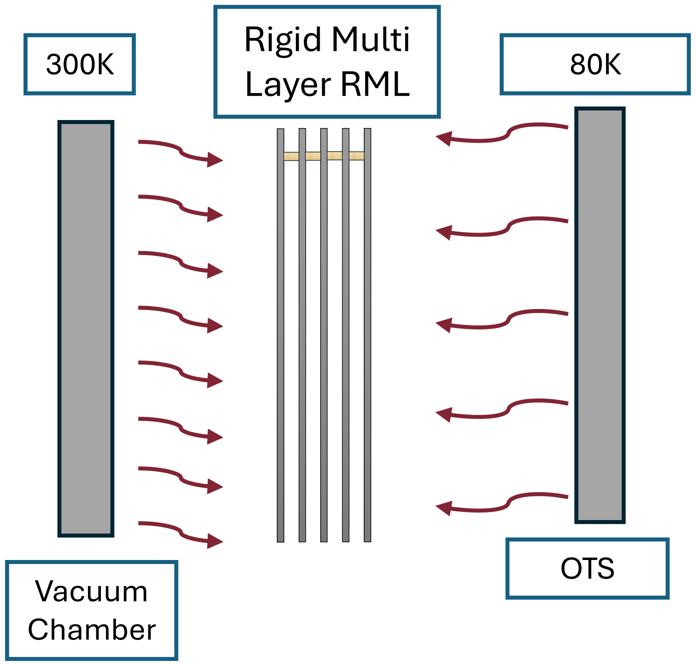
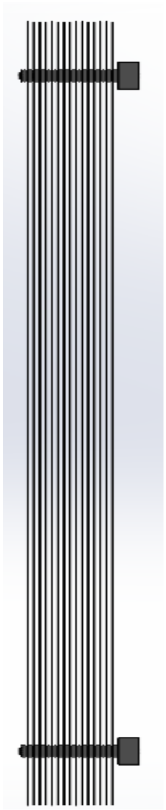
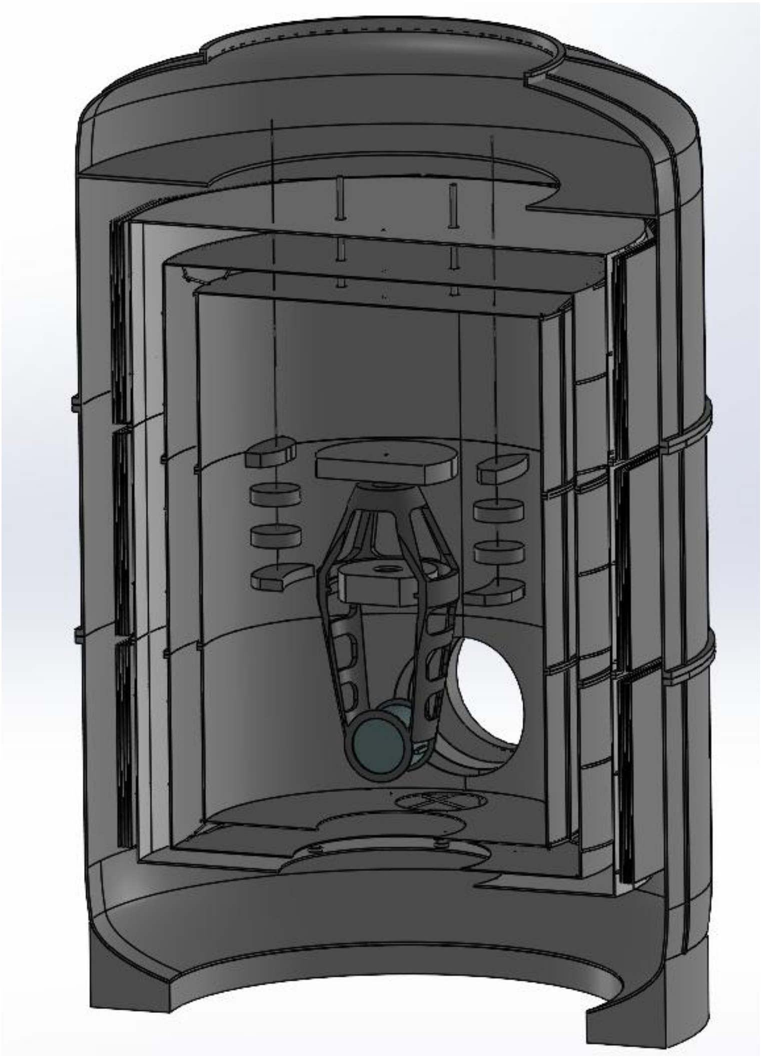
Preliminary Cooling Model of OTS and ITS with Helium

- The cooling down for both of shield is done with a MATLAB code
- The Helium is used in vapour phase for OTS and supercritical phase for ITS
- The cooling down is made by a elicoil serpentine (half pipe)
- The phisycal properties of helium is considered constant (TIME & TEMPERATURE)

The Thermal Radiation on OTS



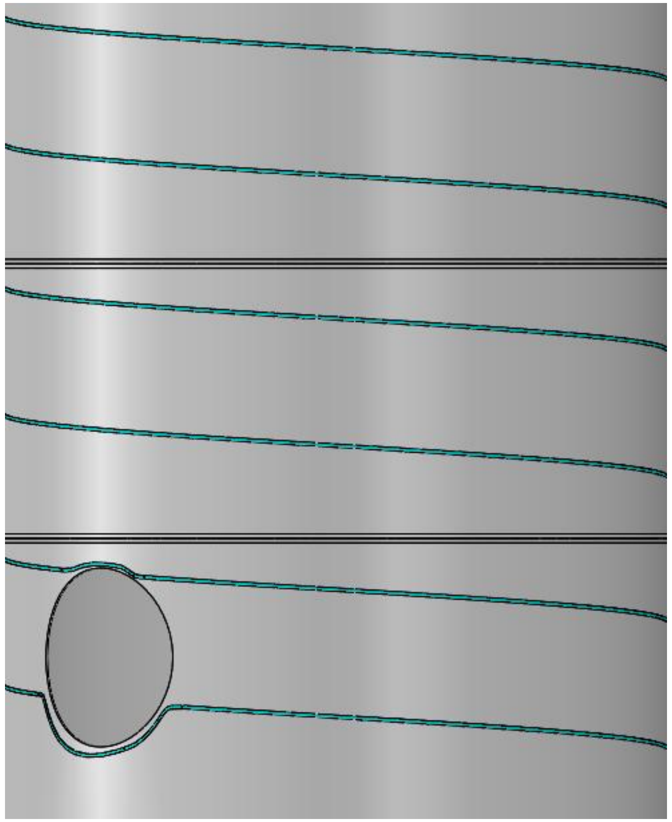




With the RML solution we expect to have a radiation value of 2 W/m^2 on the OTS shield

OTS – Geometry Data

Geometry Input Data OTS	
D_{OTS} (m)	2
H_{OTS} (m)	4.6
Th_{OTS} (m)	0.006
A_{OTS} (m^2)	108
V_{OTS} (m^3)	0.34



Geometry Input Data Helical coil (half pipe)	
D_{tube} (m)	0.025
$D_{half\text{-}Pipe}$ (m)	0.015
$H_{helical\ coil}$ (m)	4.6
Th_{tube} (m)	0.002
Coil Pitch (m)	0.76
Number of turns	6
$L_{helical\ coil}$ (m)	76
$A_{helical\ coil}$ (m)	3.64

OTS – Physical Helium Data

PRESSURE = 0.101325 [MPa]

TEMP [K]	DENSITY [kg/m³]	PV/RT [-]	ENERGY [J/g]	ENTHALPY [J/g]	ENTROPY [J/g·K]	C_v [J/g·K]	C_p [J/g·K]	VSOUND [m/s]
40.00	1.216	1.003	139.7	223.0	21.12	3.119	5.206	373.4
50.00	0.9732	1.002	170.9	275.0	22.28	3.118	5.201	417.3

PRESSURE = 0.101325 [MPa]

TEMP [K]	$\left(\frac{T}{V}\frac{\partial V}{\partial T}\right)_P$	$\left(\frac{V}{C_v}\frac{\partial P}{\partial T}\right)_V$	$\left(\frac{P}{\rho}\frac{\partial \rho}{\partial P}\right)_T$	DIEL - 1	CONDUCT [W/m·K]	VISC [μPa·s]	THDIFF [m²/s]	PRANDTL
40.00	0.9998	0.6694	0.9974	0.4716E-03	0.4045E-01	5.542	0.6387E-05	0.7134
50.00	0.9989	0.6687	0.9975	0.3773E-03	0.4668E-01	6.360	0.9223E-05	0.7087

References: *'NIST – National Institute Standard Technology'*
Book Title: *'Thermophysical Properties of Helium-4 from 0.8 to 1500 K with Pressures to 2000 Mpa'*
Author: *'Vincent D. Arp, Robert D. McCarty ,Daniel G. Friend'*

OTS – The Thermal Model – Transient Simulation (time)

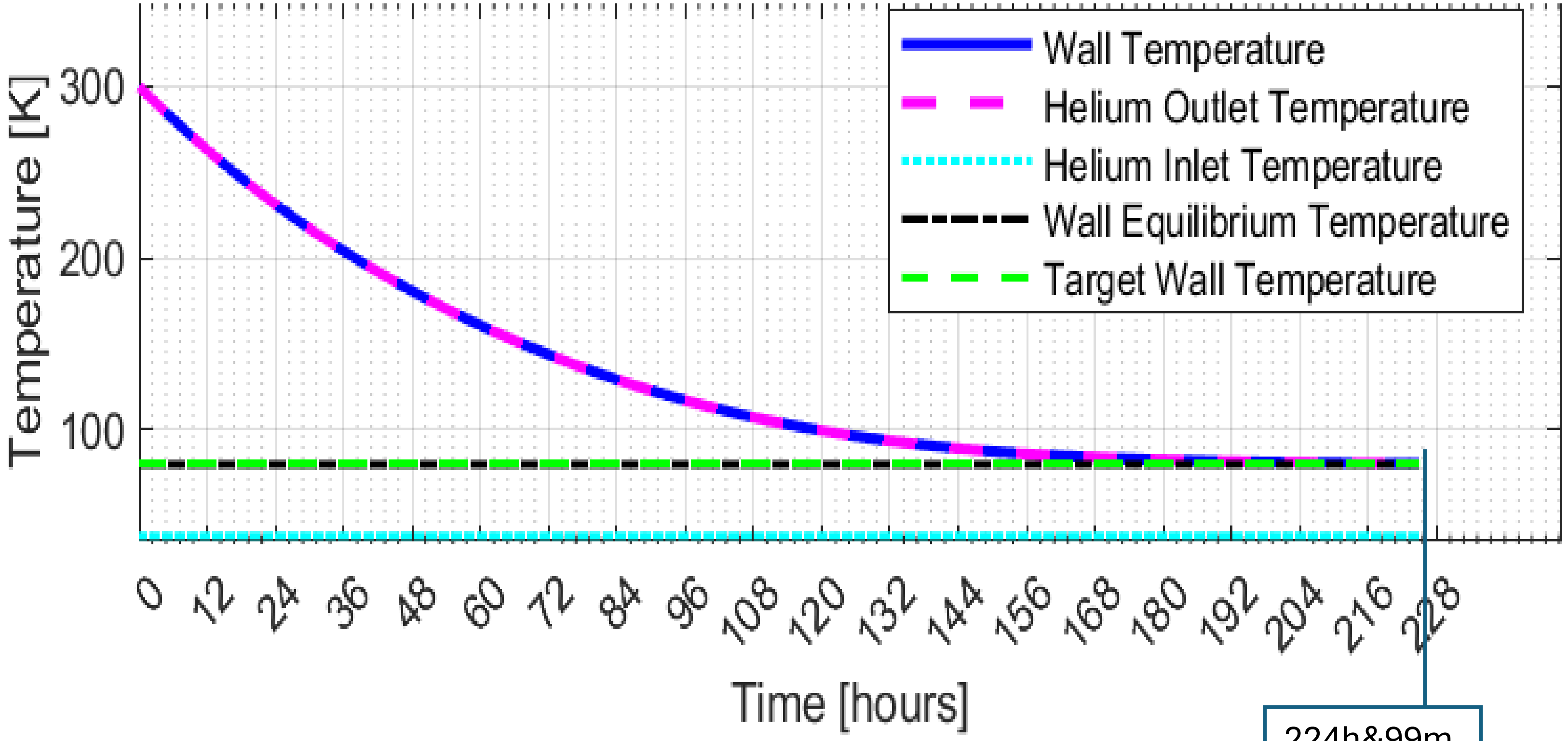
1- Global Balance

$$\mathrm{m_{OTS}} * c_{p,OTS}(T) * \frac{dT_{OTS}(t)}{dt} = Q_r - Q_{conv}(t)$$

2- Helium Balance

$$\dot{m}_{He} * c_p^{He} * \left(T_{out}^{He} - T_{in}^{He}\right) = \mathrm{U} * A_0 * \Delta T_{ML}$$

Simulation Data	
Flowrate (kg/s)	0.001
$T_{He,in}$ **(K)**	**38**
$\mathbf{Q_r(W)}$	**216**
v (m/s)	3.35
Re	11234
Pr	0.71
Nu	36.2
U(W/m2 K)	95.8
ΔP(mbar)	124

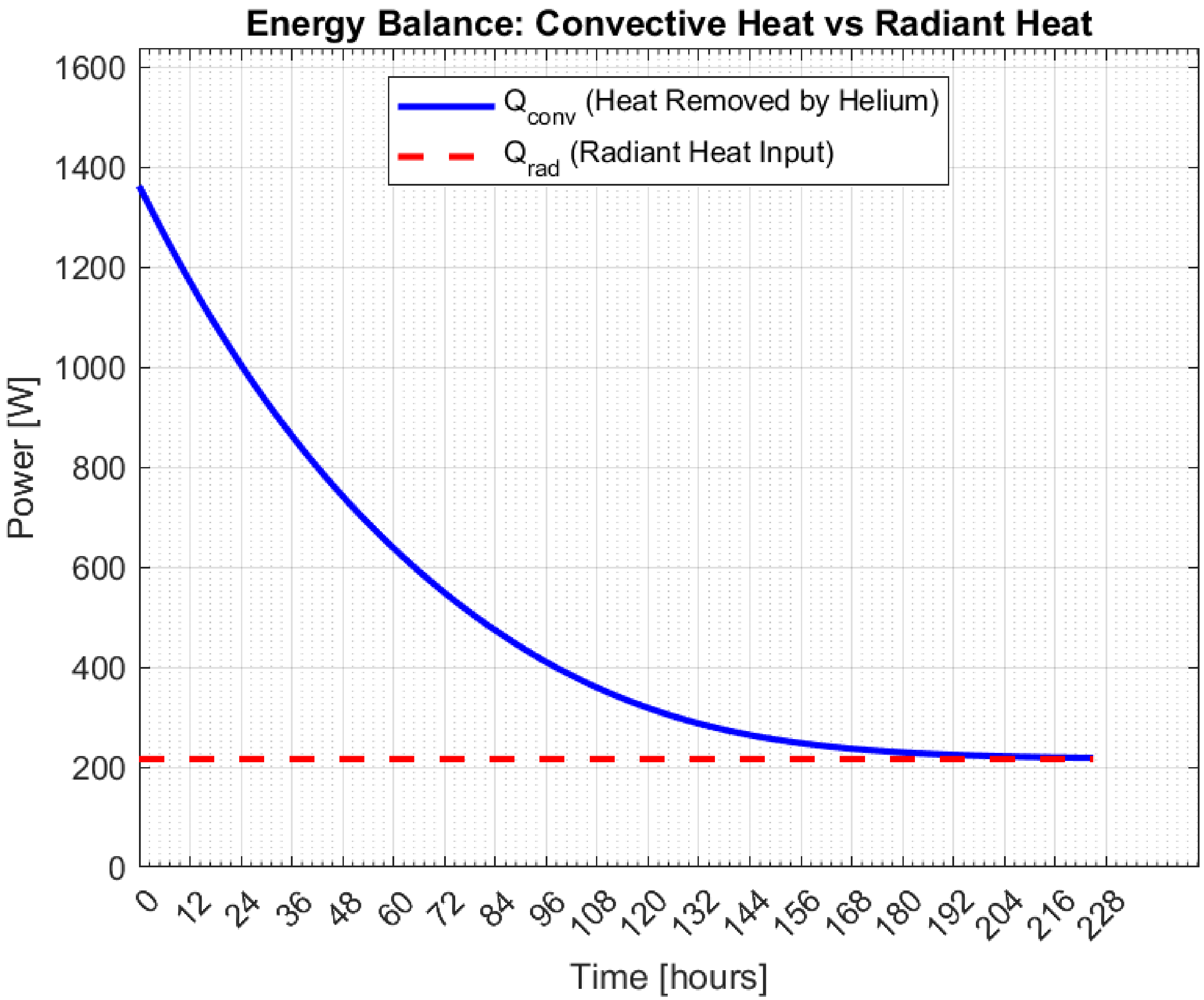


224h&99m

9 days,8 hours,59 minutes

The target temperature reached for the OTS shield is 79.59 K

OTS – The Thermal Model – Energy Balance: Q_{conv} vs Q_{rad}



Let's assume that the radiation heat transfer involves the 100% of the OTS surface and that its emissivity is $\epsilon = 0.1$

OTS – The Thermal Model – Transient Simulation (1D Model)

1- 1D Model

$$F * c_{p,He} * T_x - Q * \pi * D_{halfpipe} * \Delta x = F * c_{p,He} * T_{x+\Delta x}$$

Where $Q = U * A_{OTS} * (T_{OTS} - T(x)_{He})$

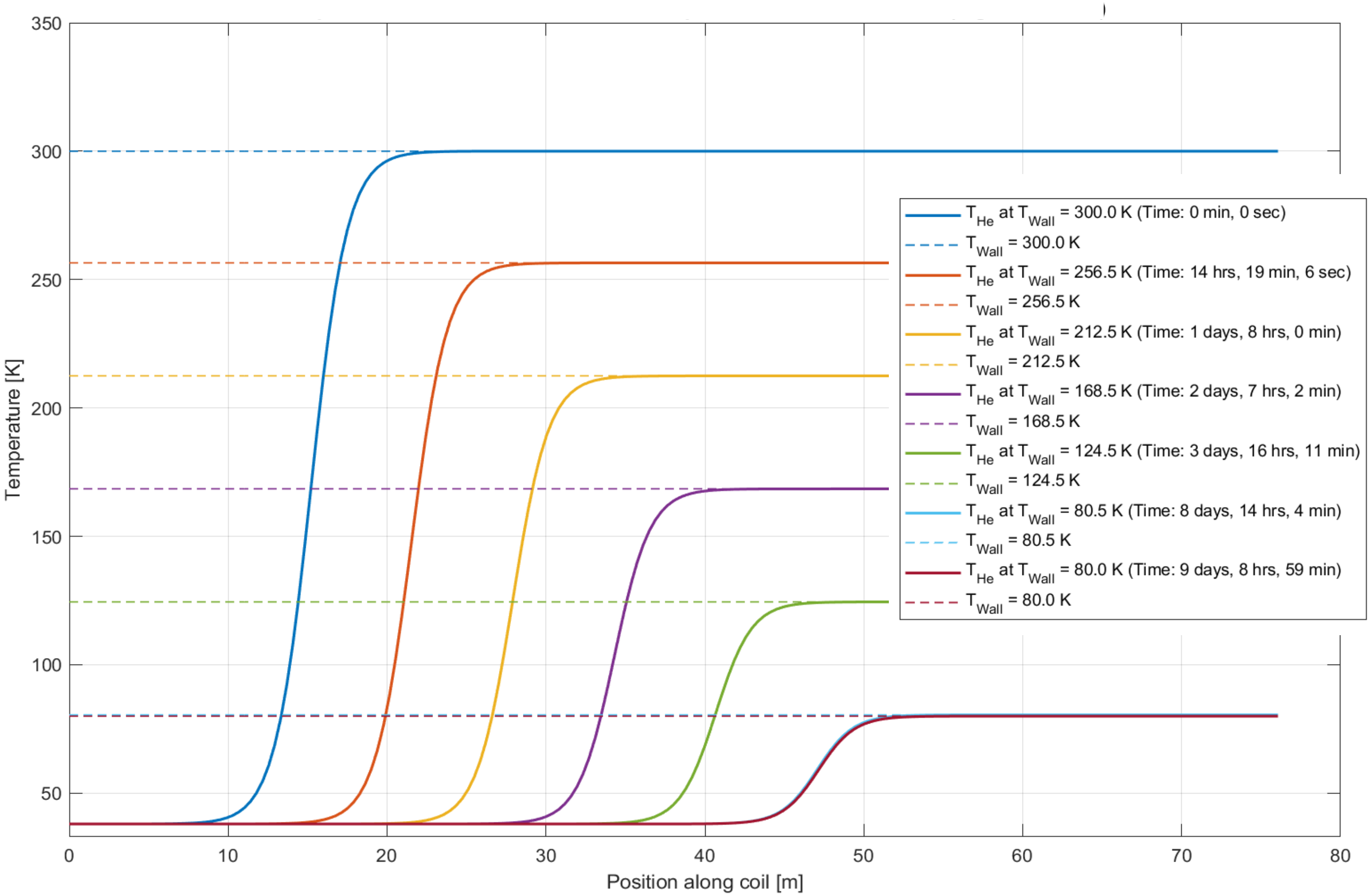
2- 1D Model solution

$$T(x)_{He} = T_{OTS} + (T_{He}^{in} - T_{OTS}) * e^{-\alpha*(x-x_0)}$$

Where $\alpha = \frac{U*\pi*D_{halfpipe}}{F*c_{p,He}}$

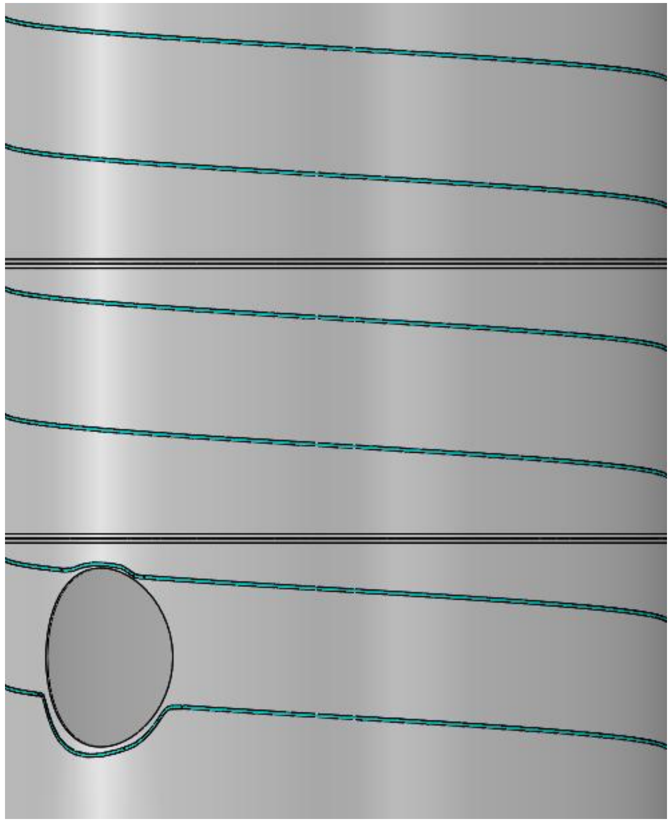
To perform the graph the equation is used how a sigmoid model

$$T(x)_{He} = T_{in,He} + \frac{T_{OTS} - T_{in,He}}{1 + e^{-k_{param}*(x - x_{inflection})}}$$



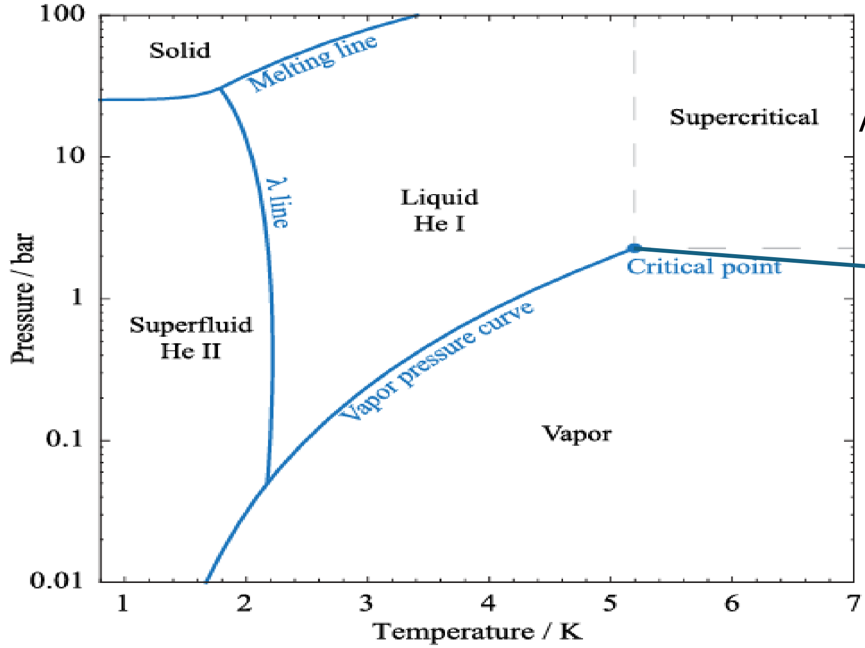
ITS – Geometry Data

Geometry Input Data OTS	
D_{ITS} (m)	1.8
H_{ITS} (m)	4.2
$Thik_{ITS}$ (m)	0.006
A_{ITS} (m^2)	63
V_{ITS} (m^3)	0.28



Geometry Input Data Sepente (half pipe)	
D_{tube}(m)	0.025
$D_{half\text{-}Pipe}$(m)	0.015
$H_{helical\ coil}$(m)	4.2
$H_{helical\ coil}$ (m)	0.002
Coil Pitch (m)	0.70
Number of turns	6
$L_{helical\ coil}$ (m)	68
$L_{helical\ coil}$ (m^2)	3.25

ITS – Physical Helium Data



References: ‘Cryogenic payloads for the Einstein Telescope: Baseline design with heat extraction, suspension thermal noise modeling, and sensitivity analyses’
Author: ‘Xhesika Koroveshi , Lennard Busch , Ettore Majorana , Paola Puppo , Piero Rapagnani ,3,4 Fulvio Ricci , Paolo Ruggi and Steffen Grohmann ’

In this incipient point:
T_c=5.19 K P_c= 2.27bar(0.227 Mpa)

PRESSURE = 0.230 [MPa]

TEMP [K]	DENSITY [kg/m^3]	PV/RT [-]	ENERGY [J/g]	ENTHALPY [J/g]	ENTROPY [J/g·K]	C_v [J/g·K]	C_p [J/g·K]	VSOUND [m/s]
5.300	43.45	0.4808	23.15	28.44	7.001	3.022	27.33	107.5

PRESSURE = 0.230 [MPa]

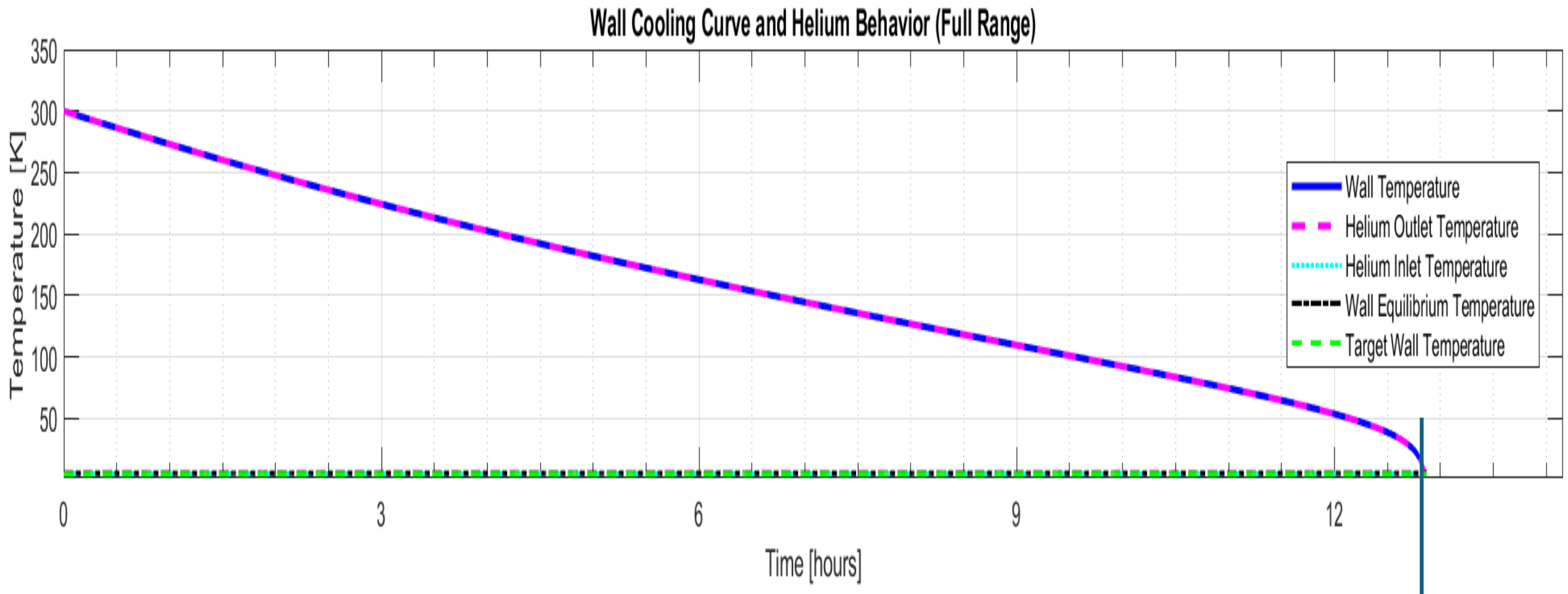
TEMP [K]	$\left(\frac{T}{V}\frac{\partial V}{\partial T}\right)_P$	$\left(\frac{V}{C_v}\frac{\partial P}{\partial T}\right)_V$	$\left(\frac{P}{\rho}\frac{\partial \rho}{\partial P}\right)_T$	DIEL - 1	CONDUCT [W/m·K]	VISC [μPa·s]	THDIFF [m^2/s]	PRANDTL
5.300	10.04	0.8011	4.144	0.1691E-01	0.1490E-01	1.828	0.1254E-07	3.355

References: *‘NIST – National Institute Standard Technology’*
Book Title: *‘Thermophysical Properties of Helium-4 from 0.8 to 1500 K with Pressures to 2000 Mpa’*
Author: *‘Vincent D. Arp, Robert D. McCarty ,Daniel G. Friend’*

The simulation is performed in the region of the helium supercritical phase
T=5.3 K
P= 2.3bar(0.230 Mpa)

OTS – The Thermal Model – Transient Simulation (time)

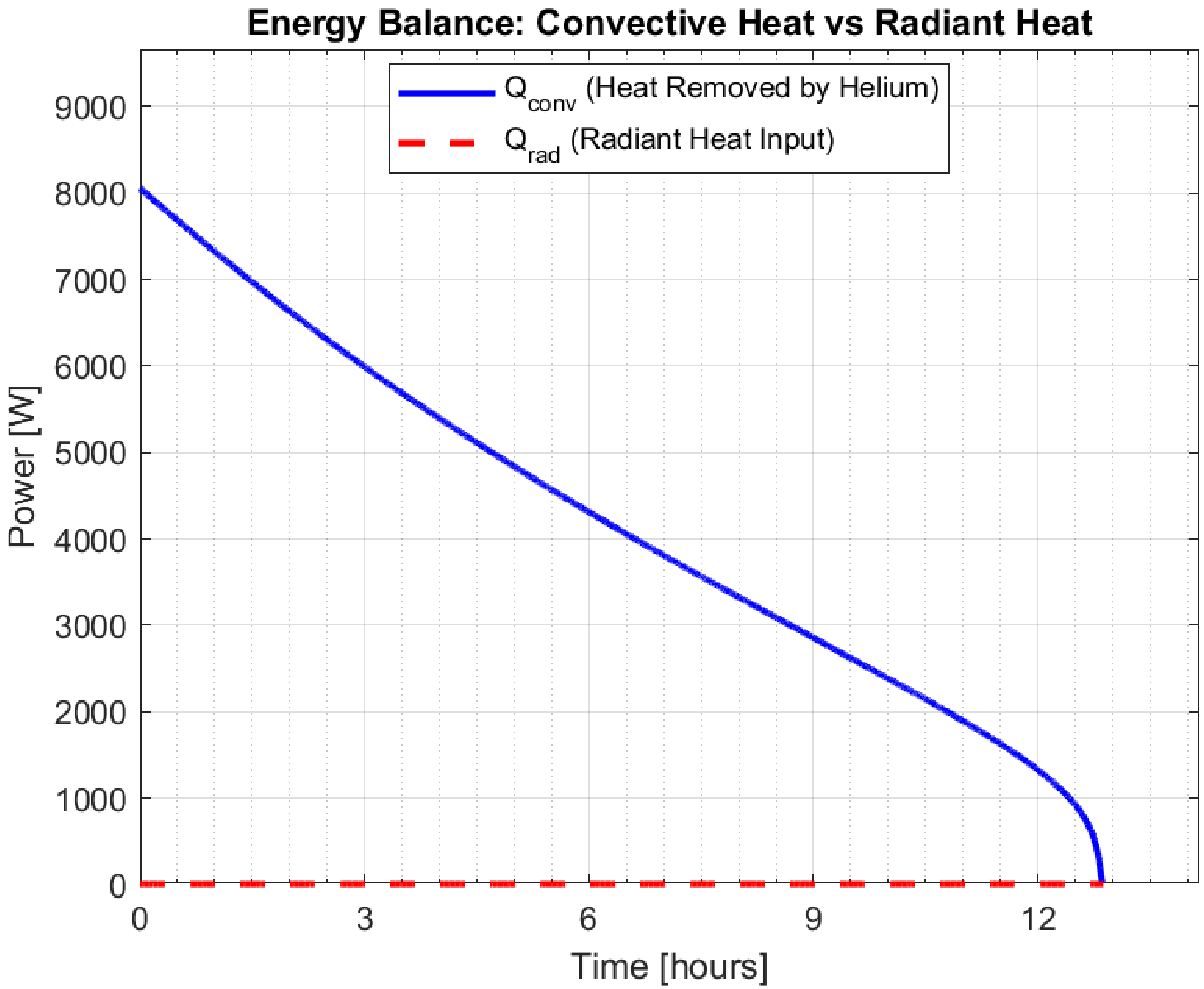
Simulation Data	
Flowrate (kg/s)	0.001
$T_{He,in}$ (K)	**5.3**
Q_r(W)	**12.6**
v (m/s)	0.58
Re	34047
Pr	3.35
Nu	177
U(W/m2 K)	172
ΔP(mbar)	2



12 hours & 52 minutes

The target temperature reached for the OTS shield is 5.53 K

OTS – The Thermal Model – Energy Balance: Q_{conv} vs Q_{rad}



Let's assume that the radiation heat transfer involves the 100% of the OTS surface and that its emissivity is $\epsilon = 0.1$

OTS – The Thermal Model – Transient Simulation (1D Model)