800°C, and the maximum steel/FLIBE interface temperature < 700°C.

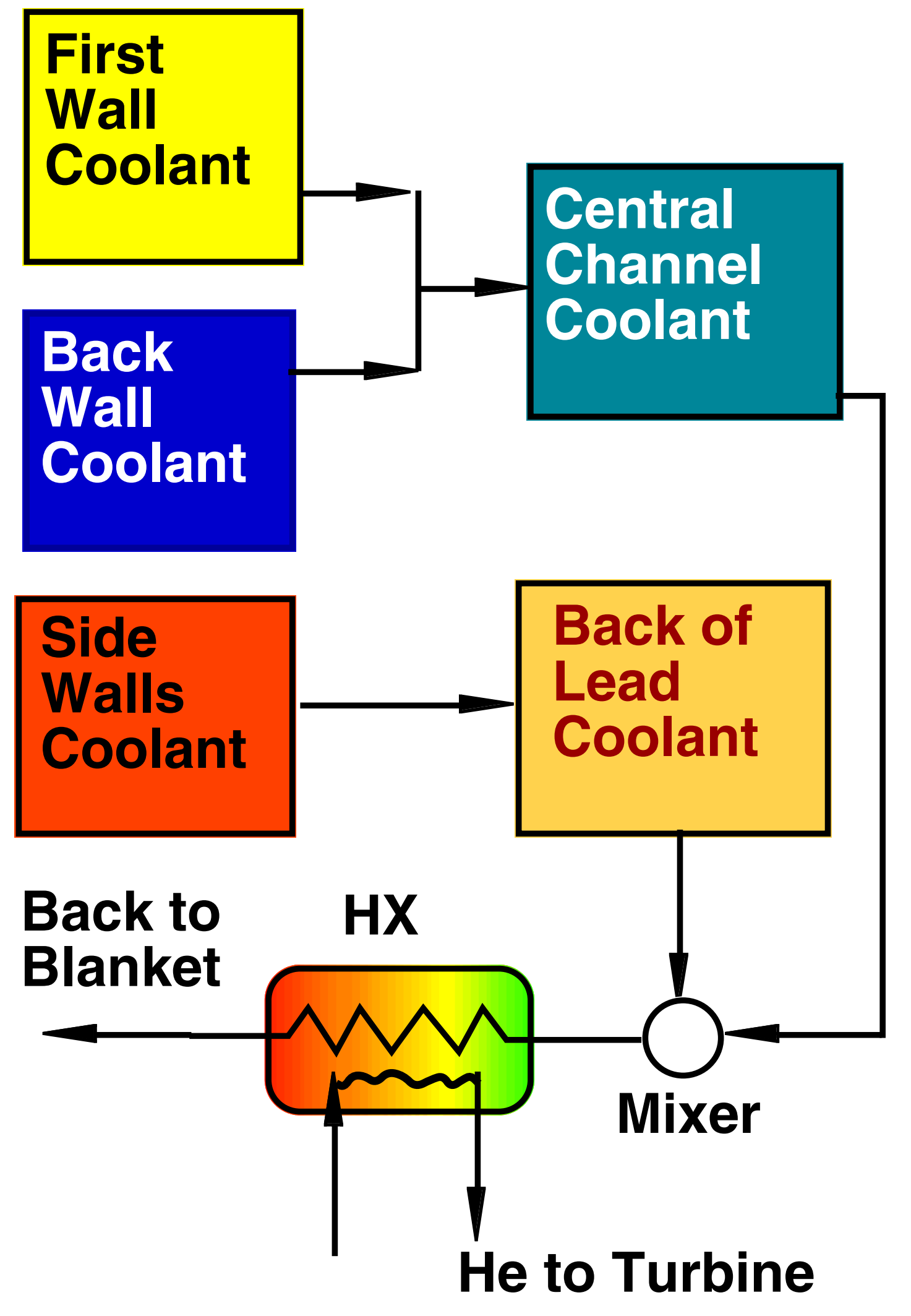
Design Criteria

1. Maximum possible outlet temperature.
2. Minimum coolant velocity.
3. Minimum pressure losses.
4. Minimum pressure driven stresses.

Results Summary

General	
Mass flow rate (kg/s)	**49.56**
Total temperature rise (°C)	**102**
Frictional pressure drop (atm)	**5.75**
Width/length of one module (cm)	**30/30**
FW thickness (steel)(mm)	**3.0**
Helix pitch (m)	**1.2**

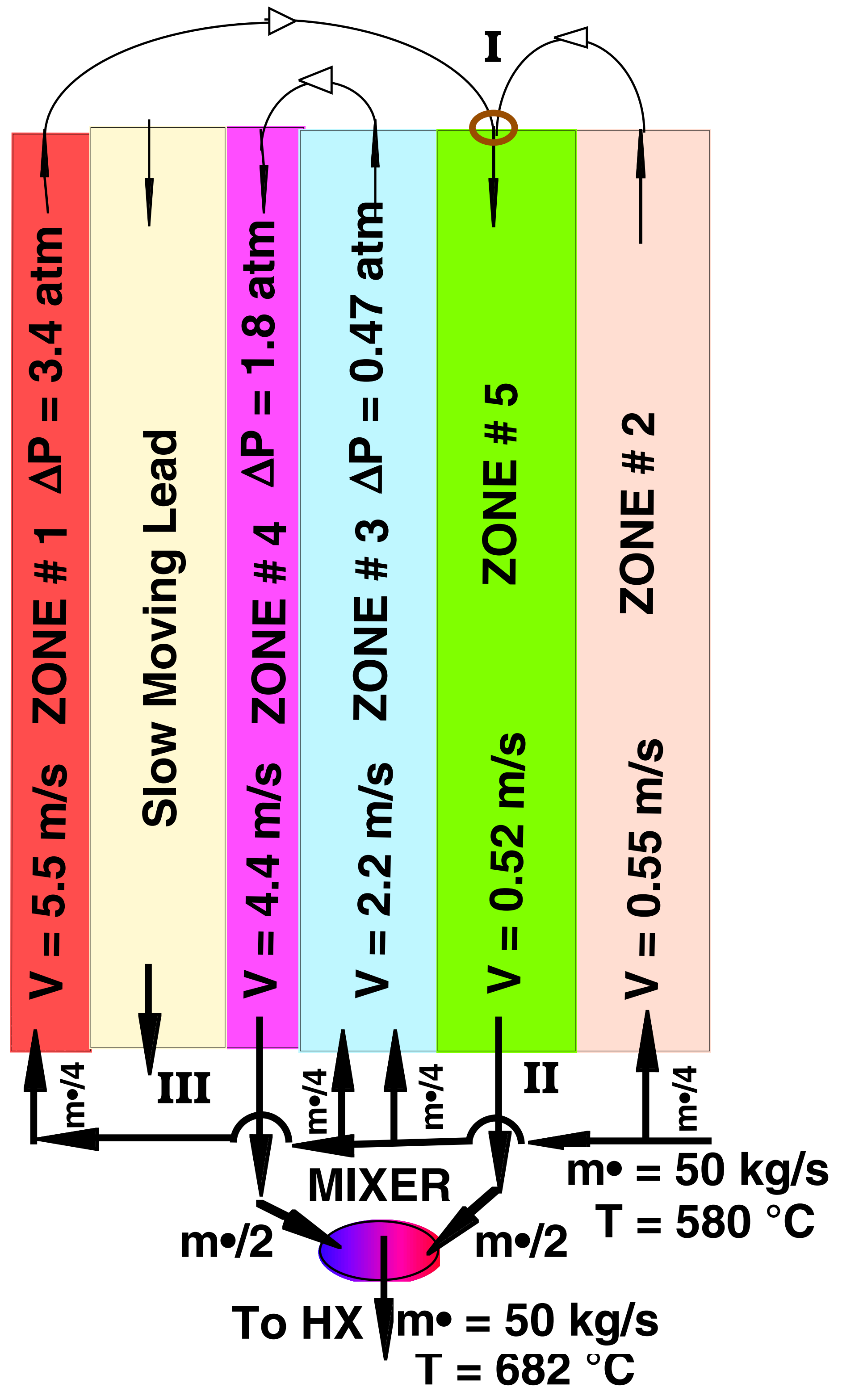




Routing scheme for the helical blanket

Parameters of different zones

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Coolant channel width, (cm)	0.4	4.0	1.0	1.0	19
Coolant speed, (m/s)	5.5	0.55	2.2	4.4	0.26
Heat transfer coefficient, (W/m^{2}K)	12,400	--	--	9,100	1,030
Temperature rise, (°C)		Total of 60		20	63
Exit temperature at the top = 640 (°C)					
Outlet temperature at the bottom, (°C)	--	--	--	660	703
Outlet temperature of the mixer = 681.5 (°C)					
Pressure drop. (atm)	3.4	small	0.47	1.8	small
Coolant direction	up	up	up	down	down



Parameters and flow direction in the optimized module.

CONCLUSIONS

One round through coolant loop gives the shortest coolant loop length (one upward and one downward) resulted in reducing the frictional pressure drop. The coolant channels are tailored in order to insure adequate cooling where it is seriously needed. The coolant speed is fast at the FW channel where it is needed and slow in the back coolant channels where it is not needed and that also contributes to the pressure frictional loss reduction. There is a simplicity in manufacturing a double-flat-straight wall with helical guide blades. The helical coolant scheme insures a homogenous temperature distribution across the entire blanket cross section. The temperature homogeneity would eliminate/reduce the thermal stresses. All the design guidelines for temperatures are satisfied. However, the temperature at lead/steel interface could reach more than 700°C, which is a concern. Two thinner lead layers (2 cm thick each) could be used and a FLIBE channel in between them would insure that the lead/steel interface temperature would be less than 700°C.