Heat removal and pressure losses in the Helium cooling circuit for the rotating target concept of ESS

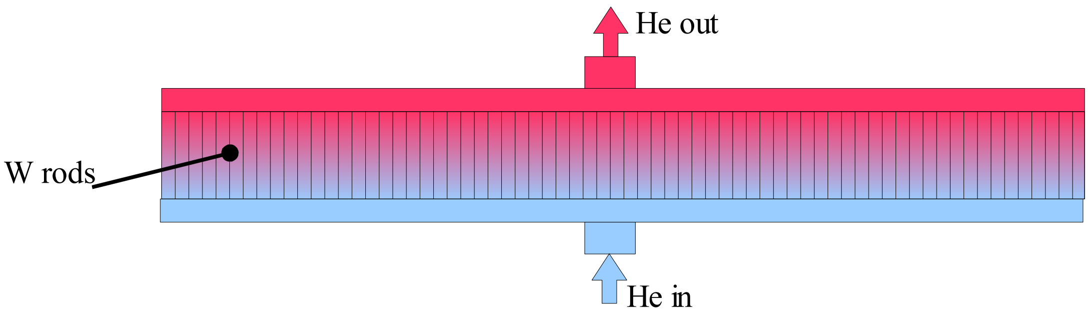
L. Massidda,

CRS4, Centre for Advanced Studies, Research and Development in Sardinia

August 26th 2010
Version 2.0

1 The problem

The scope of the document is to calculate the basic performance of the cooling system of a solid tungsten target for ESS.
The system is a rotating target of 10 cm long, 20 mm diameter vertical tungsten rods in hexagonal arrangement (i.e. the channels between rods represent about 10 % of the cross section). The rods constitute a horizontal target ring of 150 cm external and 50 cm internal diameter (and 10 cm height = length of the vertical rods), which rotates with 30 RPM. Helium is blown over the total surface. from below for cooling 3 MW heat deposition by the beam hitting at one position, perpendicularly to the outer surface of the target ring.
We want to address the pressure drop and the temperature rise in the He cooling system.



The cold He is first contained in a high pressure and low temperature chamber below the rods, flows through a reduced section and cools down the rods, and is collected in a low pressure, high temperature chamber above the target.

2 Heat removal

The total cross section of the target, on an horizontal plane is 1.57m^2, and as mentioned fraction of this section open to flow is 10% of the total.
The number of rods is 4500, the cross section of the "channel" between the rods is S_c = 0.16m^2.
The wet perimeter of the rods may be calculated as:

$$p_w = n_{rods} \cdot \pi \, d_{rod}$$

resulting in 282.7m, and the wet surface is calculated as:

$$S_w = n_{rods} \cdot \pi \, d_{rod} \, l_{rod}$$

and results 28.27m^2.
The hydraulic diameter of the channel is thus:

$$d_h = \frac{4 S_c}{p_w}$$

and is equal to 2.2mm.

We examine three cases with different mass flow and pressure of the helium. The properties are taken from the NIST database and are summarized in the following table.

Property	**Case 1**	**Case 2**	**Case 3**
Pressure	10 bar	20 bar	10 bar
Temperature	500 K	500 K	500 K
Density	0.96 kg/m3	1.92 kg/m3	0.96 kg/m3
Specific heat	5193 J/kgK	5193 J/kgK	5193 J/kgK
Dynamic viscosity	2.85e-5 Pa s	2.85e-5 Pa s	2.85e-5 Pa s
Thermal conductivity	0.22 W/mK	0.22 W/mK	0.22 W/mK
Mass flow rate	20 kg/m3	6 kg/m3	6 kg/m3
Velocity in channel	132 m/s	19.8 m/s	39.7 m/s
Reynolds number	9930	2980	2980

The velocity in the channel is calculated as:

$$v_c = \frac{\dot{m}_{He}}{\rho S_c}$$

and the Reynolds number is:

$$\mathrm{Re} = \frac{\rho v_c d_h}{\mu}$$

The Prandtl number results: Pr = 0.67, constant for the gas.
The nusselt number is calculated using Dittus Boelter correlation for turbulent flow, as is assumed for the Case 1 with Re = 10000

$$Nu = 0.023\,\mathrm{Re}^{0.8}\,Pr^{0.4}$$

If the flow is laminar Nu may be considered constant and a value of 4.36 is taken as suggested in Incropera and DeWitt. Cases 2 and 3 are considered laminar.
The heat transfer coefficient on the rod surface is calculated as:

$$h = \frac{Nu\,k}{d_h}$$

It is possible to calculate the temperature increase in the Helimu flow as it passes through the channel with the rods to cool them down:

$$\Delta T_{He} = \frac{Q}{\dot{m}_{He} c_p}$$

Where Q is the power to be extracted equal to 3MW, and it is possible to calculate also the mean temperature difference between the fluid flow and the rod surface and the fluid flow to with the heat exchange coeffcient previuosly calculated and have therefore an idea of the temperature reached by the rods.

$$\Delta T_S = \frac{Q}{h S_w}$$

The results are summarized in the following table for the cases examined.

Property	Case 1	Case 2	Case 2
Nusselt number	31	4.36	4.36
Heat exc. coeff.	3062 W/m2K	432 W/m2K	432 W/m2K
DT in the flow	28.9 K	96.3 K	96.3 K
DT between surface and flow	34.7 K	246 K	246 K

3 Pressure losses

It is also possible to have an estimation of the pressure losses in the target.
The pressure losses are found at the inlet, and at the outlet where the kinetic component of pressure is dissipated and along the channel.
The concentrated losses at the inlet and at the outlet are:

$$\Delta P = 1 \cdot \rho \frac{v^2}{2}$$

The pressure losses along the channel are calculated with the Darcy formula:

$$\Delta P = f \frac{l}{d_h} \rho \frac{v^2}{2}$$

and the friction factor f is taken from the Moody diagram and is 0.032 for case 1 and 0.021 for cases 2 and 3.
The total pressure loss results to be lower than 0.3 bar for case 1, and 0.01 bar for case 2 and 0.02 bar for case 3, almost negligible in the all the cases.