EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
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EURISOL-DS/TASK2/ TN-02-25-2008-0030

EURISOL-DS Multi-MW Target Preliminary Study of the Thermal Behaviour of the fission target inspired by the MAFF project

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and the EURISOL-DS Task#2 collaboration

Abstract

This technical note summarises the design calculations performed within Task #2 of the European Isotope Separation On-Line Radioactive Ion Beam Facility Design Study (EURISOL-DS) [1] for the thermal behaviour of the fission target.

A preliminary study was carried out in order to determine the heat deposition within the fissile material and estimate the temperature raise.

Table of Contents

I. Introduction

This study has been carried on the behalf of task#2. It is a preliminary study of the thermal comportment of the MAFF design target integrated around the EURISOL proton to neutron converter. The main objective is to prove the feasibility of the integration of those targets from the thermal point of view. In order to perform this analysis and because of the lack of properties for some materials, worst and best cases have been taken in to account. This will also be applied for the heat deposition.

The first thing presented in this note is the presentation of a new proposal for the layout of the MMW target station. This will be followed by the description of the target design from MAFF. The model chosen will then be described with the conditions applied to it. In order to finish presenting the modeling, all the material properties chosen are recorded in this notes, before showing the results of the simulation and their commentaries.

The conclusion of this note will present the status of the work and a prevision of what may need to be examined.

II. Presentation of the MAFF target concept integration into EURISOL MWW target Station

The MAFF target is integrated in a body tube, which could be extracted from the top. When the all tube is extracted, several maintenance operations could be performed on the target, like changing the target. The radioactive waste is then move remotely to a radioactive waste facility.

As the converter creates a high flux of neutron, material irradiation facilities and neutron experimental hall could be include around this target station

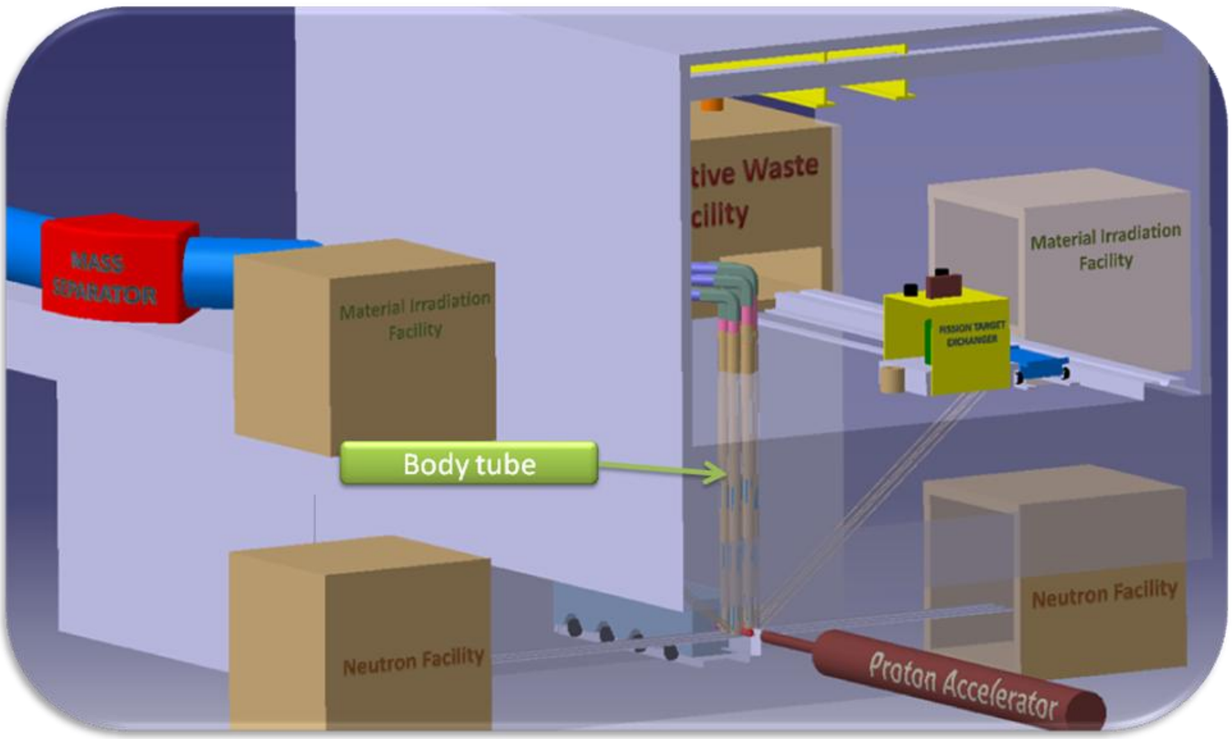


Figure 1: Overall view of the EURISOL MWW target station

The MAFF target design is made of a Graphite matrix which presents a high porosity. Throughout a chemical process the Uranium is imbibed inside the matrix. The loading of Uranium in the target is a multi-level process. The graphite is soaked first in a concentrated liquid solution by $UO_2(NO_3)_2$, until saturation is reached. Subsequently, the matrix is dehydrogenated and heated up then in vacuum. At temperatures around 600 °C the UO_2 will be formed from the $UO_2(NO_3)_2$. Nitrogen oxides (NOX) will also become free. The nitrogen oxide development is supervised with a mass spectrometer; the reaction is finished, if no more nitrogen oxides are produced. The final step is to heat up the target up to 1500 °C; the UO_2 will be then transformed into UC_2 [1].

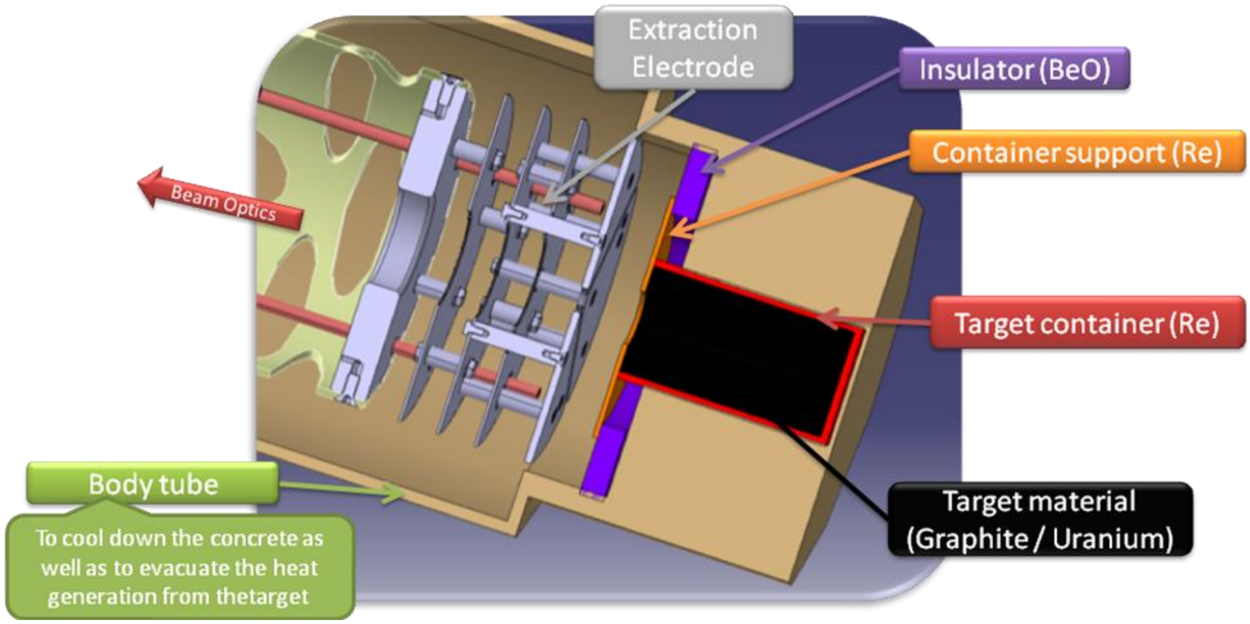


Figure 2 : Bottom view of the Bodytube including the fissile target

The Graphite target is surrounded by a Rhenium container held up on a Rhenium support, which is standing on an insulator made of Beryllium oxide. The heat is extracted by the cooling system inside the body tube.

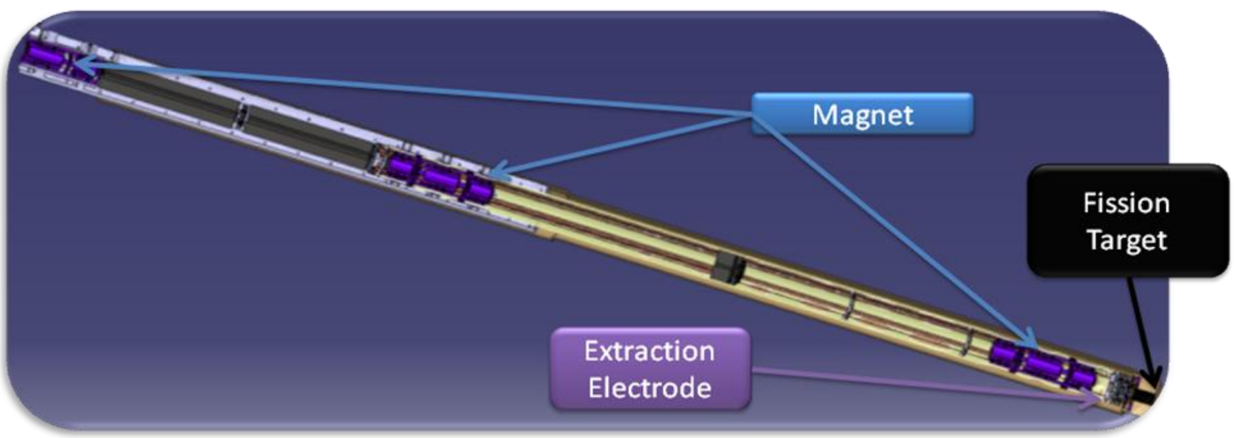


Figure 3: Overall view of the Bodytube, the beam optics, the extraction electrode and the fission target

Note: all the beam optics has been took from the MAFF design study and calculation of it will need to be carried on.

6 or 7 Bodytubes are inserted verticaly around the proton to neutron converter.

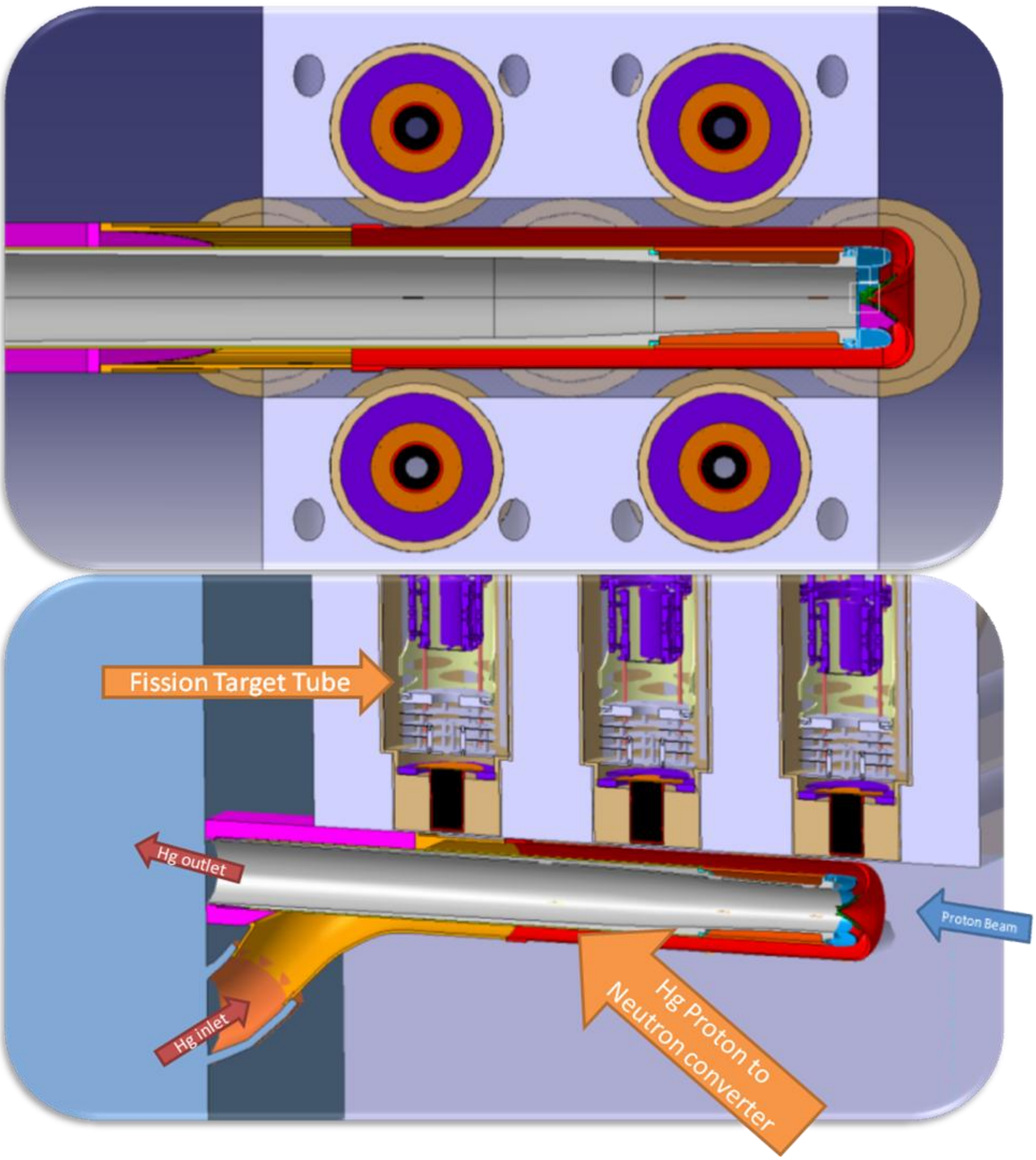


Figure 4: Cut view of the converter and the Bodytubes

III. Material Data

All the material datas have been collected though the ref [2] and ref [3] for the graphite.

1. Graphite - low thermal conductivity

TABLE 290
Graphite - low thermal conductivity > Constants

Thermal	
Thermal Conductivity	45. W/m·°C
Specific Heat	830. J/kg·°C

2. Rhenium

FIGURE 99
Rhenium > Thermal Conductivity

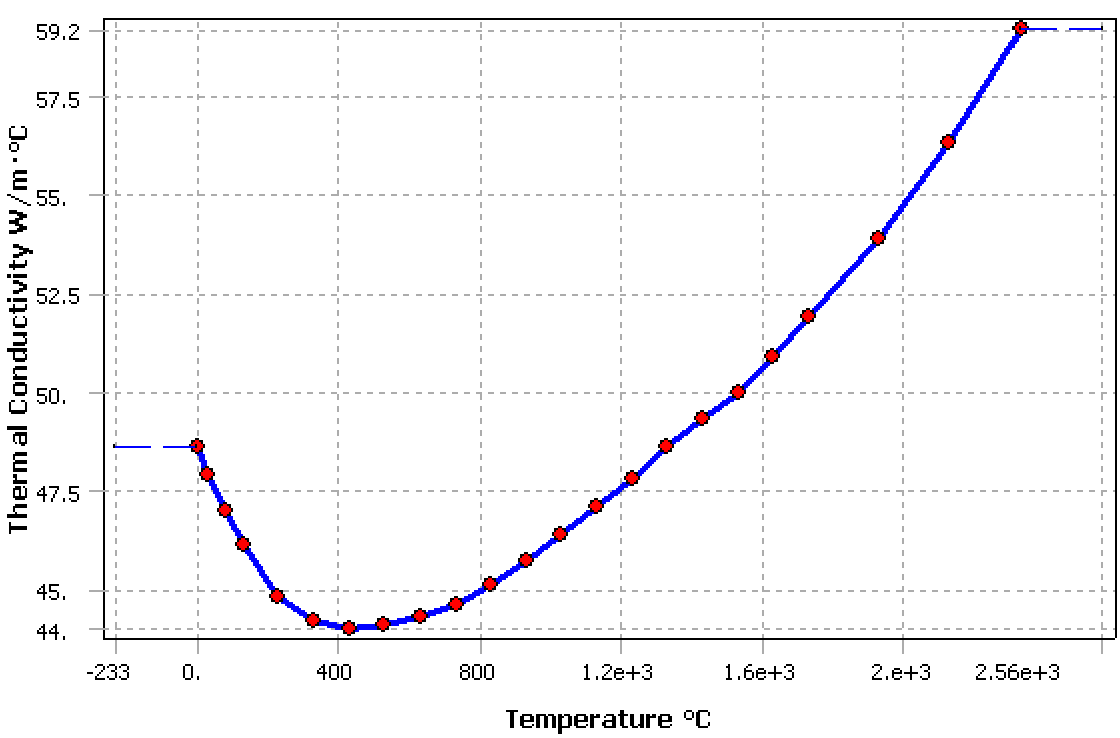


TABLE 291
Rhenium > Thermal Conductivity > Thermal Conductivity vs. Temperature

Temperature °C	Thermal Conductivity W/m·°C
5.e-002	48.6
26.85	47.9
76.85	47.
126.85	46.1

226.85	44.8
326.85	44.2
426.85	44.
526.85	44.1
626.85	44.3
726.85	44.6
826.85	45.1
926.85	45.7
1026.8	46.4
1126.8	47.1
1226.8	47.8
1326.8	48.6
1426.8	49.3
1526.8	50.
1626.8	50.9
1726.8	51.9
1926.8	53.9
2126.8	56.3
2326.8	59.2

FIGURE 100
Rhenium > Specific Heat

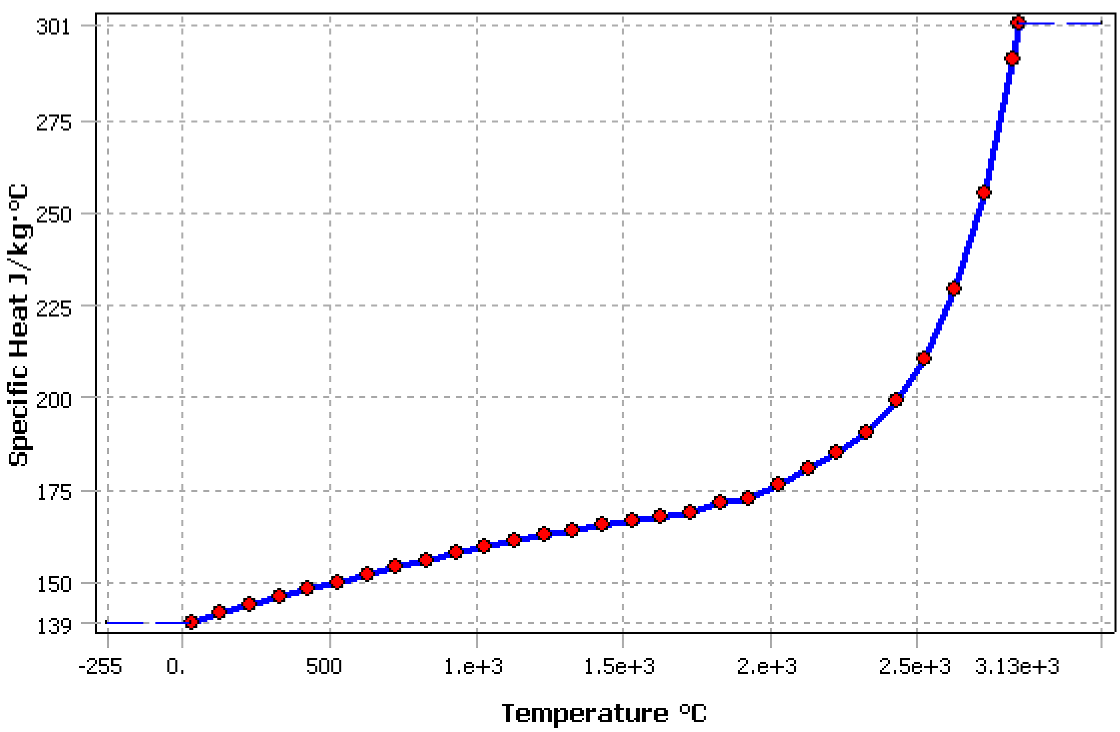


TABLE 292
Rhenium > Specific Heat > Specific Heat vs. Temperature

Temperature °C	Specific Heat J/kg·°C
26.85	138.96
126.85	141.47
226.85	143.56
326.85	146.07
426.85	147.75
526.85	149.84
626.85	151.93
726.85	154.03
826.85	155.7
926.85	157.79
1026.8	159.47
1126.8	160.72
1226.8	162.4
1326.8	163.65
1426.8	165.33
1526.8	166.58
1626.8	167.42
1726.8	168.68
1826.8	171.19
1926.8	172.44
2026.8	176.21
2126.8	180.4
2226.8	185.
2326.8	190.02
2426.8	198.81
2526.8	210.11
2626.8	229.37
2726.8	255.32
2826.8	291.31
2846.8	300.94

3. Acier inoxydable

TABLE 293
Acier inoxydable > Constants

Structural	
Young's Modulus	1.93e+011 Pa
Poisson's Ratio	0.31
Density	7750. kg/m³
Thermal Expansion	1.7e-005 1/°C
Tensile Yield Strength	2.07e+008 Pa
Compressive Yield Strength	2.07e+008 Pa
Tensile Ultimate Strength	5.86e+008 Pa
Compressive Ultimate Strength	0. Pa

Thermal	
Thermal Conductivity	15.1 W/m·°C
Specific Heat	480. J/kg·°C
Electromagnetics	
Relative Permeability	10000
Resistivity	7.7e-007 Ohm·m

4. Berylium Oxyde

FIGURE 101
Berylium Oxyde > Specific Heat

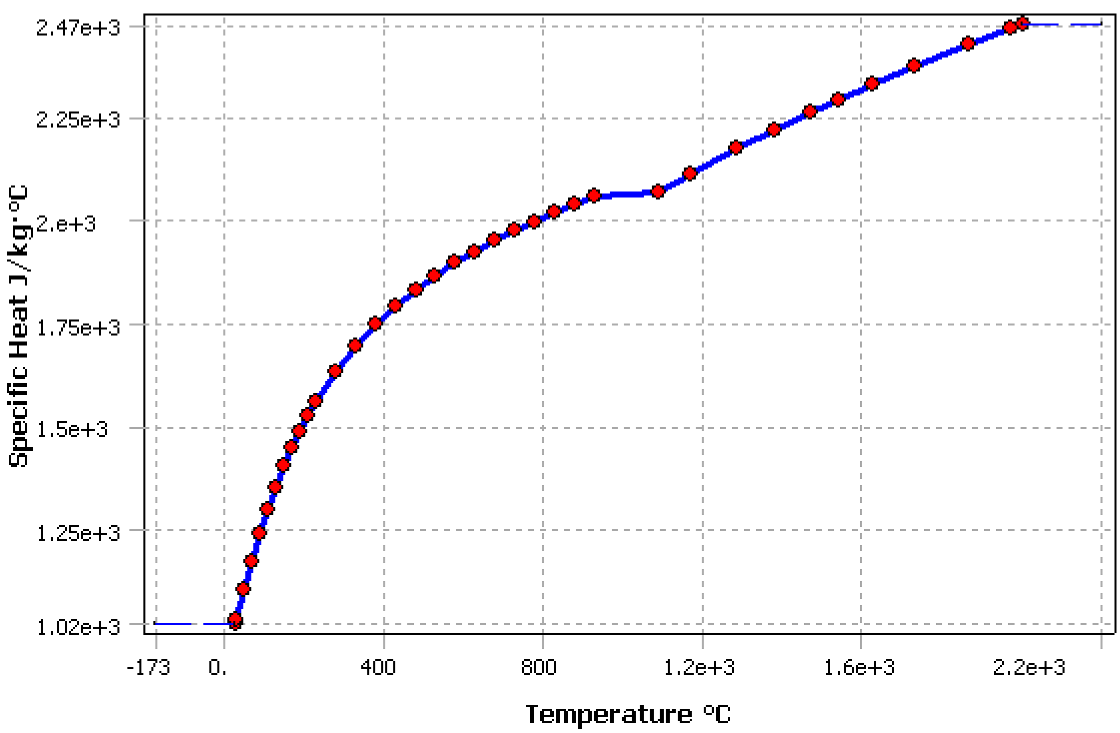


TABLE 294
Berylium Oxyde > Specific Heat > Specific Heat vs. Temperature

Temperature °C	Specific Heat J/kg·°C
25.	1021.3
26.85	1028.4
46.85	1103.7
66.85	1173.2
86.85	1237.2
106.85	1296.2
126.85	1351.9
146.85	1401.3
166.85	1445.7

186.85	1486.3
206.85	1523.5
226.85	1557.4
276.85	1631.9
326.85	1693.5
376.85	1745.8
426.85	1790.6
476.85	1829.9
526.85	1864.6
576.85	1895.6
626.85	1924.1
676.85	1950.
726.85	1974.3
776.85	1996.9
826.85	2018.2
876.85	2038.3
926.85	2057.6
1085.6	2068.9
1167.2	2112.4
1282.8	2171.9
1380.6	2219.6
1471.7	2262.3
1538.9	2292.8
1626.7	2330.5
1732.2	2374.
1865.6	2425.1
1973.9	2463.6
2004.4	2474.

FIGURE 102
Berylium Oxyde > Thermal Conductivity

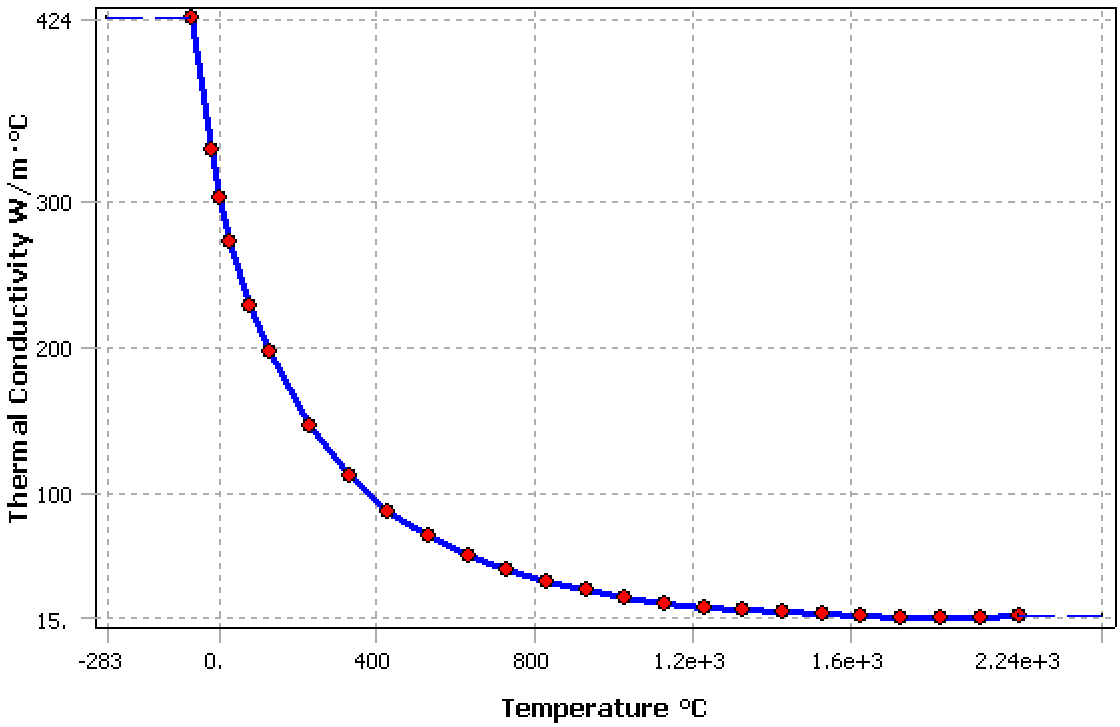


TABLE 295
Berylium Oxyde > Thermal Conductivity > Thermal Conductivity vs. Temperature

Temperature °C	Thermal Conductivity W/m·°C
-73.15	424.
-23.15	334.
5.e-002	302.
26.85	272.
76.85	228.
126.85	196.
226.85	146.
326.85	111.
426.85	87.
526.85	70.
626.85	57.
726.85	47.
826.85	39.
926.85	33.
1026.8	28.3
1126.8	24.5
1226.8	21.5
1326.8	19.5
1426.8	18.
1526.8	16.7

1626.8	15.6
1726.8	15.
1826.8	
1926.8	15.2
2026.8	16.4

5. Graphite - middle thermal conductivity

TABLE 296
Graphite - middle thermal conductivity > Constants

Thermal	
Thermal Conductivity	85. W/m·°C
Specific Heat	830. J/kg·°C

6. Graphite - high thermal conductivity

TABLE 297
Graphite - high thermal conductivity > Constants

Thermal	
Thermal Conductivity	150. W/m·°C
Specific Heat	830. J/kg·°C

IV. Modeling

The simulation and the modeling have done using ANSYS Workbench. Only the bottom o the Bodytube has been taken into account in order to have a simple and fost to solve model, more details will have to be taken into account in the full analysis.

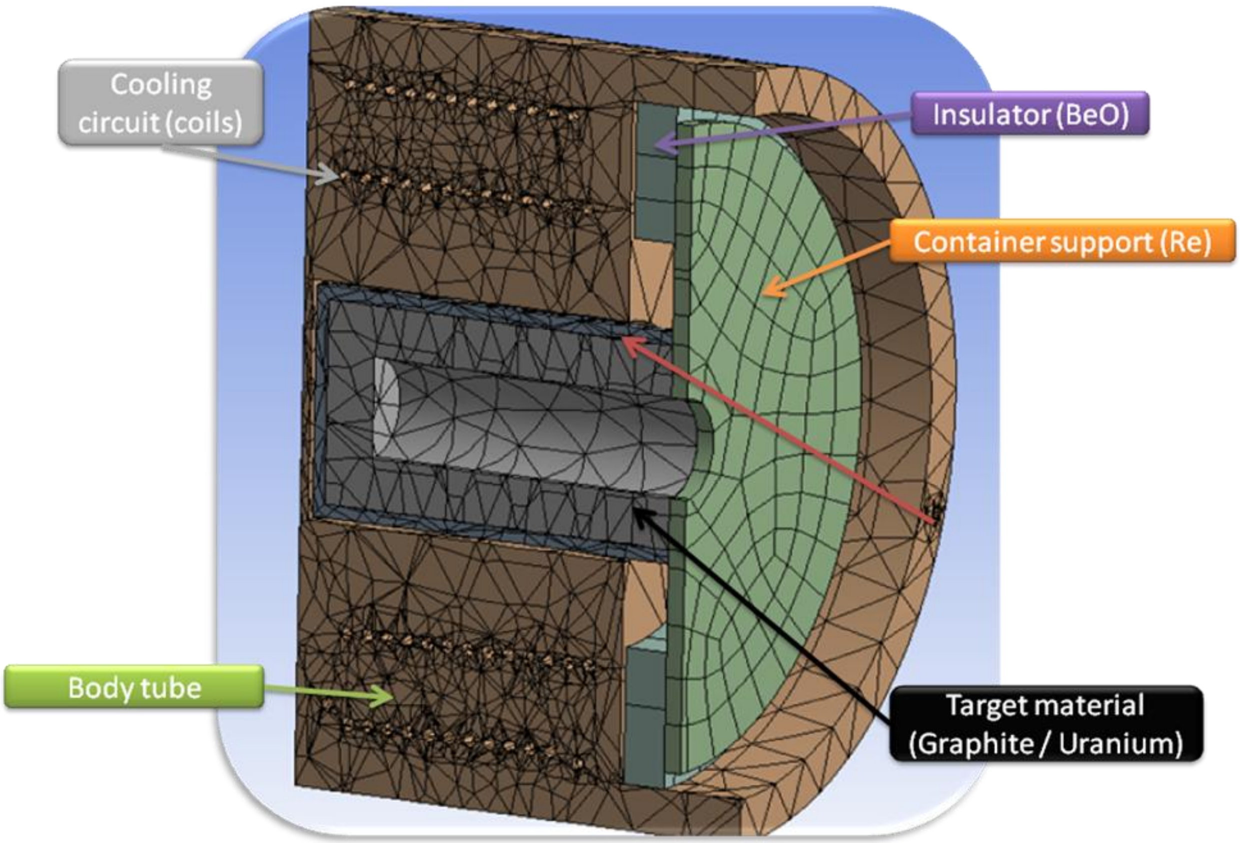


Figure 5: Cut view of the model

In order to estimate the worst case it has been taking into account the lack of known properties for the graphite.

3 thermal conductions for the graphite have been tested: 45W/m/K and 85W/m/K and 150W/m/K. For each of those cases several analyses with different boundary condition have been performed:

- Convection in the coils + Heat radiation exchange between the target container and the body tube
- Constant temperature for the body tube + Heat radiation exchange between the target container and the body tube
- Convection in the coils + convection on the target
- Convection on the target + constant temperature on the body tube

As well for each case the internal heat deposition was introduced as uniform in the graphite and 3 values were considered regarding the aimed fission rate.

For example, if we consider that one single target should produce the $1O^{15}$ fission/s it means:

- 10^{15} x 2.10^{8} eV/s in $100cm^{3}$
- 2 $x10^{23}$ x 1.602 176 53(14)×10^{-19} J/s in $100cm^{3}$
- 3,2 10^{3} W in $100cm^{3}$

- **320W/cm^3**

So the 3 values used for the simulation are 320W/cm^3, 160W/cm^3 and 80 W/cm^3; respectively those values correspond to the hypothesis that the aimed fission rate is achieved by one target, 2 targets or 4 targets.
To model the forced convection inside the cooling cicuit a heat transfer coefficient of 1000 W/m²/K has been used [4].

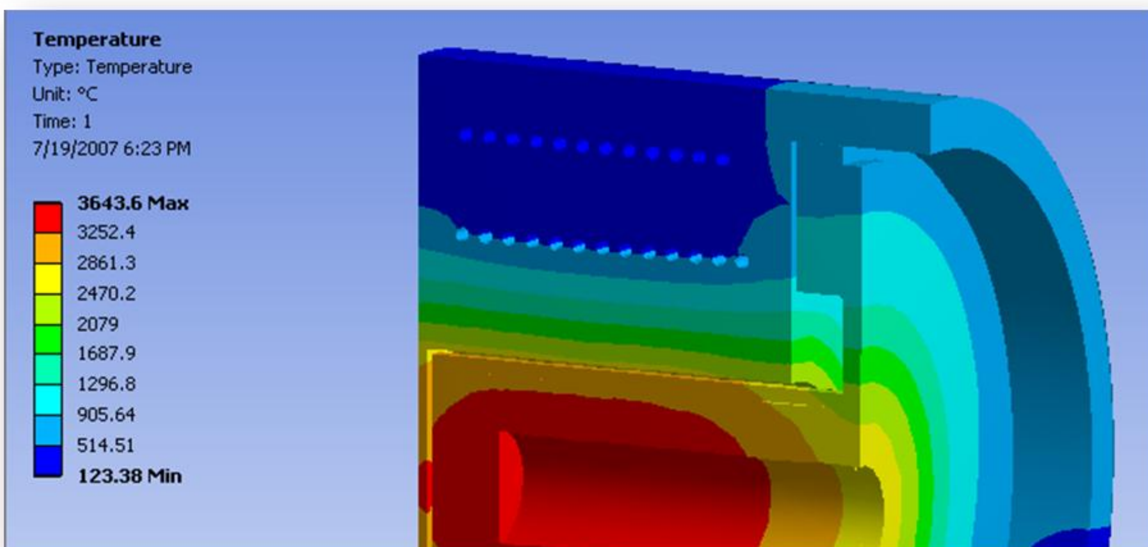
To summarize, there are 36 simulations in total: 12 cases per graphite conductivity (low, middle and high) regarding the 3 power deposition used and the several boundary conditions applied.

V. Analysis results

1. Analysis with the low thermal conductivity graphite material

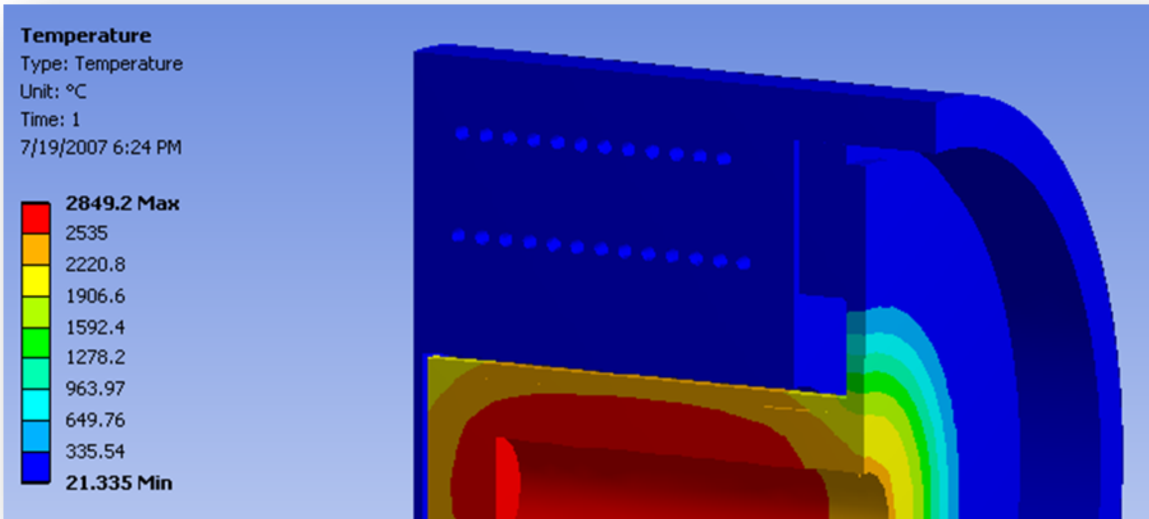
A. Full power density deposition

i. Convection in the cooling circuit and heat radiation between the target container and the Bodytube

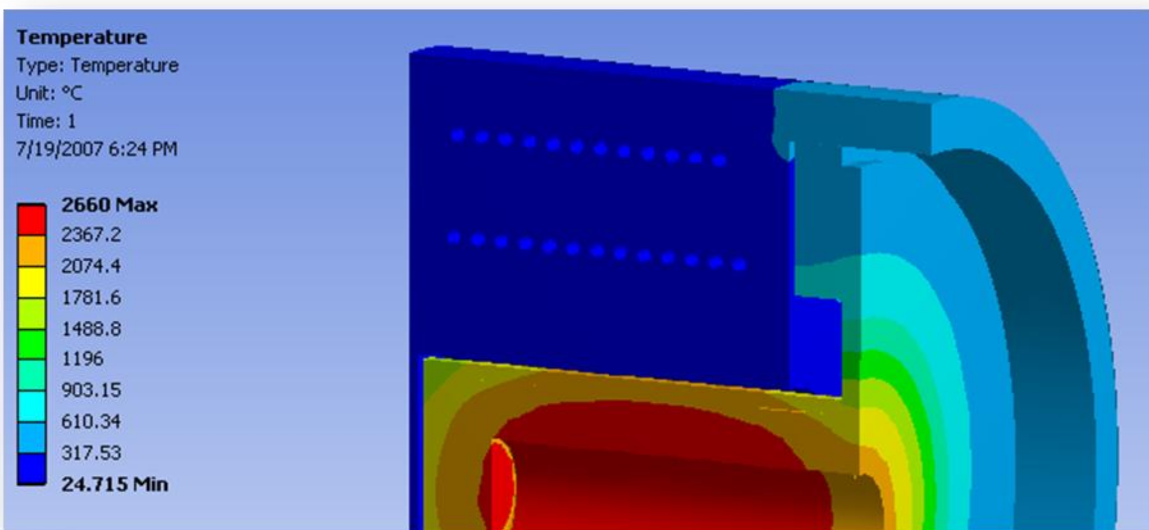


This is the worst cases!

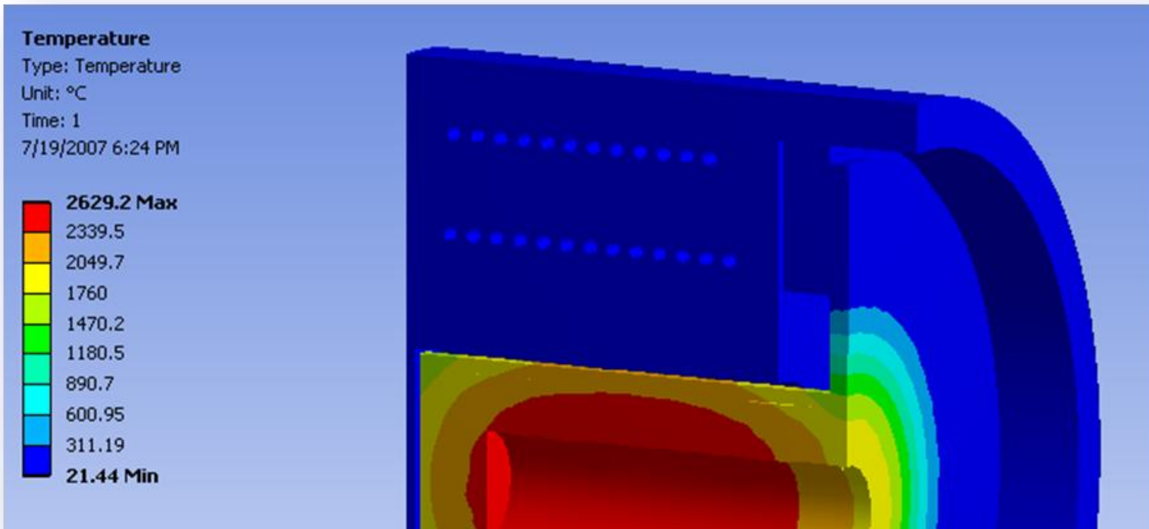
ii. Bodytube at a constant temperature and heat radiation between the target container and the Bodytube



iii. Convection in the cooling circuit and on the target container



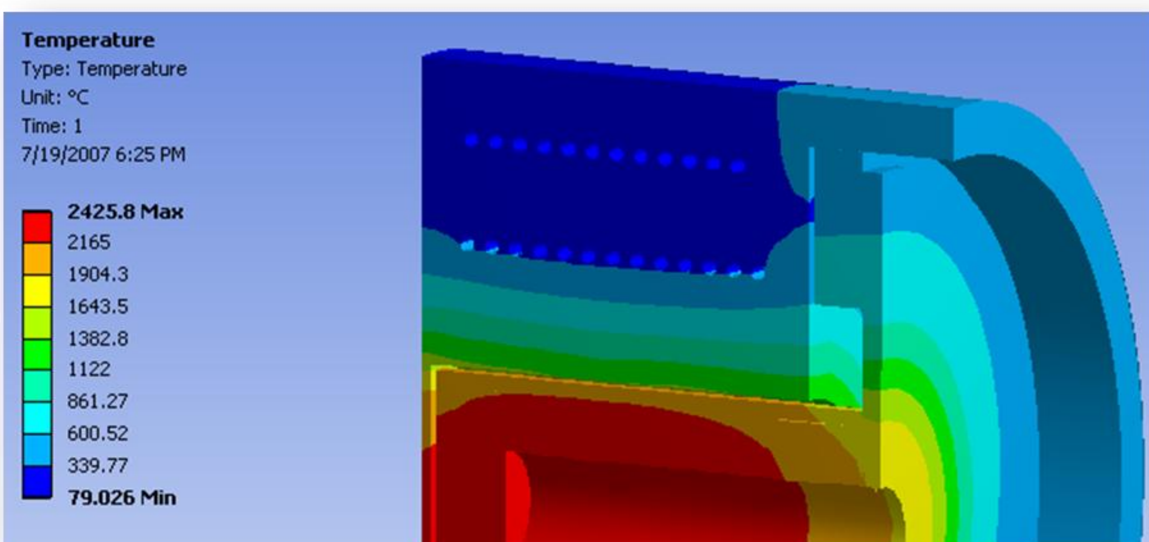
iv. Convection on the target container and Bodytube at a constant temperature



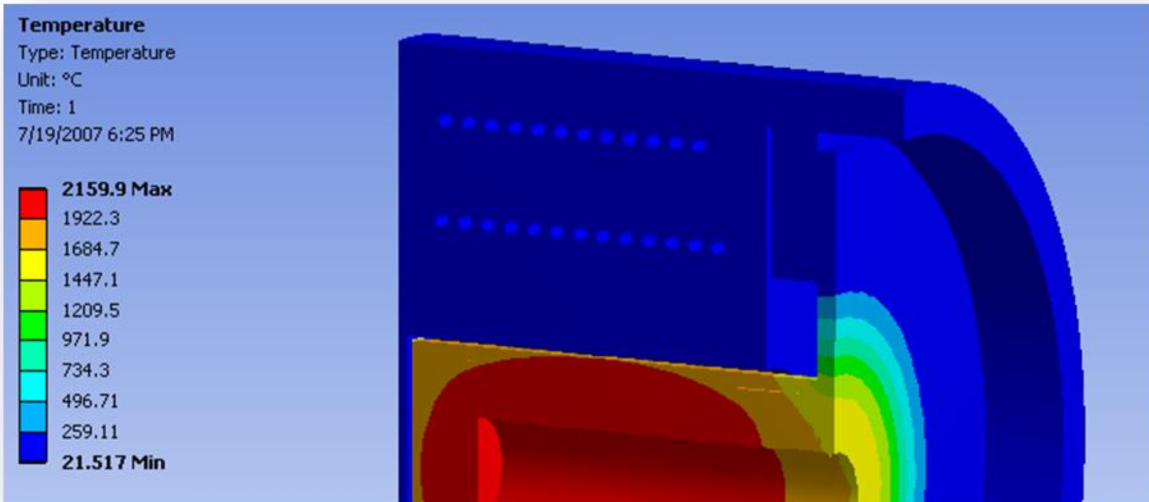
These cases are showing the main objective which is to get the full fission rates in one of those targets. It looks like it is feasible to achieve the $1O^{15}$ fission per second in one target.

B. Half power density deposition

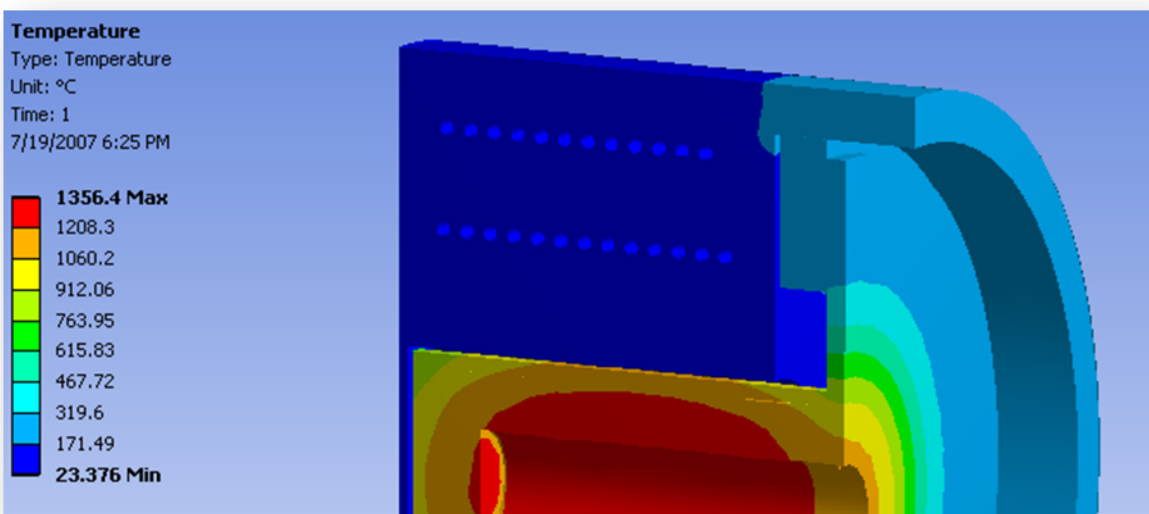
i. Convection in the cooling circuit and heat radiation between the target container and the Bodytube



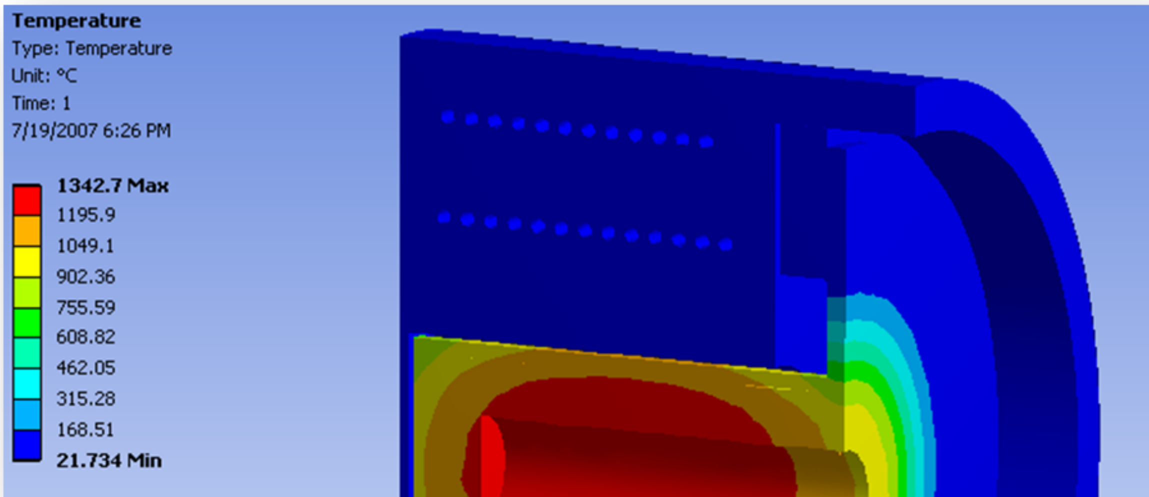
ii. Bodytube at a constant temperature and heat radiation between the target container and the Bodytube



iii. Convection in the cooling circuit and on the target container

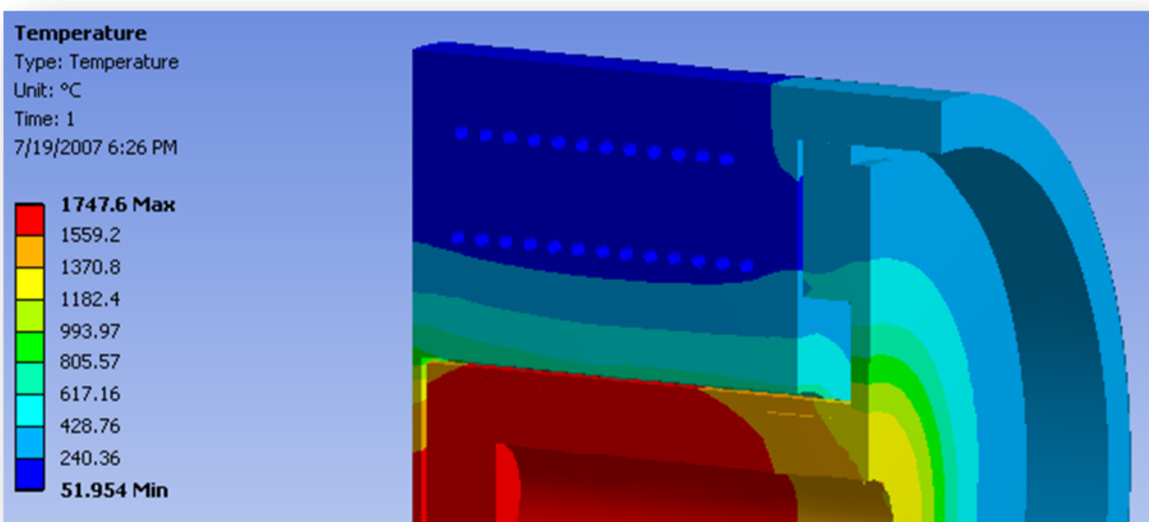


iv. Convection on the target container and Bodytube at a constant temperature

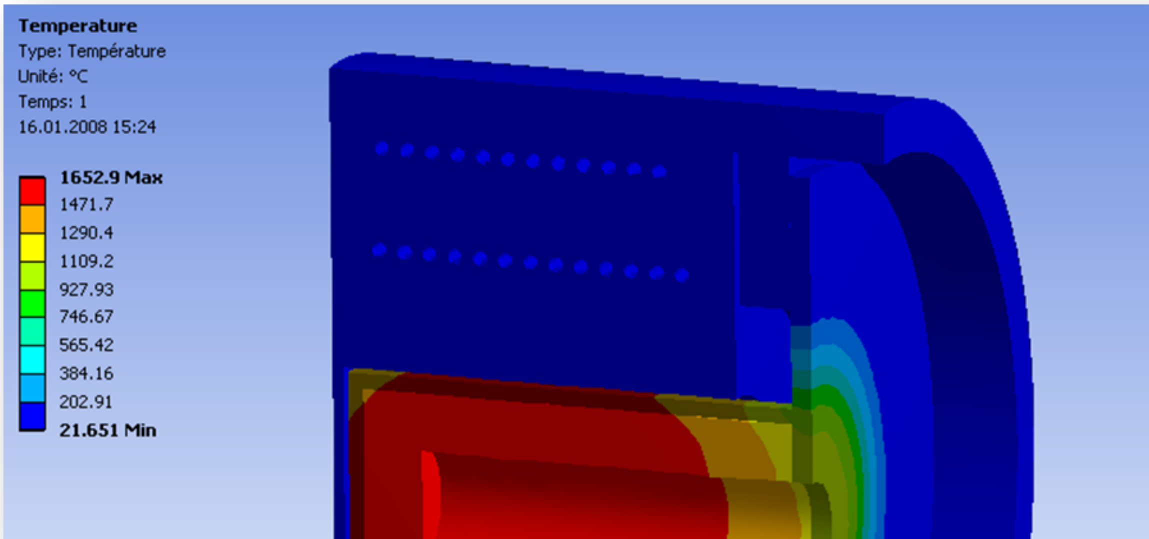


C. Quarter power density deposition

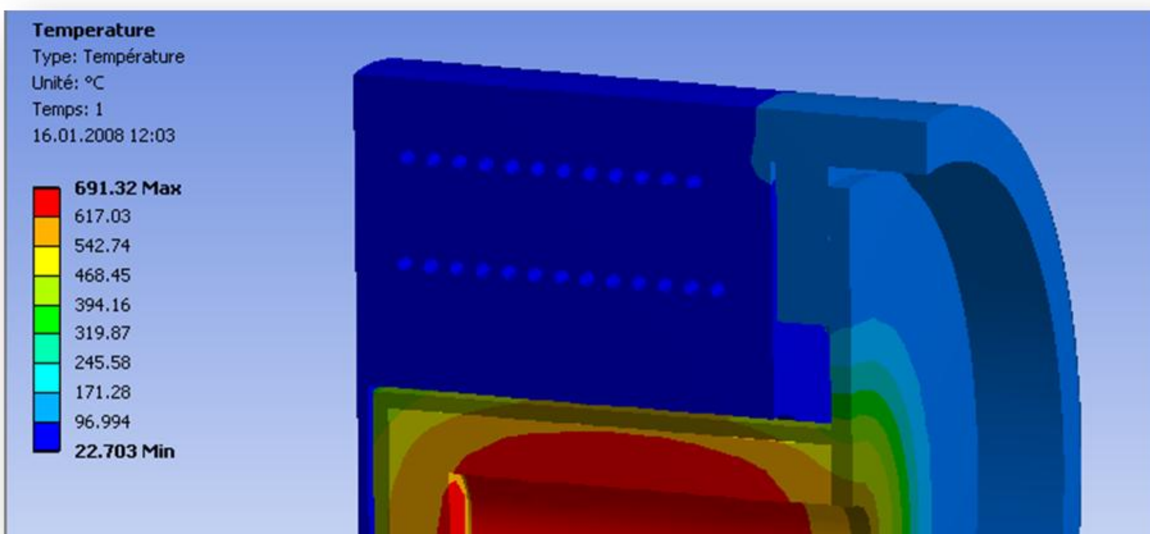
i. Convection in the cooling circuit and heat radiation between the target container and the Bodytube



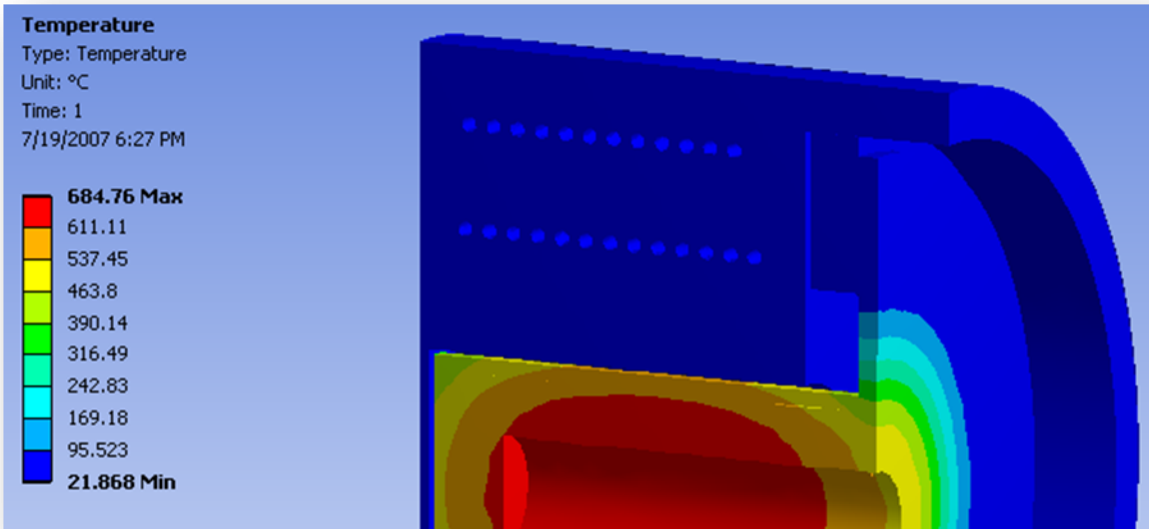
ii. Bodytube at a constant temperature and heat radiation between the target container and the Bodytube



iii. Convection in the cooling circuit and on the target container



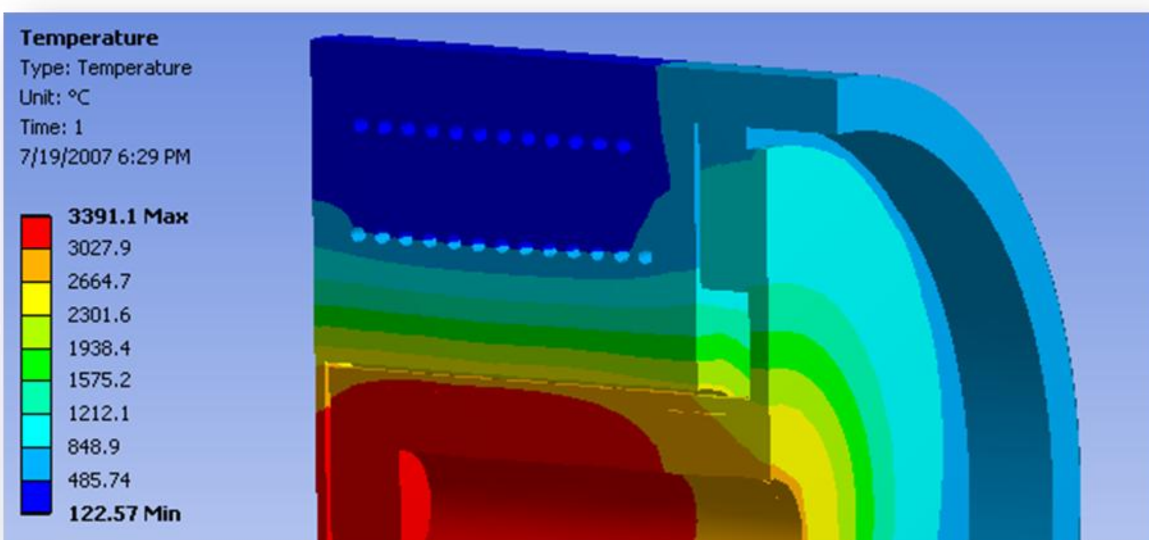
iv. Convection on the target container and Bodytube at a constant temperature



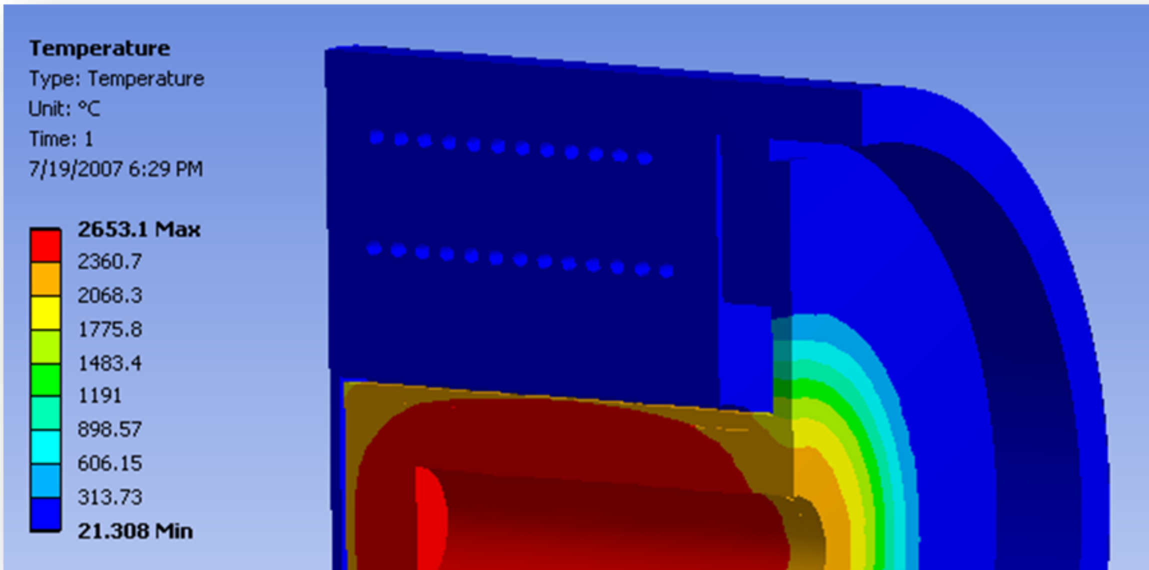
2. Analysis with the middle thermal conductivity graphite material

A. Full power density deposition

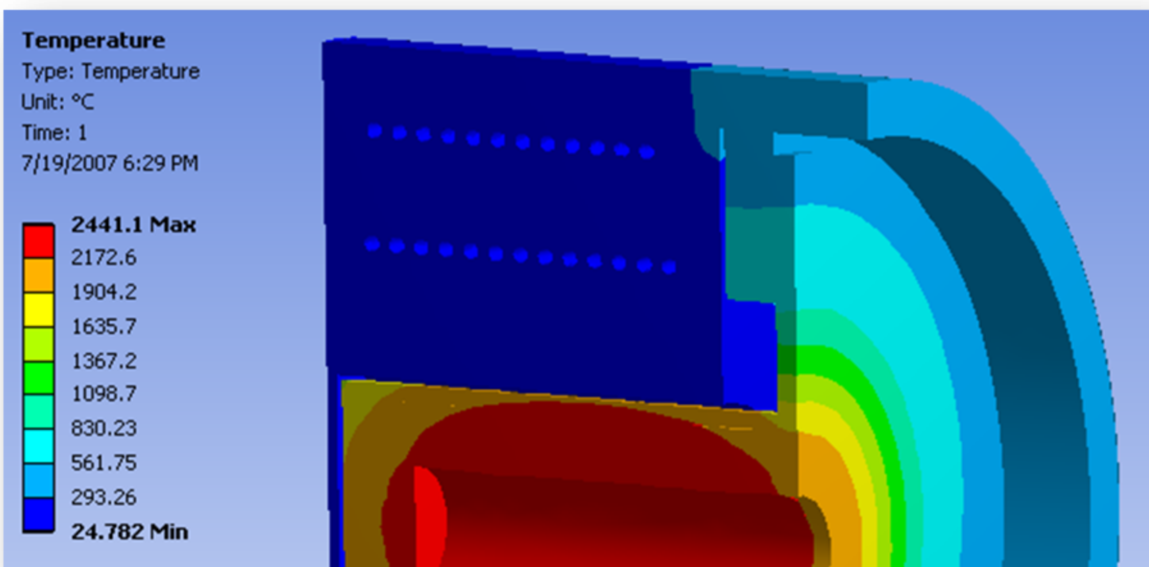
i. Convection in the cooling circuit and heat radiation between the target container and the Bodytube



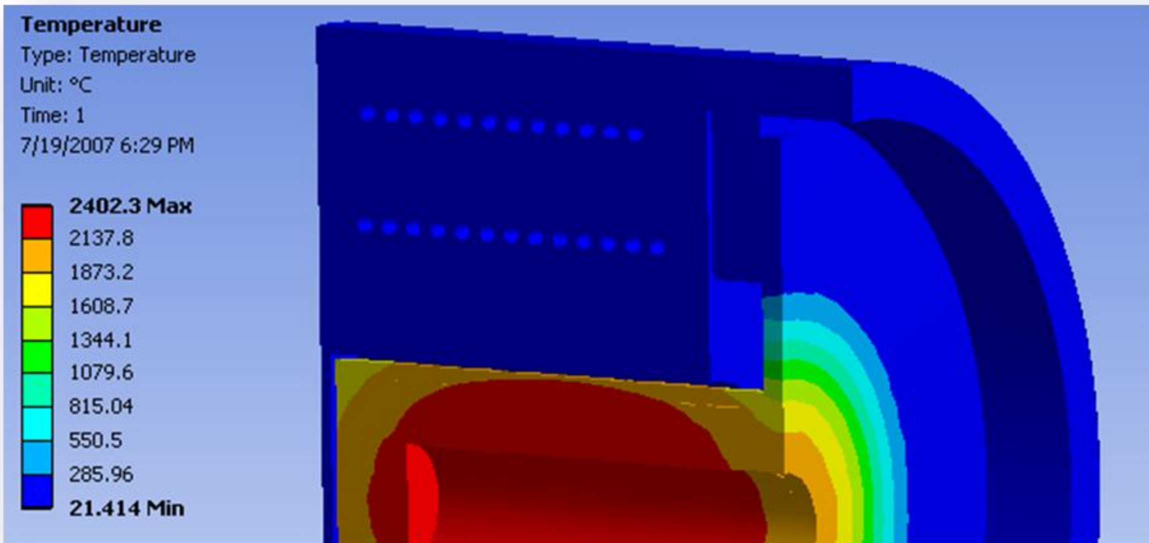
ii. Bodytube at a constant temperature and heat radiation between the target container and the Bodytube



iii. Convection in the cooling circuit and on the target container

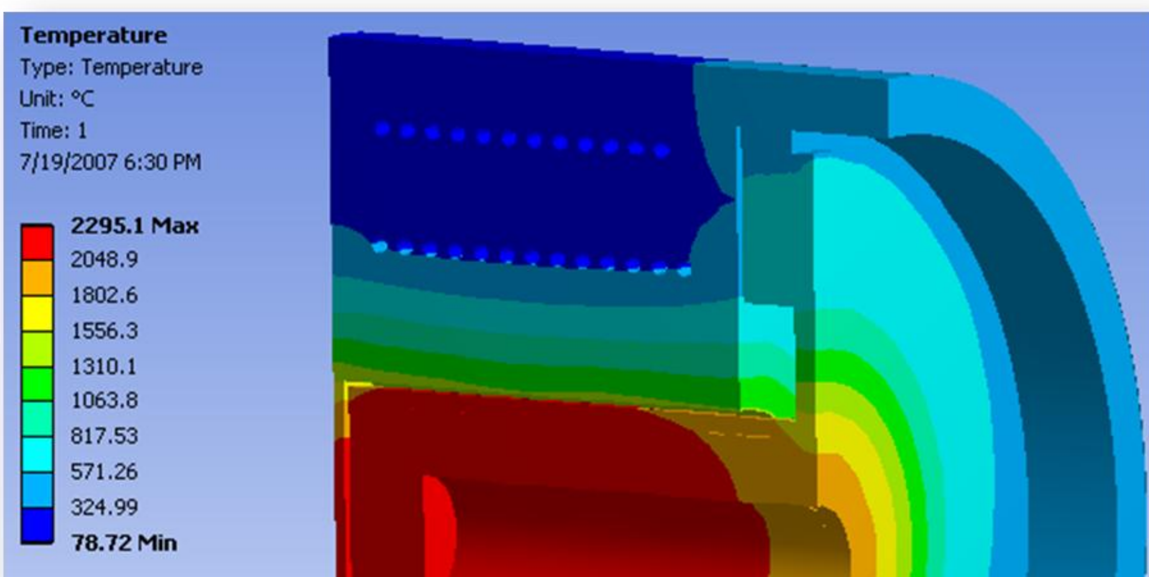


iv. Convection on the target container and Bodytube at a constant temperature

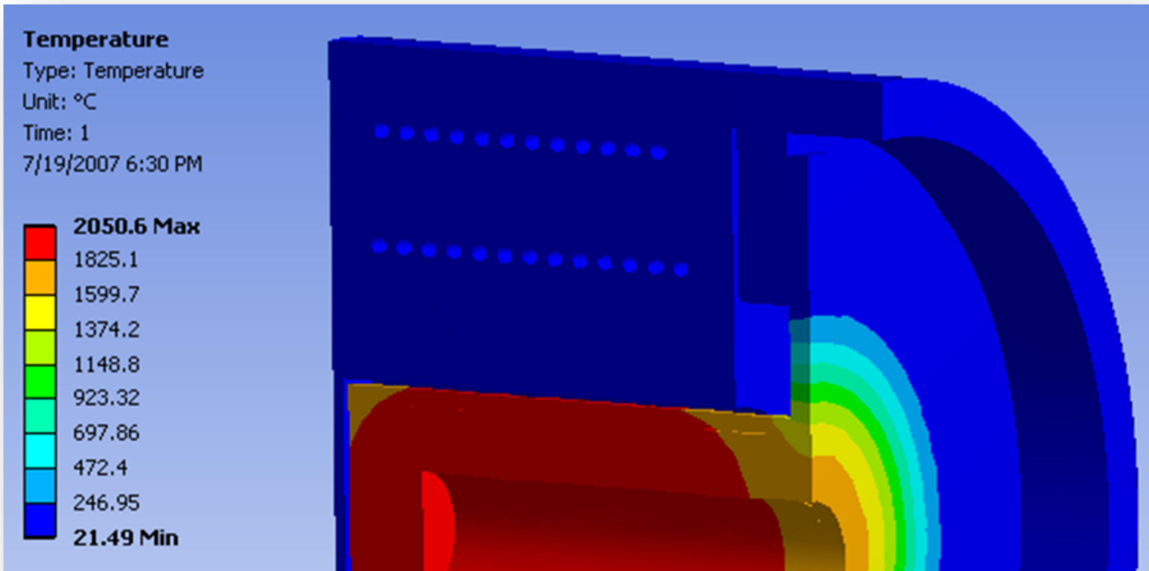


B. Half power density deposition

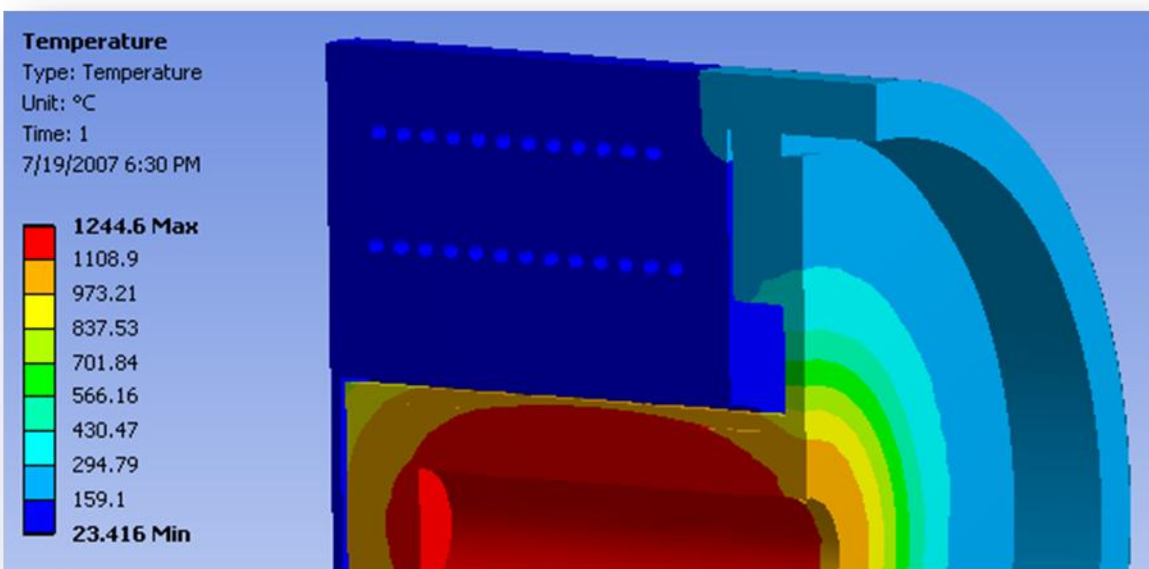
i. Convection in the cooling circuit and heat radiation between the target container and the Bodytube



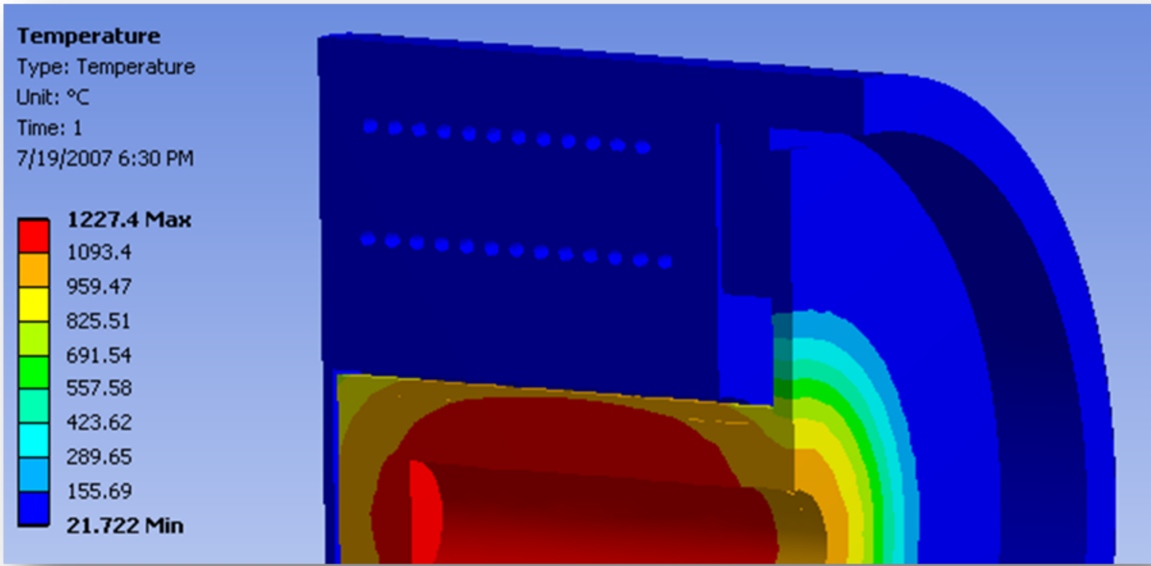
ii. Bodytube at a constant temperature and heat radiation between the target container and the Bodytube



iii. Convection in the cooling circuit and on the target container

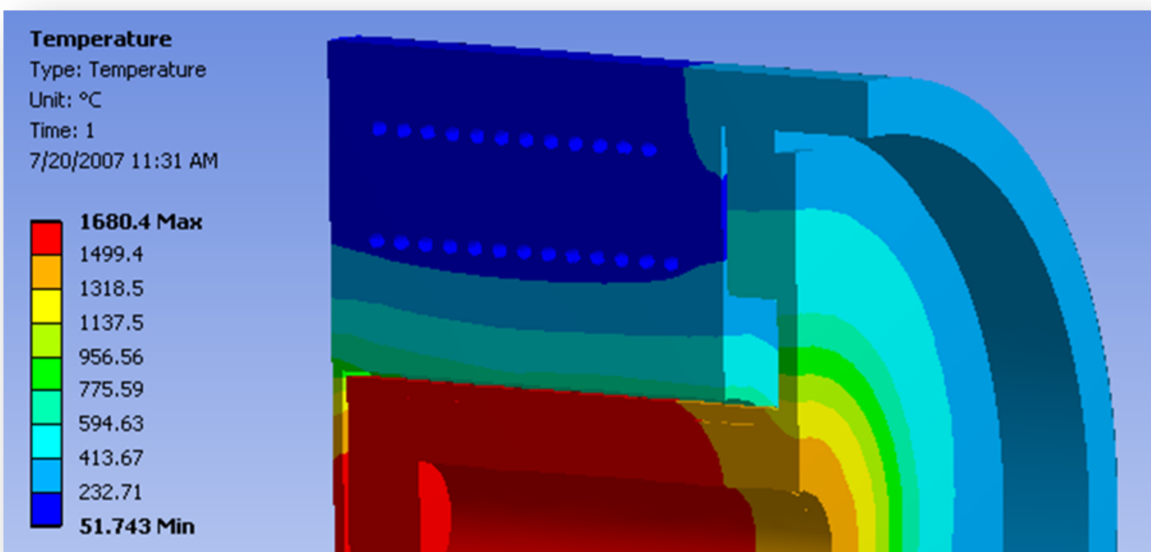


iv. Convection on the target container and Bodytube at a constant temperature

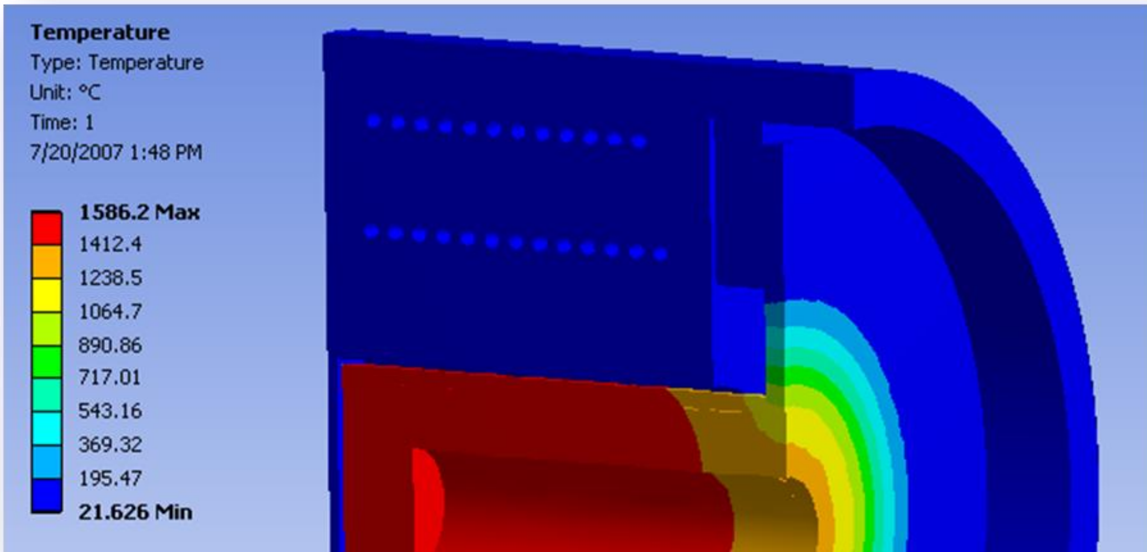


C. Quarter power density deposition

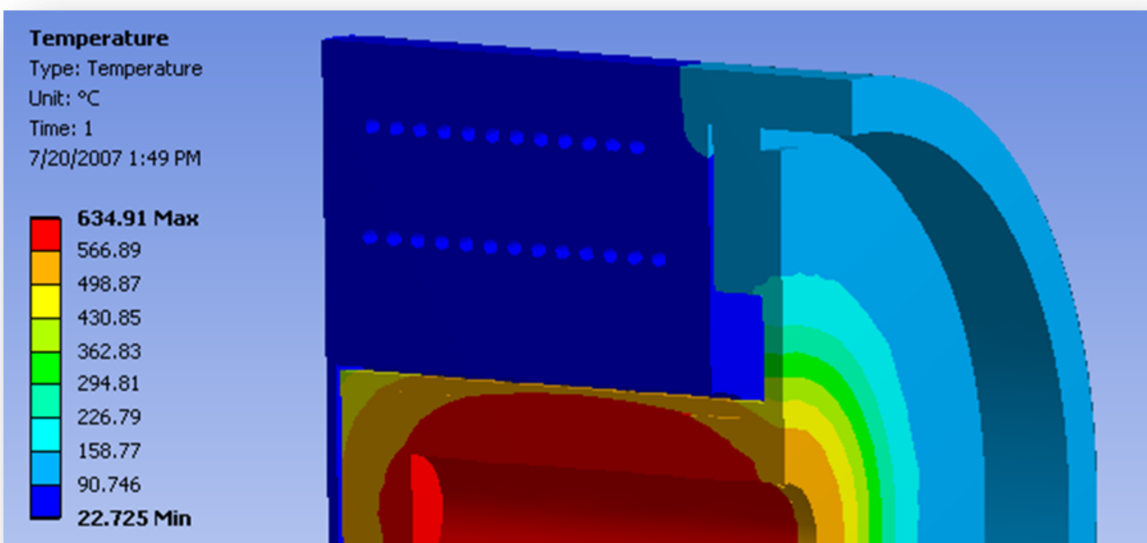
i. Convection in the cooling circuit and heat radiation between the target container and the Bodytube



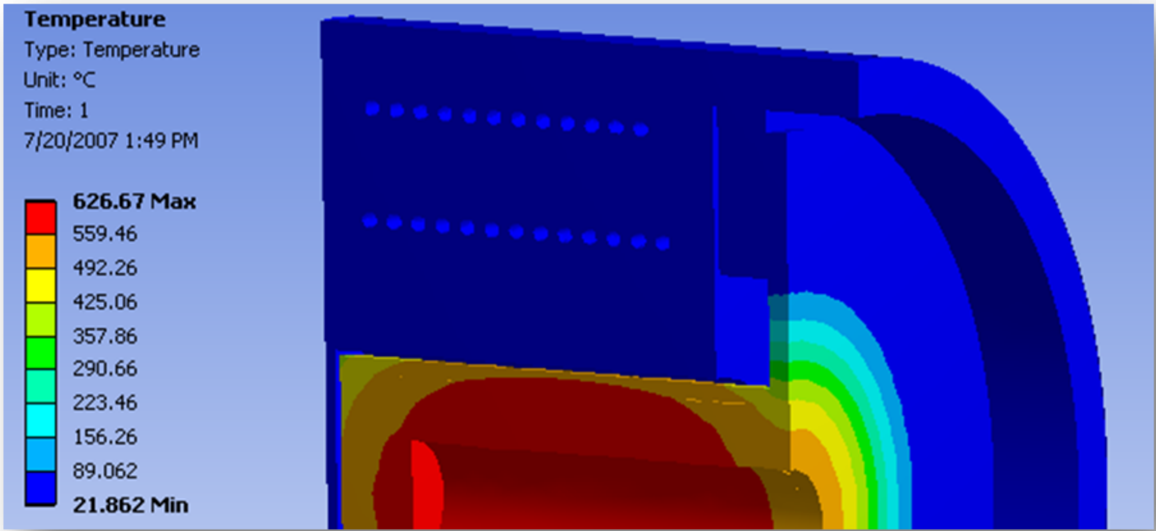
ii. Bodytube at a constant temperature and heat radiation between the target container and the Bodytube



iii. Convection in the cooling circuit and on the target container



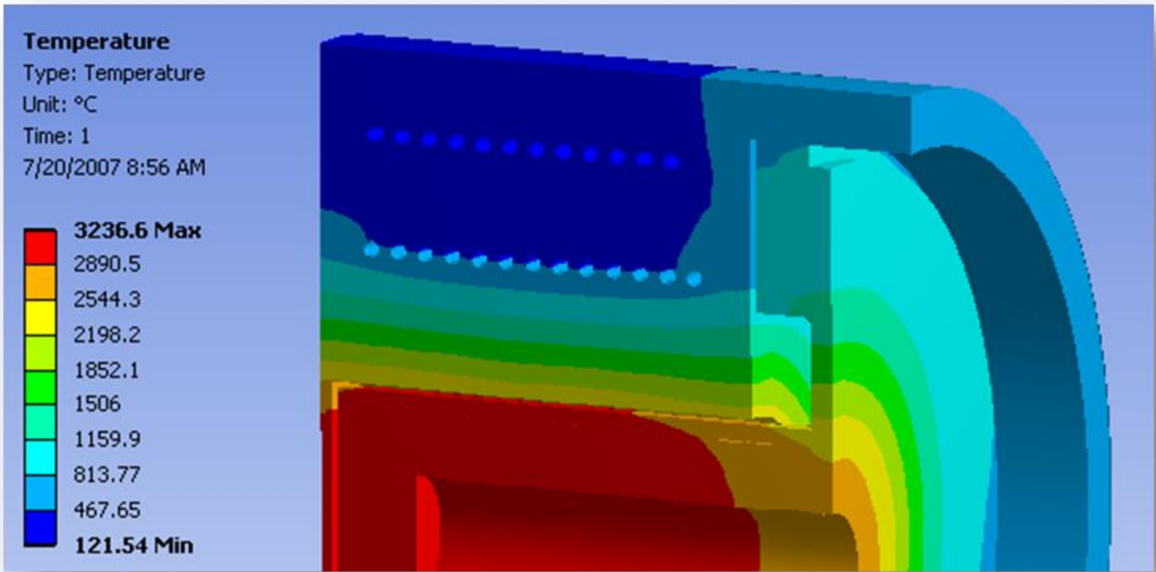
iv. Convection on the target container and Bodytube at a constant temperature



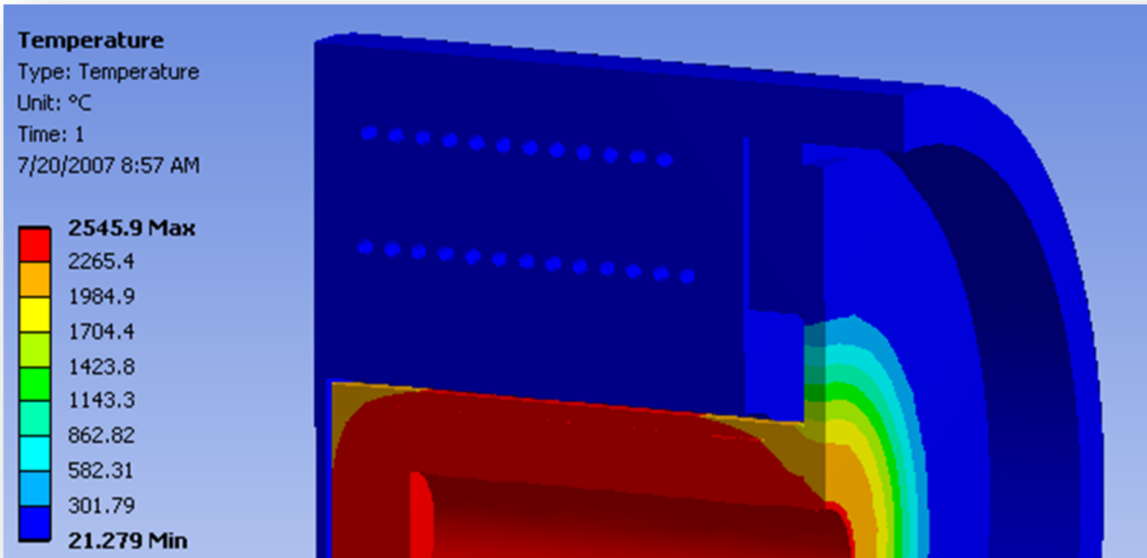
3. Analysis with the high thermal conductivity graphite material

A. Full power density deposition

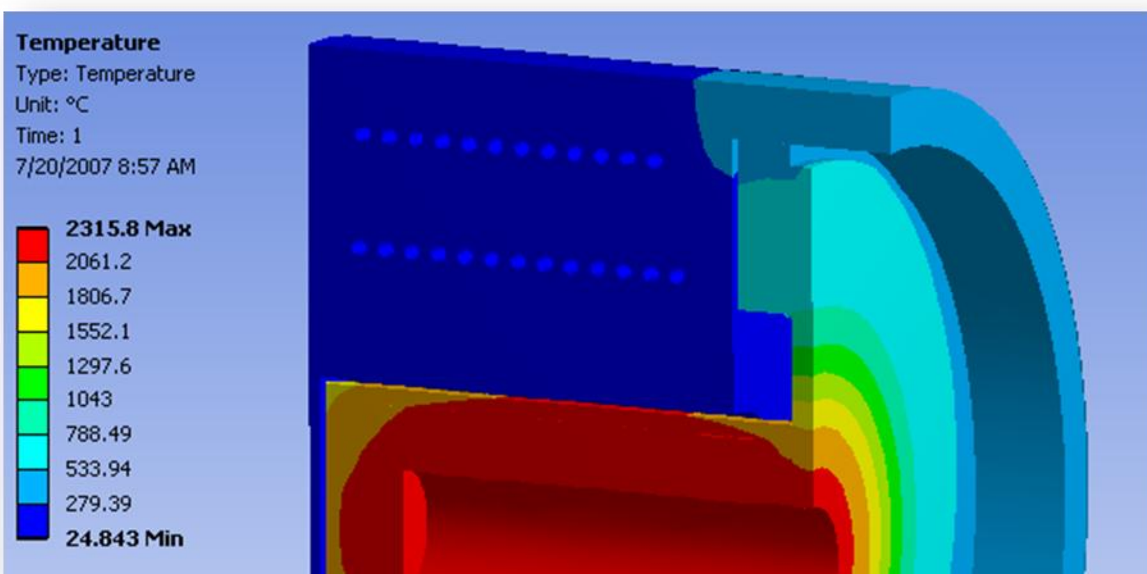
i. Convection in the cooling circuit and heat radiation between the target container and the Bodytube



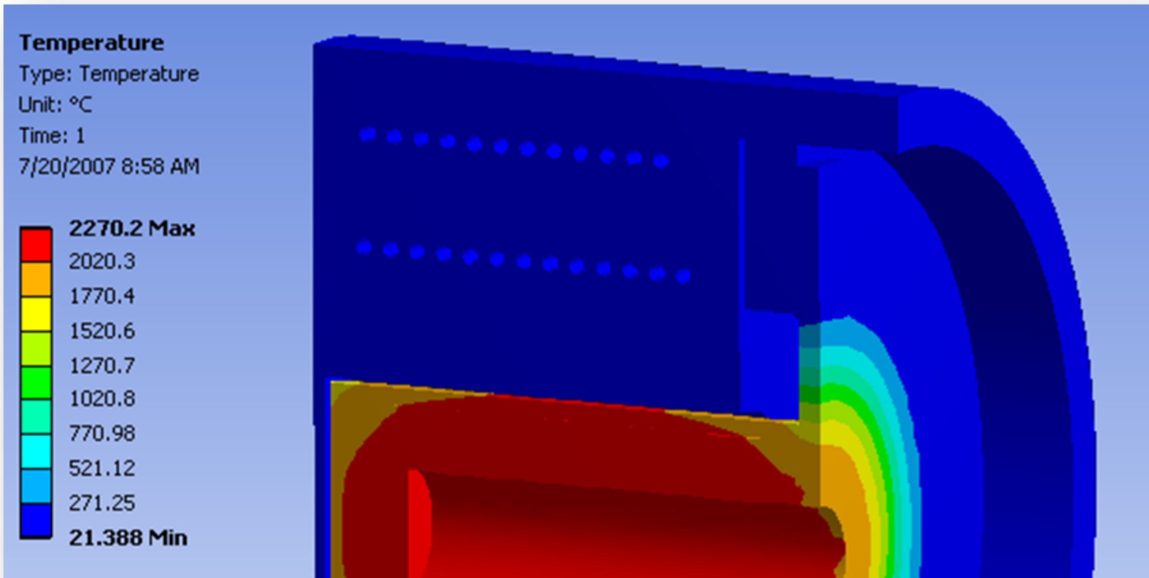
ii. Bodytube at a constant temperature and heat radiation between the target container and the Bodytube



iii. Convection in the cooling circuit and on the target container

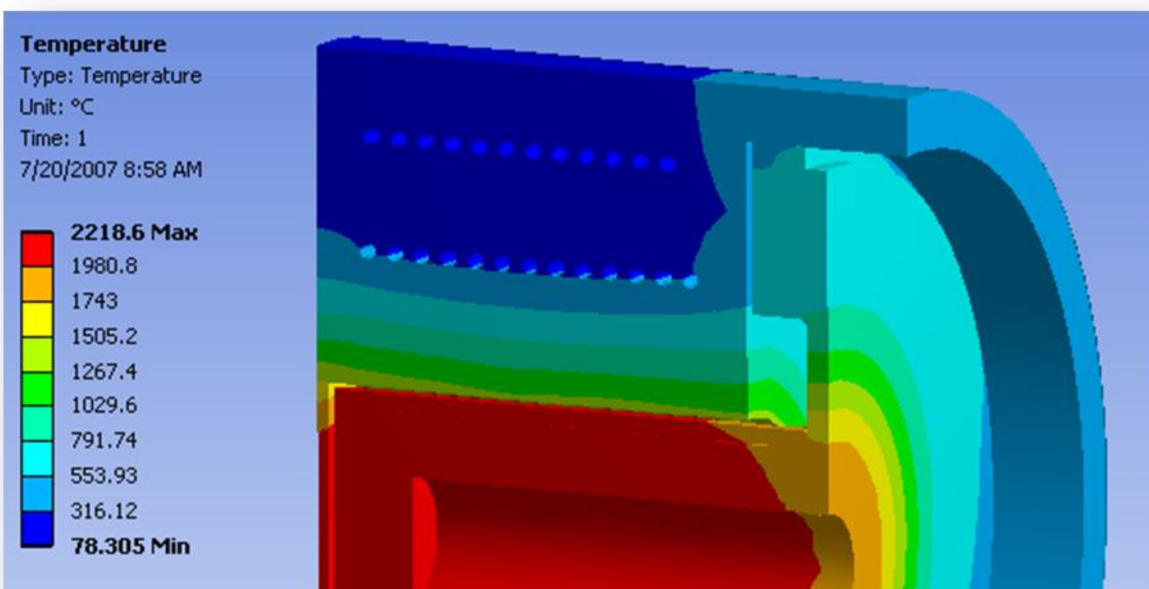


iv. Convection on the target container and Bodytube at a constant temperature

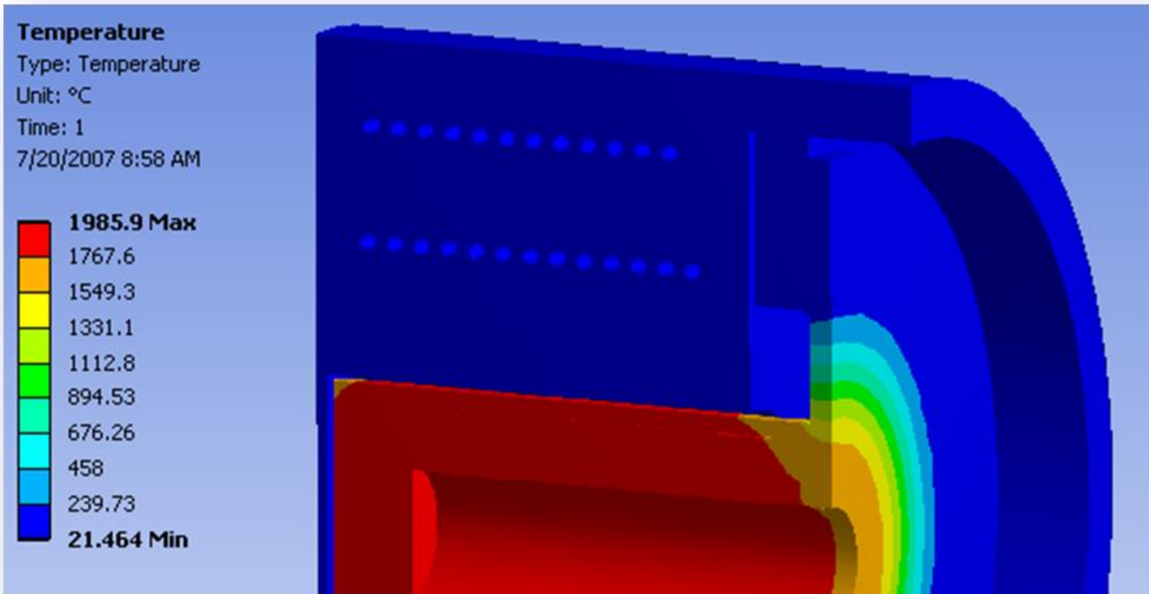


B. Half power density deposition

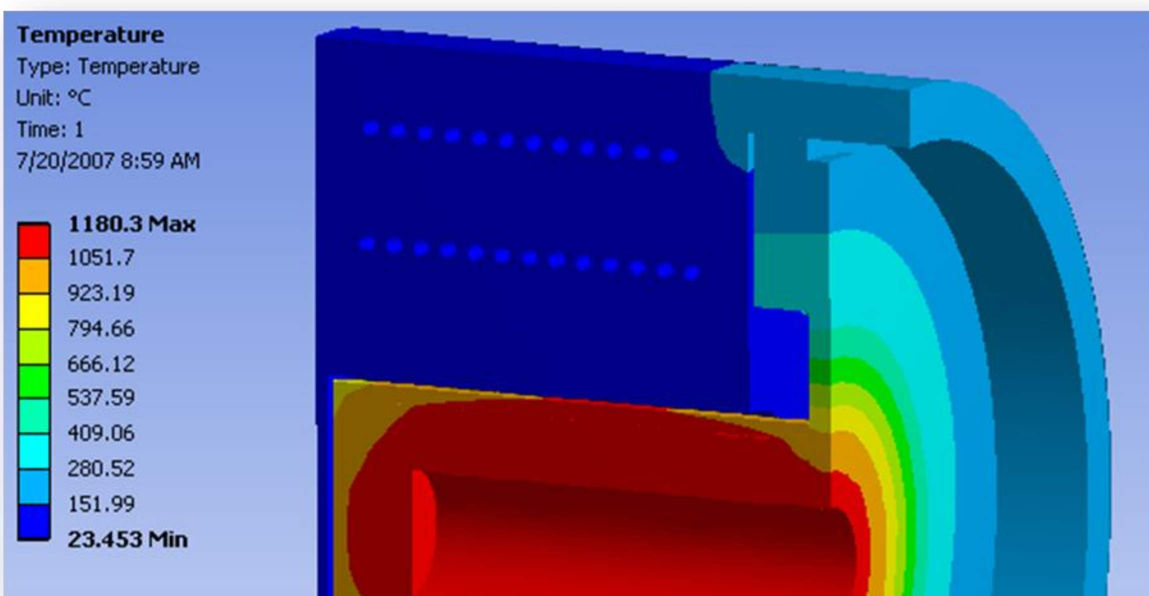
i. Convection in the cooling circuit and heat radiation between the target container and the Bodytube



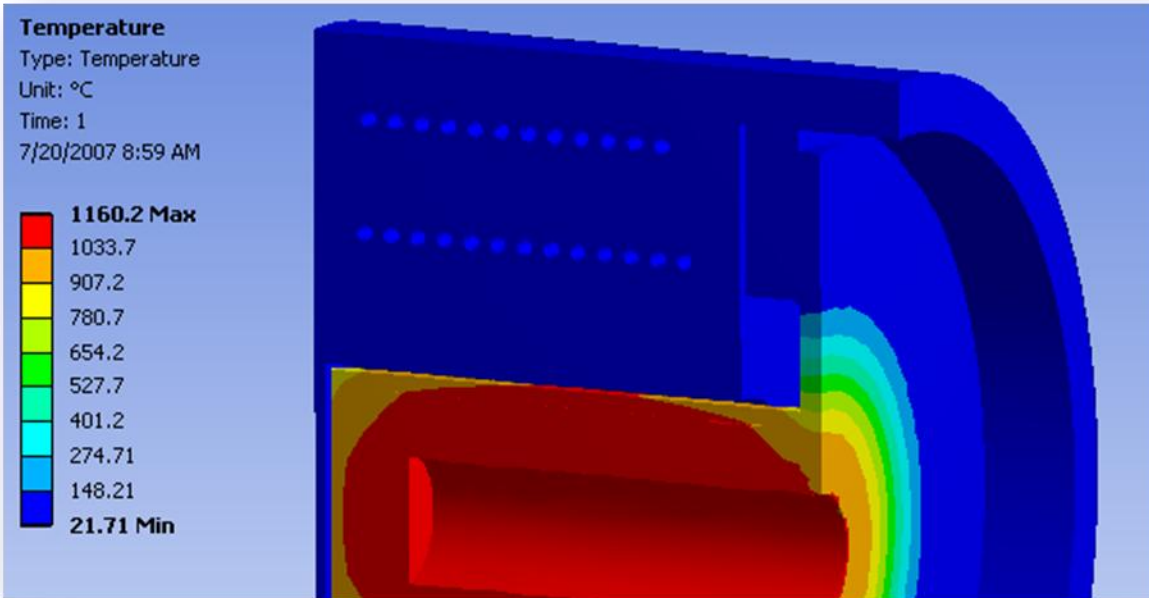
ii. Bodytube at a constant temperature and heat radiation between the target container and the Bodytube



iii. Convection in the cooling circuit and on the target container

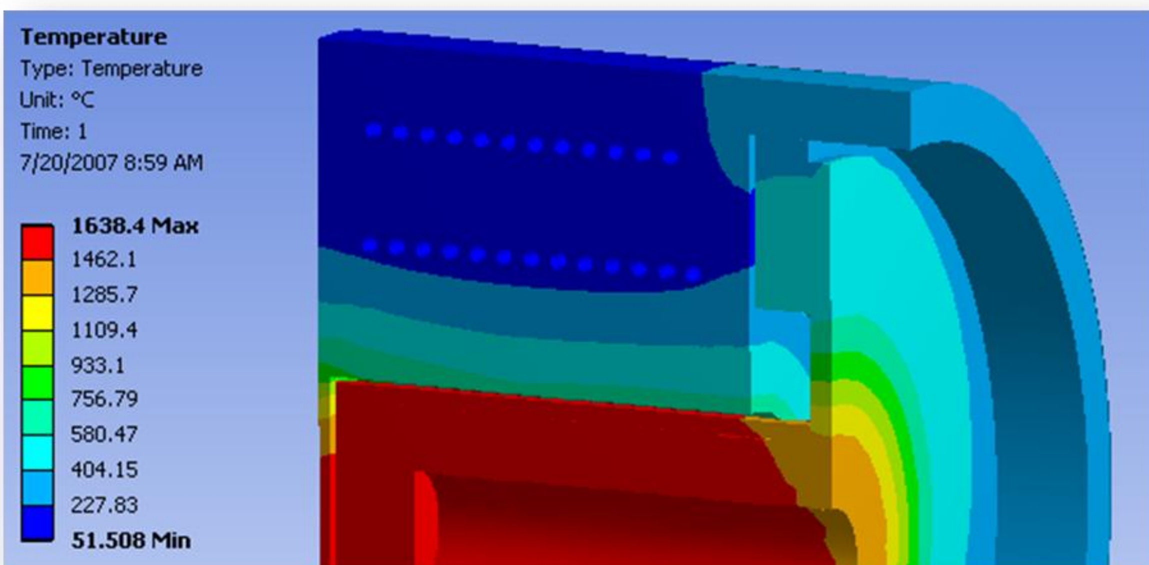


iv. Convection on the target container and Bodytube at a constant temperature

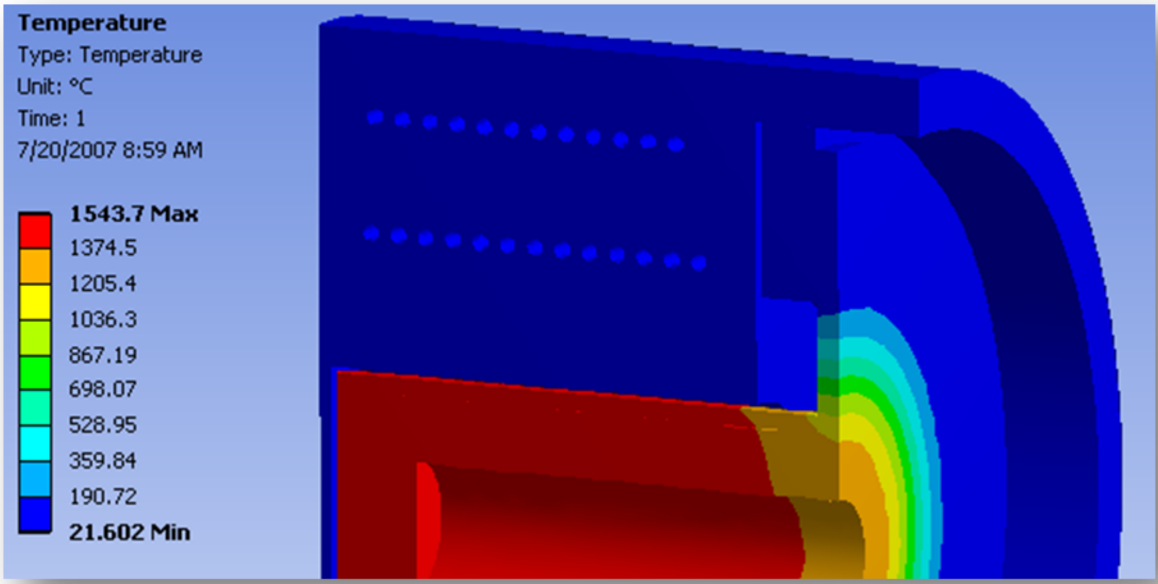


C. Quarter power density deposition

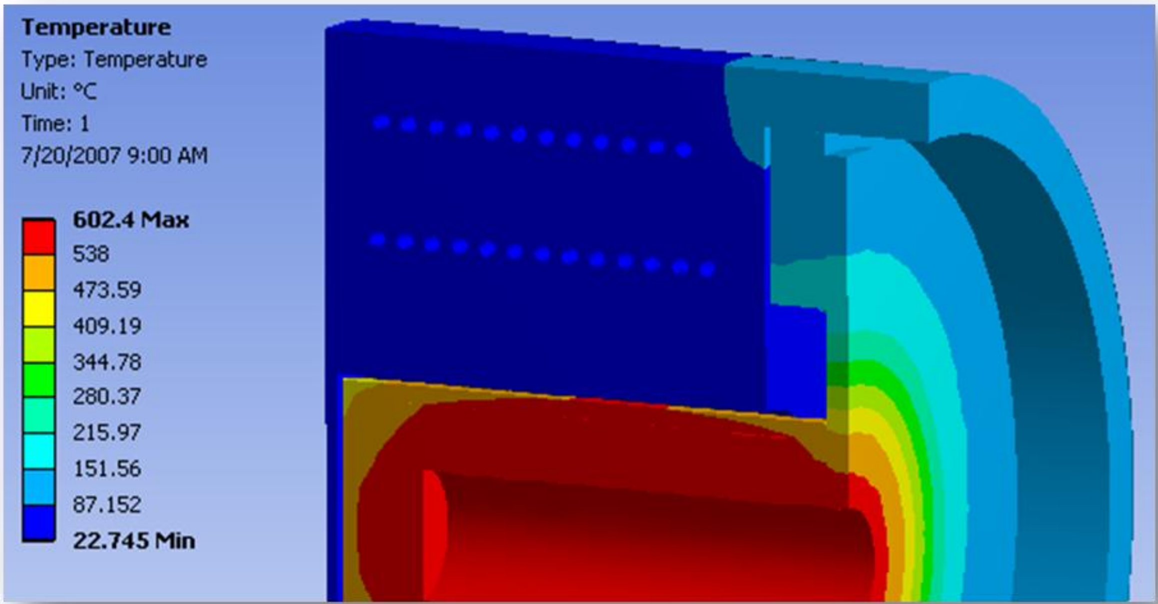
i. Convection in the cooling circuit and heat radiation between the target container and the Bodytube



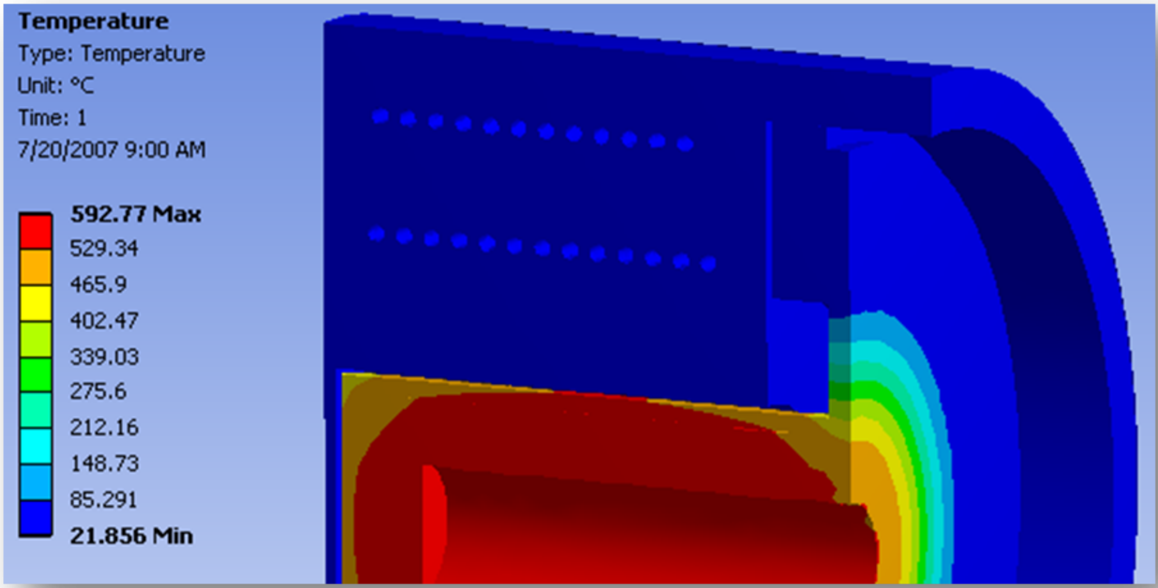
ii. Bodytube at a constant temperature and heat radiation between the target container and the Bodytube



iii. Convection in the cooling circuit and on the target container



iv. Convection on the target container and Bodytube at a constant temperature



4. Summary of results

Material conductivity	Energy deposition	Type of cooling	Maximum temperature
Graphite with Low Thermal conductivity	Full energy deposition in 1 target (32KW ~)	convection in bodytube	3644
		Body tube at constante temperatur	2849
		convection in bodytube + on container surface	2660
		Bodytube at constant temperatur + convection on container surface	2629
	Half energy deposition in 1 target (16KW ~)	convection in bodytube	2426
		Body tube at constante temperatur	2160
		convection in bodytube + on container surface	1356
		Bodytube at constant temperatur + convection on container surface	1343
	Quarter energy deposition in 1 target (8KW ~)	convection in bodytube	1748
		Body tube at constante temperatur	1653
		convection in bodytube + on container surface	691
		Bodytube at constant temperatur + convection on container surface	685
Graphite with middle Thermal conductivity	Full energy deposition in 1 target (32KW ~)	convection in bodytube	3391
		Body tube at constante temperatur	2653
		convection in bodytube + on container surface	2441
		Bodytube at constant temperatur + convection on container surface	2402
	Half energy deposition in 1 target (16KW ~)	convection in bodytube	2295
		Body tube at constante temperatur	2051
		convection in bodytube + on container surface	1245
		Bodytube at constant temperatur + convection on container surface	1227
	Quarter energy deposition in 1 target (8KW ~)	convection in bodytube	1680
		Body tube at constante temperatur	1586
		convection in bodytube + on container surface	635
		Bodytube at constant temperatur + convection on container surface	627
Graphite with high Thermal conductivity	Full energy deposition in 1 target (32KW ~)	convection in bodytube	3237
		Body tube at constante temperatur	2546
		convection in bodytube + on container surface	2316
		Bodytube at constant temperatur + convection on container surface	2270
	Half energy deposition in 1 target (16KW ~)	convection in bodytube	2219
		Body tube at constante temperatur	1986
		convection in bodytube + on container surface	1180
		Bodytube at constant temperatur + convection on container surface	1160
	Quarter energy deposition in 1 target (8KW ~)	convection in bodytube	1638
		Body tube at constante temperatur	1544
		convection in bodytube + on container surface	602
		Bodytube at constant temperatur + convection on container surface	593

VI. Conclusion

The several cases study shows the feasibility of the integration of the MAFF target into EURISOL Multi Megawatt target station. It is clearly shown that a lot of development needs to be done in order to achieve the aimed fission rate in one single target. But the possibility of achieving such an objective seems to be a lot more realistic by combining the output of two targets (so far the plan is to integrate 6 or 7 targets around the converter).

In order to perform a full thermal analysis of the proposed design, the graphite material imbibed with the desired quantity of Uranium need to be fully analyzed. The following properties need to be measured over the temperature range of the target usage condition (25°C up to 2500°C):

- specific heat
- thermal conductivity
- density

It is plan to carry test at CERN in order to specify this material in this range of temperature. It will be also necessary to include a more realistic map for the heat deposition, by importing the result from the neutronics simulation. As well when most of those neutronics calculations will be finished, it will be easier to design the cooling system because it is where the neutron moderators or reflectors are placed.

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