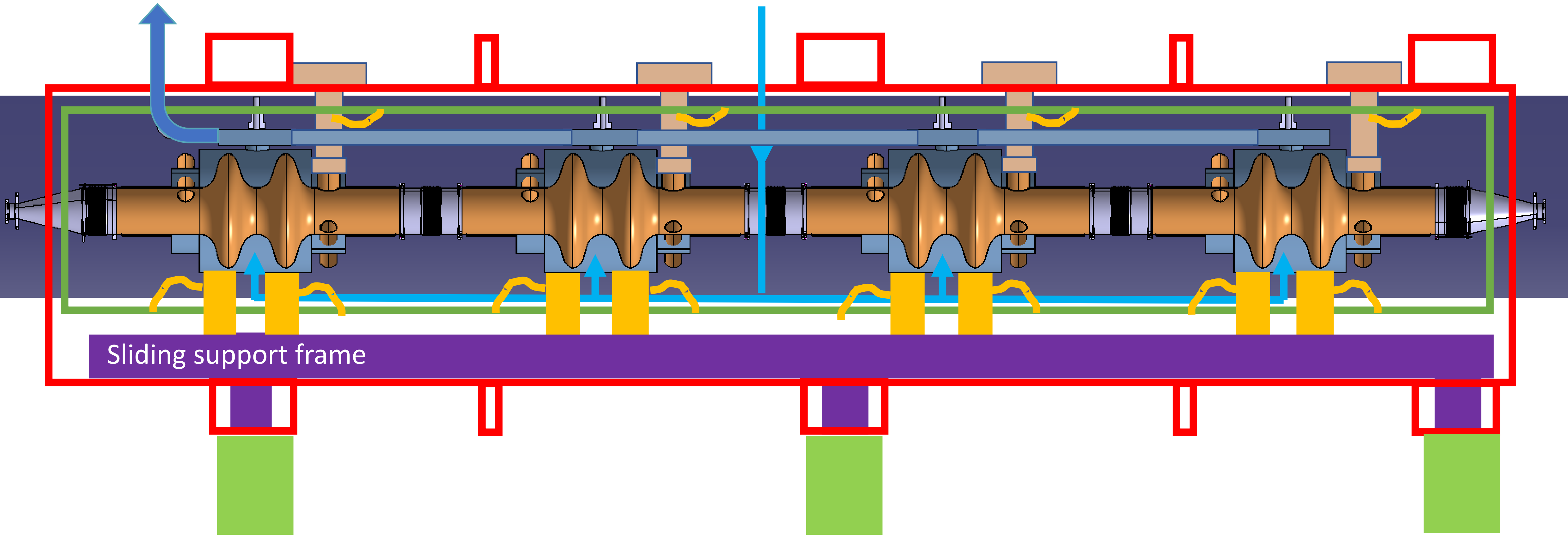
«COOLEST TEAM»

CRYOSTAT DESIGN


Sliding support frame

Item	Description	Value	Comments
1 a.	Helium tank thickness	15 mm	Thickness should be reduced by adding stiffener rings
1 b.	Vacuum vessel material Vacuum vessel diameter Vacuum vessel thickness	304L Ø1600 mm 15mm	 Must add stiffener rings
1 c.	Thermal shield material Thermal shield diameter Thermal shield thickness	AW 1050 Ø1100 mm 5 mm	 Add MLI 30 layers
1 d.	Support Support diameter Support thickness Support material	3 posts per cavity (1 fixed + 2 sliding) Ø100 mm 4 mm G11	
1 e.			

Helium tank :

Pressure

$$\frac{pr}{t} \leq \sigma_a$$

P = 4 bar, r = 400 mm, stainless steel 316L, Rp0.2% = 190 Mpa, Practical value = 120 Mpa.
t = 2mm

Buckling

- If we use a safety factor of 3:

$$\frac{t}{r} \geq 3.7\%$$

t = 15 mm Option : thinner + stiffeners

Vacuum tank :

stainless steel 316L, diameter = 1600 mm

Buckling

- If we use a safety factor of 3:

$$\frac{t}{r} \geq 3.7\%$$

t = 15 mm + stiffeners

Thermal shield:

Aluminium Al1050, diameter = 1100 mm, thickness 5 mm + stiffeners, MLI 30 layers

Assembling:

In clean room class ISO4

1- Cavity sub-assembly : Helium tank + cavity + couplers.
2- Support frame as assembling support + adjusting supports
3- Assemble cavity sub-assemblies on support frame (independently)
4- Connect cavities together.

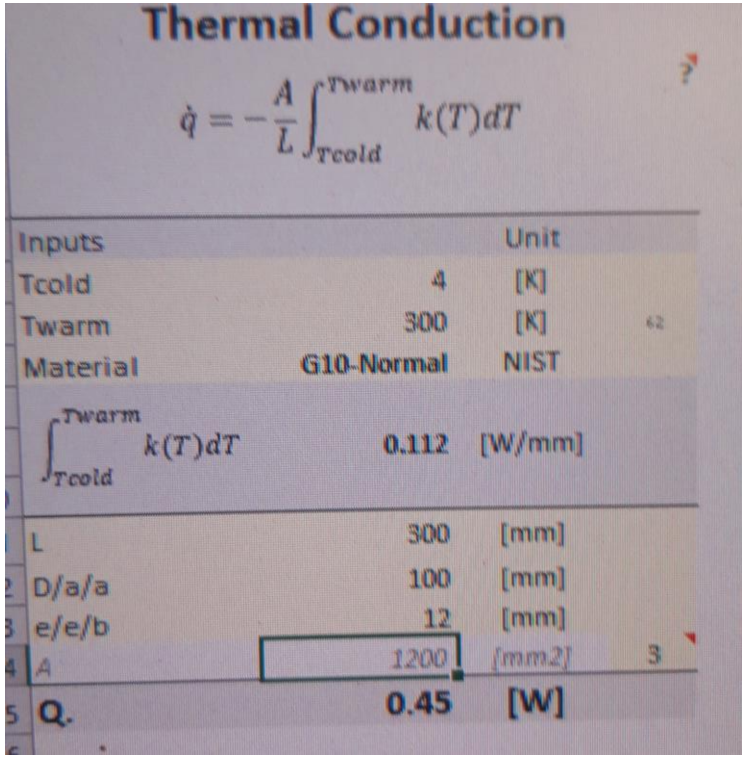
Out of clean room

5- Weld cryolines.
6- Assemble thermal screen + thermalization + MLI
7- Slide the assembly inside the vacuum vessel.
8 – Connect warm feet
9 – Connect couplers
10 – Connect cryo lines
11- Close end caps.

Cold feet:

- 3 posts by cavity (adjustable)
- 1 fixed post + 2 sliding posts
- Diameter=100mm, length=300mm, t=4mm, A=1200mm2
- G11

Thermal conduction = 0.45W per post, 1.35 W per cavity, 5.4 W total



Thermal Conduction

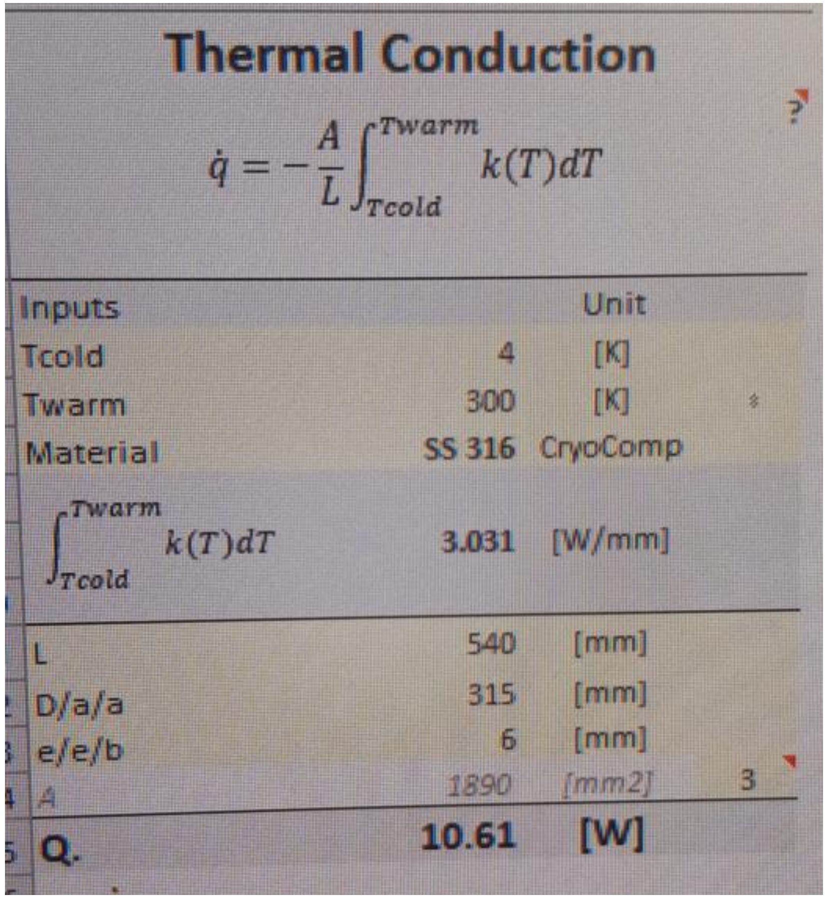
$$\dot{q} = -\frac{A}{L}\int_{Tcold}^{Twarm} k(T)dT$$

Inputs		Unit
Tcold	4	[K]
Twarm	300	[K]
Material	G10-Normal	NIST
$\int_{Tcold}^{Twarm} k(T)dT$	0.112	[W/mm]
L	300	[mm]
D/a/a	100	[mm]
e/e/b	12	[mm]
A	1200	[mm2]
Q.	0.45	[W]

Beam tube cone:

- Dmax=300mm, length=540mm, t=1mm, A=1890mm2
- Stainless steel 304L

Thermal conduction = 11W per cone, 22W total



Thermal Conduction

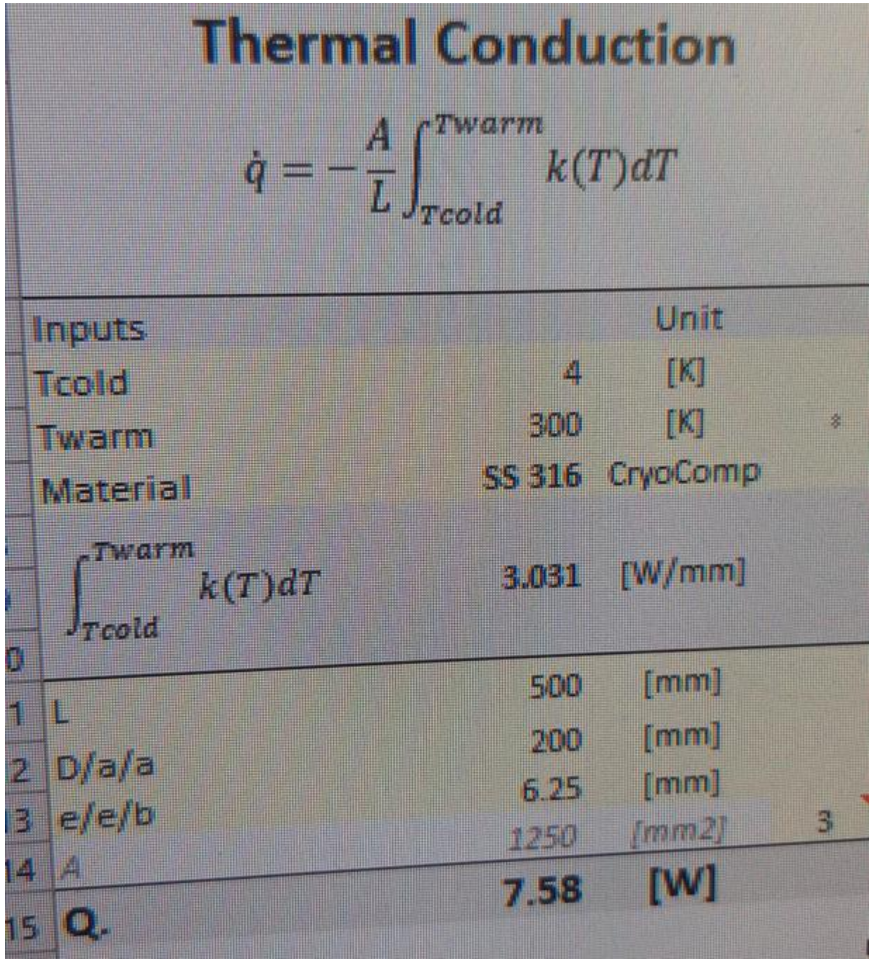
$$\dot{q} = -\frac{A}{L}\int_{Tcold}^{Twarm} k(T)dT$$

Inputs		Unit
Tcold	4	[K]
Twarm	300	[K]
Material	SS 316	CryoComp
$\int_{Tcold}^{Twarm} k(T)dT$	3.031	[W/mm]
L	540	[mm]
D/a/a	315	[mm]
e/e/b	6	[mm]
A	1890	[mm2]
Q.	10.61	[W]

Coupler:

- Dmax=200mm, length=500mm, t=2mm, A=1250mm2
- Stainless steel 304L

Thermal conduction = 7.6W per cone, 30.4W total



Thermal Conduction

$$\dot{q} = -\frac{A}{L}\int_{Tcold}^{Twarm} k(T)dT$$

Inputs		Unit
Tcold	4	[K]
Twarm	300	[K]
Material	SS 316	CryoComp
$\int_{Tcold}^{Twarm} k(T)dT$	3.031	[W/mm]
L	500	[mm]
D/a/a	200	[mm]
e/e/b	6.25	[mm]
A	1250	[mm2]
Q.	**7.58**	**[W]**

Radiation, with TS @ 50K:

- Cavity, D=800mm, L=800 : Cold surface = 2,9 m2, 4 cavities = 11.6 m2
- Tube total, D=300, L=6780 : Cold surface = 6.4 m2
- Cryo lines, D=50mm, L=7000 : Cold surface = 1.1 m2
- Couplers, D=200mm, L=500 : Cold surface = 0.3 m2, 4 couplers= 1.2 m2
- Cold feet D=100, L=300 : Cold surface = 0.1 m2, 12 feet = 1,2 m2.

- Total cold surface = 21,5 m2
- Thermal shield internal surface = 34.4 m2

Heat load from WV to TS :
74W with 30 layers of MLI
2290W without MLI

Heat load from TS to CS :
0.42W with 30 layers of MLI
0.42W without MLI

Thermal Radiation with intermediate thermal shield with MLI (*)

$$q_{w-sh} = \frac{\sigma\, Aav(T_{warm}^4 - T_{sh}^4)}{(N+1)\left(\frac{2}{\varepsilon_{av\,sh}} - 1\right)} \qquad q_{sh-c} = \frac{\sigma(T_{sh}^4 - T_{cold}^4)}{\frac{1-\varepsilon_{sh}}{\varepsilon_{sh}A_{sh}} + \frac{1}{A_{sh}F_{shc}} + \frac{1-\varepsilon_c}{\varepsilon_c A_c}} \qquad q_{sh} = q_{w-sh} - q_{w-sh}$$

Inputs		Unit	Comment
Tcold	4.2	[K]	
Twarm	293	[K]	
Tsh	50	[K]	
Ac	21.5	[m2]	
Aw	54.3	[m2]	
Ash	34.4	[m2]	
F_{shc}	0.63		
σ	5.67E-08	[W/m2.K4]	
εcold	0.08		
εwarm	0.34		
εsh	0.1		
No MLI layers on thermal shield	30		
εav sh	0.22		average between shield and warm vessel
Aav	44.35		average between shield and warm vessel
q_{w-sh}	**73.83**	[W]	heat load from warm vessel to thermal shield
q_{sh-c}	**0.4203**	[W]	heat load from thermal shield to cold surface
q_{sh}	**73.41**	[W]	thermal shield cooling power (from energy conservation)

* this formulation is conservative (x1.5 wrt MLI sample data) at the thermal shield for geometry ratios and temperature ranges close to those of the LHC cryostats. Between thermal shield and cold surface (without MLI) it strongly depends on Tsh, and depends on emissivities.

Thermal Radiation with intermediate thermal shield with MLI (*)

$$q_{w-sh} = \frac{\sigma\, Aav(T_{warm}^4 - T_{sh}^4)}{(N+1)\left(\frac{2}{\varepsilon_{av\,sh}} - 1\right)} \qquad q_{sh-c} = \frac{\sigma(T_{sh}^4 - T_{cold}^4)}{\frac{1-\varepsilon_{sh}}{\varepsilon_{sh}A_{sh}} + \frac{1}{A_{sh}F_{shc}} + \frac{1-\varepsilon_c}{\varepsilon_c A_c}} \qquad q_{sh} = q_{w-sh} - q_{w-sh}$$

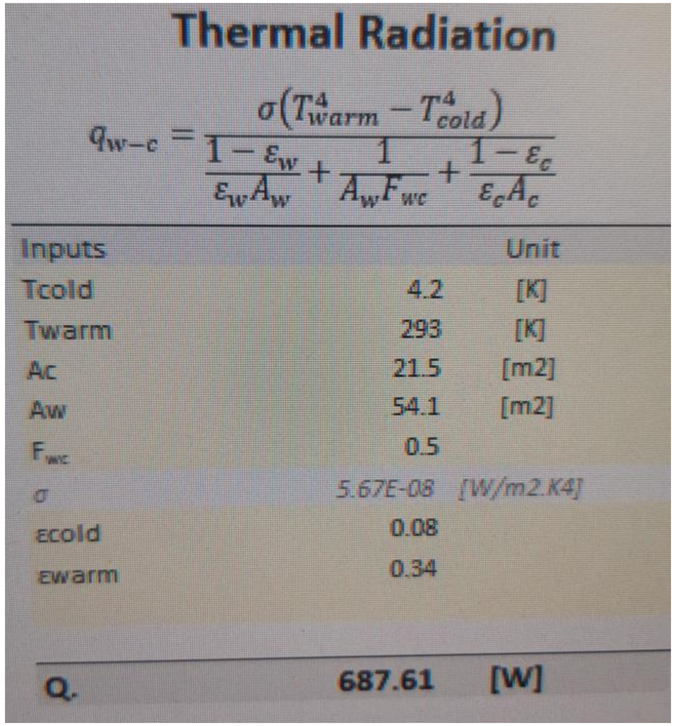
Inputs		Unit	Comment
Tcold	4.2	[K]	
Twarm	293	[K]	
Tsh	50	[K]	
Ac	21.5	[m2]	
Aw	54.3	[m2]	
Ash	34.4	[m2]	
F_{shc}	0.63		
σ	5.67E-08	[W/m2.K4]	
εcold	0.08		
εwarm	0.34		
εsh	0.1		
No MLI layers on thermal shield	0		
εav sh	0.22		average between shield and warm vessel
Aav	44.35		average between shield and warm vessel
q_{w-sh}	**2288.66**	[W]	heat load from warm vessel to thermal shield
q_{sh-c}	**0.4203**	[W]	heat load from thermal shield to cold surface
q_{sh}	**2288.24**	[W]	thermal shield cooling power (from energy conservation)

* this formulation is conservative (x1.5 wrt MLI sample data) at the thermal shield for geometry ratios and temperature ranges close to those of the LHC cryostats. Between thermal shield and cold surface (without MLI) it strongly depends on Tsh, and depends on emissivities.

Radiation, without TS :

- Cavity, D=800mm, L=800 : Cold surface = 2,9 m2, 4 cavities = 11.6 m2
- Tube total, D=300, L=6780 : Cold surface = 6.4 m2
- Cryo lines, D=50mm, L=7000 : Cold surface = 1.1 m2
- Couplers, D=200mm, L=500 : Cold surface = 0.3 m2, 4 couplers= 1.2 m2
- Cold feet D=100, L=300 : Cold surface = 0.1 m2, 12 feet = 1,2 m2.

- Total cold surface = 21,5 m2
- Vacuum vessel internal surface = 54.1 m2



Thermal Radiation

$$q_{w-c} = \frac{\sigma(T_{warm}^4 - T_{cold}^4)}{\frac{1-\varepsilon_w}{\varepsilon_w A_w} + \frac{1}{A_w F_{wc}} + \frac{1-\varepsilon_c}{\varepsilon_c A_c}}$$

Inputs		Unit
Tcold	4.2	[K]
Twarm	293	[K]
Ac	21.5	[m2]
Aw	54.1	[m2]
F_{wc}	0.5	
σ	5.67E-08	[W/m2.K4]
εcold	0.08	
εwarm	0.34	
Q.	687.61	[W]

Heat load from WV to CS = 688W

TS mass flow:

$$\dot{q} = \Delta H = \dot{m} \cdot cp \cdot (T_{out} - T_{in})$$

q=70W
Cp=5.3^{E}3
Tout = 55K
Tin = 50K

m = 2.6 g/s

AVAILABLE FLUIDS

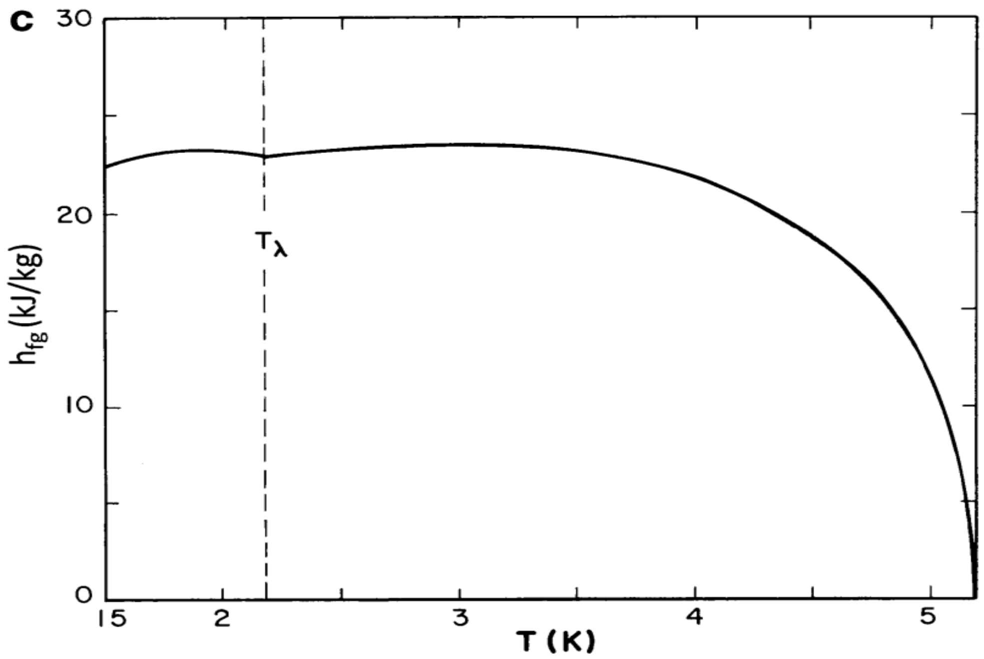
Input	Unit	Helium (Hepak)	Helium (REFPROP)	Nitrogen	Argon
T	[K]	50	45	100	100
P	[bara]	15	1.5	1.5	1.5
ρ	[kg/m3]	1.4E+01	1.6E+00	5.2E+00	7.5E+00
Cp	[J/kg/K]	5.3E+03	5.2E+03	1.1E+03	5.6E+02
μ	[Pa.s]	6.6E-06	6.0E-06	7.0E-06	8.3E-06
k	[W/m/K]	4.9E-02	4.4E-02	9.4E-03	6.5E-03

4.2K liquid boil-off:

$$\dot{q} = \dot{m} \cdot Lv$$

q=57.42W
Lv=20 KJ/kg = 20 J/g

m = 2.9 g/s



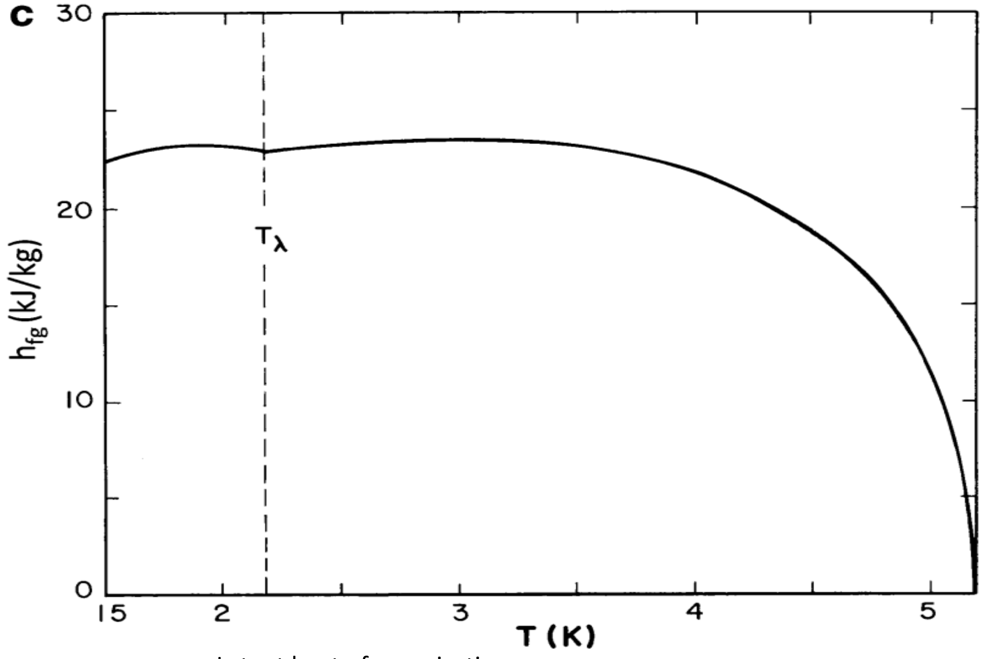
Latent heat of vaporization

Liquefaction load:

$$\dot{q} = \dot{m} \cdot Lv$$

Per coupler q=30.4/4/7 = 0.26W
Total = 1.1 W

m = 0.055 g/s



Latent heat of vaporization

Task 1.2. Table of Static Heat Loads and mass flows

Source of HL	HL (W) @ 4.2 K	HL (W) @ 50 K	4.2 K liquid boil-off (g/s)	Liquefaction load (g/s)	Thermal shield mass flow (g/s) (with T_{in}=50K, T_{out}=55 K)
Supports conduction	5.4	-		-	-
Beam tube cones conduction	21.2	-		-	-
RF Couplers conduction (uncooled)	30.4 / -	-		-	-
RF Couplers conduction (ideal vapor cooling)	- / 1.1				
Radiation, with thermal shield @ 50 K (+ MLI 30 layers)	0.42	2290 (74)		-	2.6
Radiation, without thermal shield	688	-		-	-
Radiation from beam tube cones	Included in CM	-		-	-
Totals	**57.42 (745)**	**2290 (74)**	**2.9**	**0.055**	**2.6**