06. Thermal analyses

ESS-Bilbao

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CDR PBW-PB & Vessel - 04 July 2019, Lund (ESS)

Table of contents

Modelling and Calculation methodology

Thermal analyses

Results from MCNP

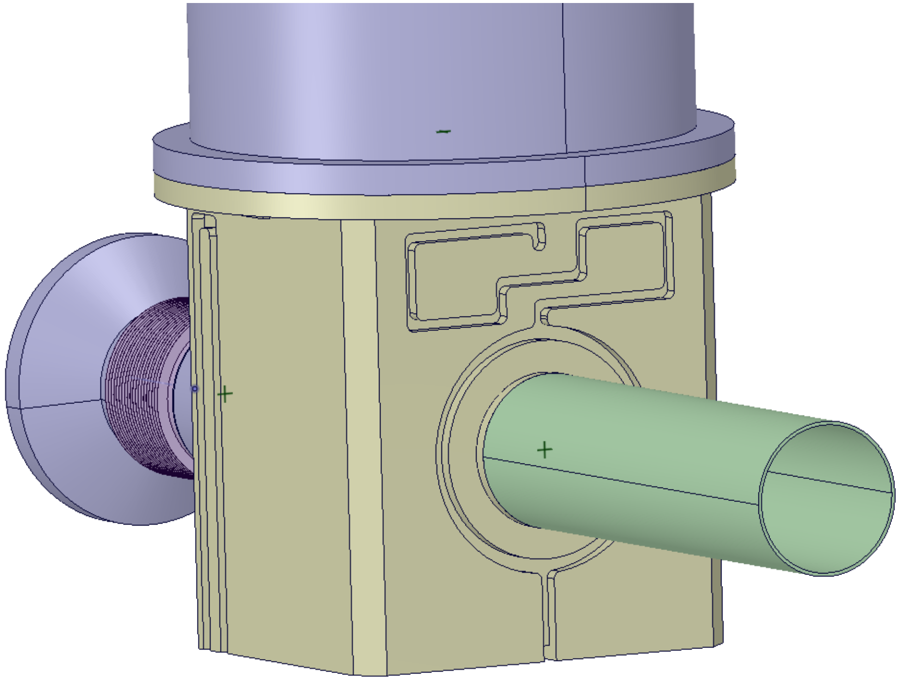
- Results from nuclear calculations in MeV/g of voxel.
- Converted to W/m3 per voxel.
- Imported and corrected to measured power deposition.

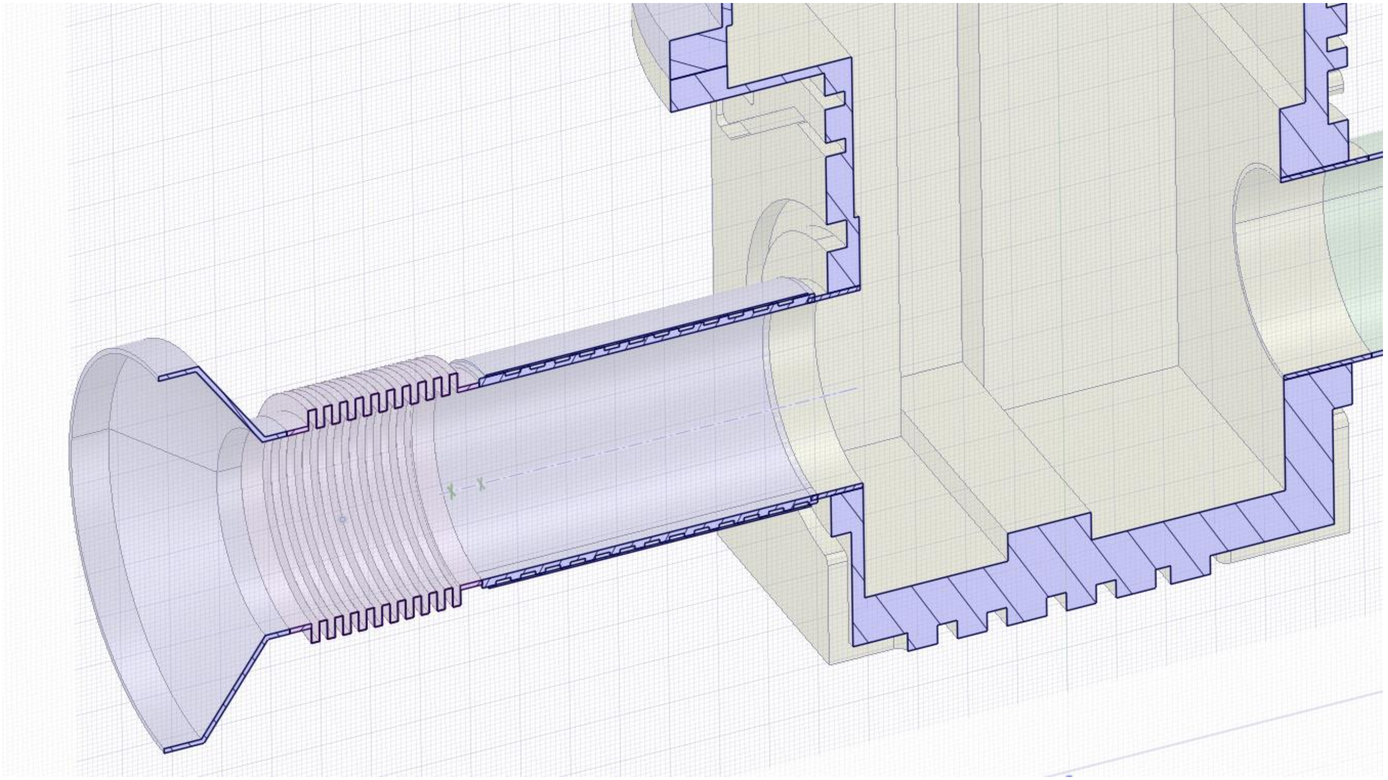
Component	Heat load [kW]
Port Block	2.300
Connecting Pipe	0.877
Shielding blocks	1.750
TOTAL	4.920

Thermal analyses

Modelling

- Geometry adapted. Deteil in cooling channels.
- Rectangular shaped bellow to ease meshing.
- Drift pipe modelled.
- PBW-Vessel: only modelled the bottom .

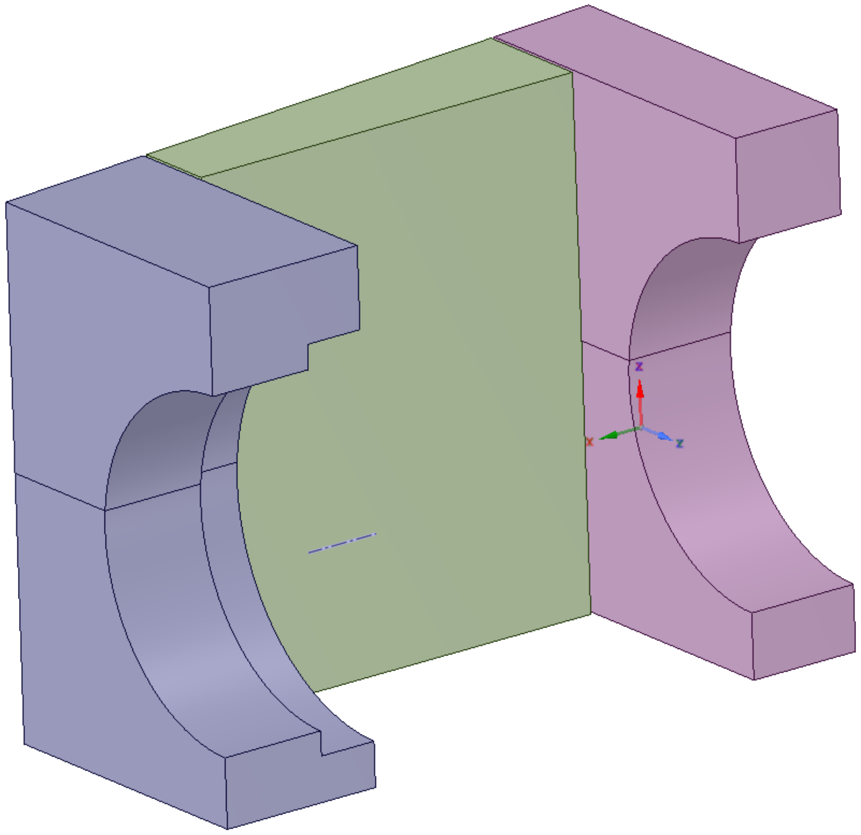


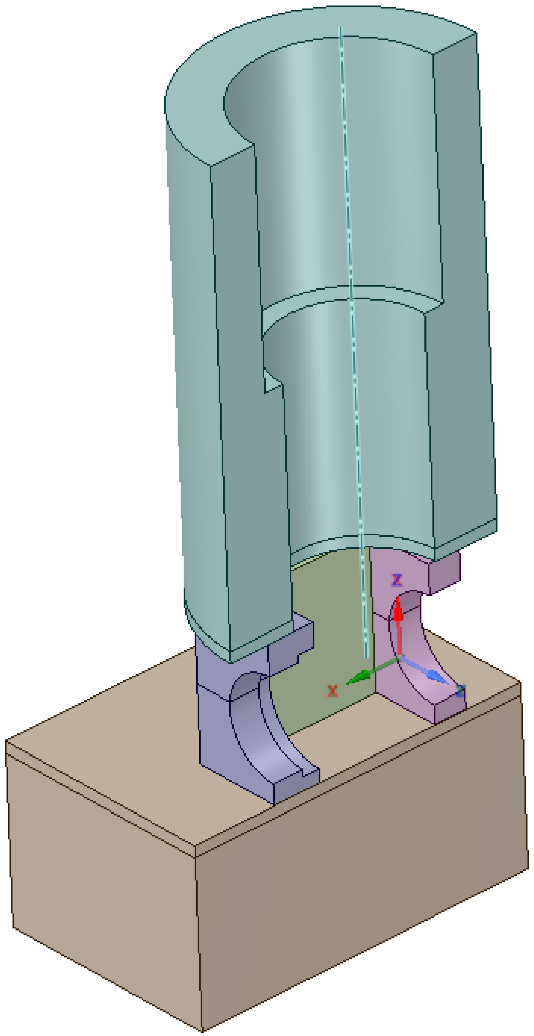


Thermal analyses

Modelling

- Half of components modelled (symmetry).
- Need to include shielding above and below to evaluate conduction heat transfer.

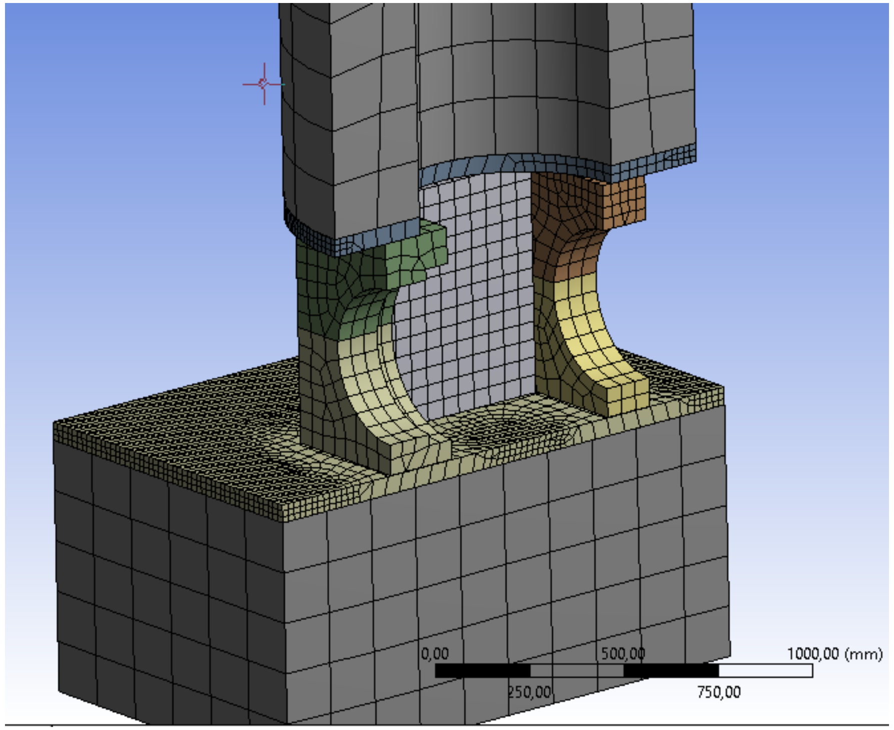


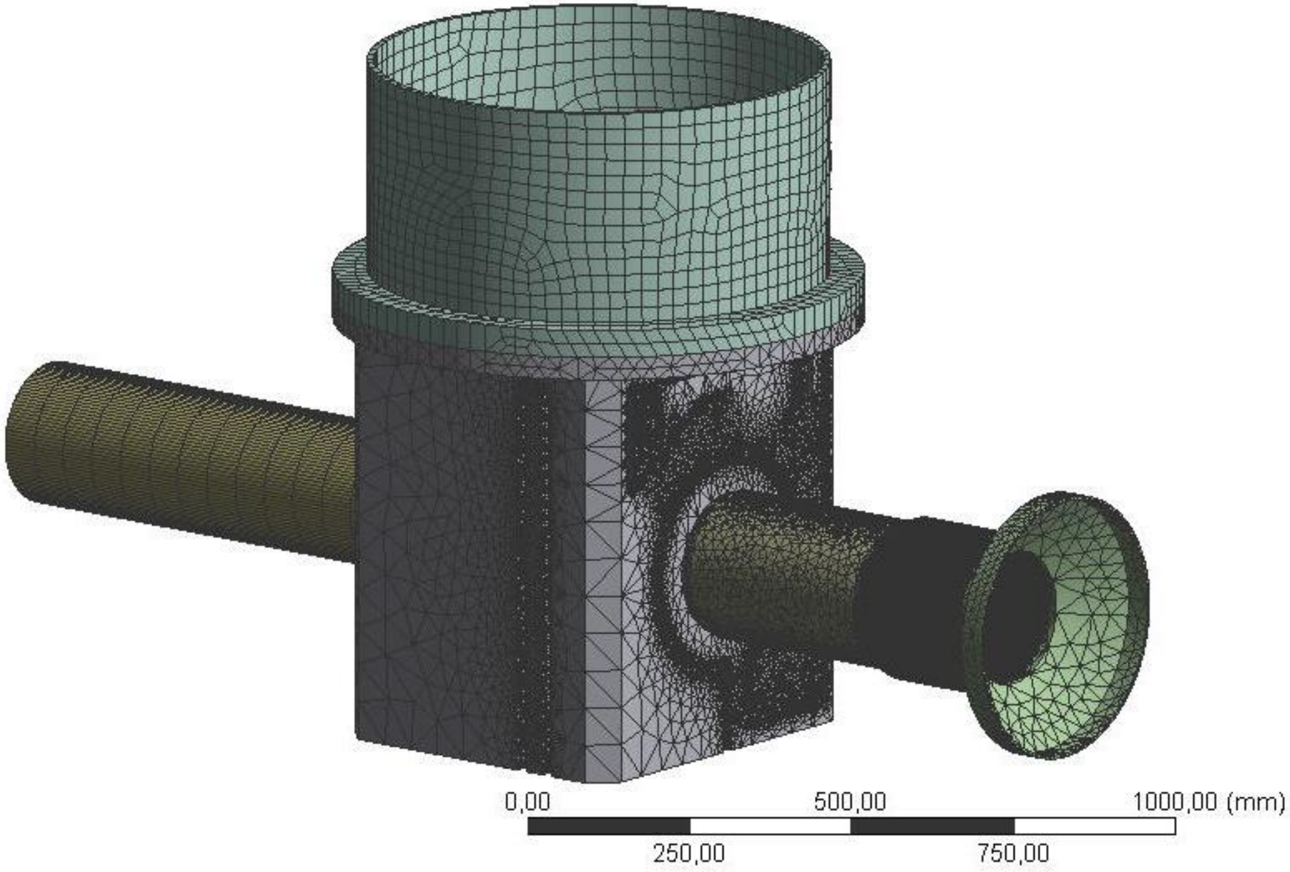


Thermal analyses

Meshing

- Focusing on cooling channels.
- Refine meshing around PB Sealing surfaces and Connecting Pipe.

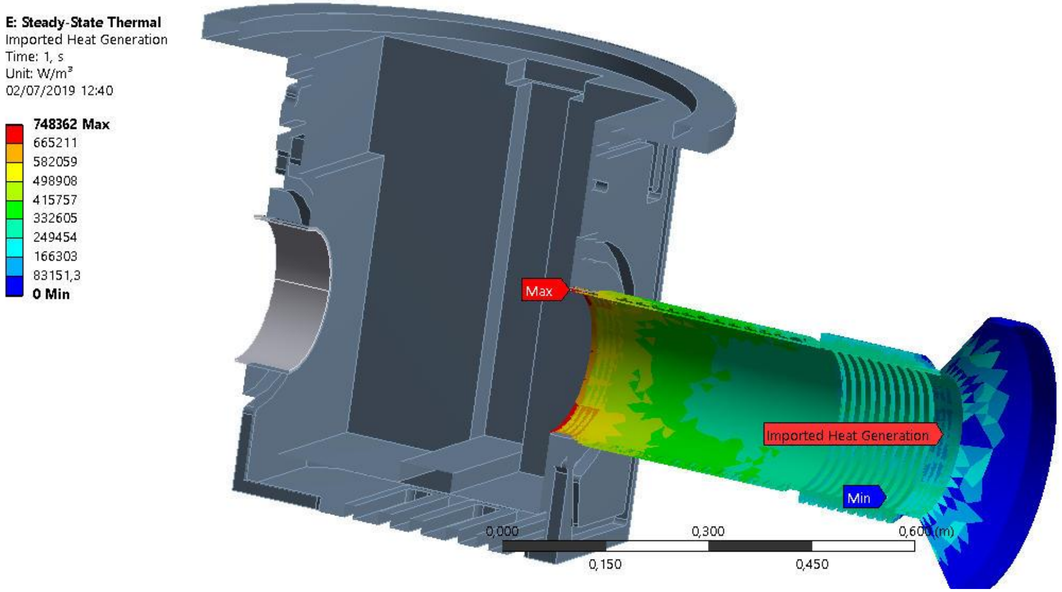


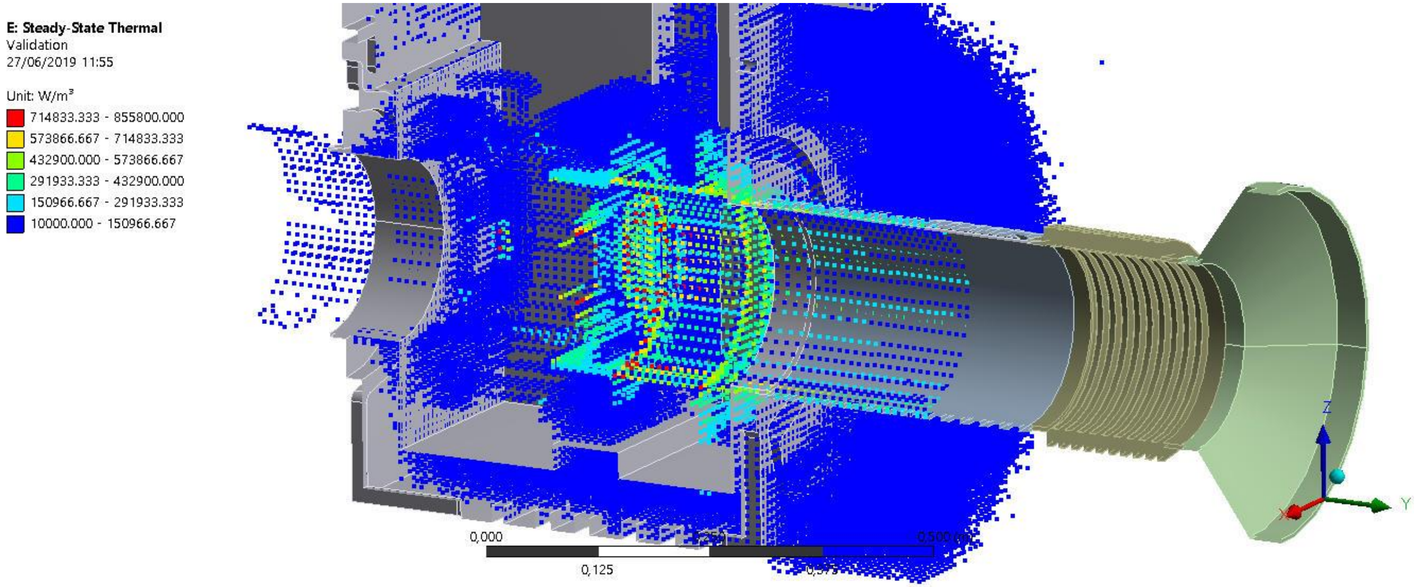


Thermal analyses

Source importation

- Heat deposition checked an corrected to MCNP values.





Thermal analyses

Models used to determine heat transfer coeficients

Active cooling. It will occur inside cooling channels, present in the PB and Connecting Pipe.
High Reynolds number combined with developed regions will lead to turbulent flow in the whole cooling channels. Dittus-Boelter equation in internal tubes with equivalent hydraulic diameter is highly accurate.

$$Nu_D = 0.023 {Re_D}^{4/5} Pr^{1/3}$$

Natural convection. Appears outside the PBW-Vessel and Port block. It will depend on Rayleigh number. The small height of the PB will result in laminar flow, while the PBW-Vessel will see both laminar and turbulent. Nusselt correlation from Churchill and Chu for free convection in vertical plates can be applied (valid for all Ra range).

$$Nu_L = \left[0.825 + \frac{0.387 Ra^{1/6}}{(1 + (0.492/Pr)^{9/16})^{8/27}}\right]^2$$

Limited natural convection. This mechanism will appear in all gaps between components where there is presence of air. Note that the sub-pressure of the atmosphere will reduce this coefficient.
Nusselt number for natural convection, depending on Ra, corrected for small cavities is used.

$$Nu_S = \left[\frac{C1}{(Ra_S S/L)^2} + \frac{C1}{(Ra_S S/L)^{1/2}}\right]$$

Thermal analyses

Heat transfer Coeficients

- Heat Transfer coef. are calculated.
- Thermal contact resistance are determined from pressure estimated in connections.

Heat transfer Coefficient	Value [W/m^2-K]
Force convection in PB	2700-3300
Force convection connecting Pipe	8700
Natural convection PB (T_S=80ºC)	4.47
Natural convection Vessel (T_S=60ºC)	2.84
Shielding blocks Natural convection. 5 mm gap	2.04
Shielding blocks Natural convection. 2 mm gap	0.14

Thermal contact resistance	Value [m^2-K/W]
Seals to PB surface (P>800 kN/m^2 , gap<20 µm)	4.0E-4
Shielding blocks to baseplate (P>30 kN/m^2, gap<20 µm)	1.7E-3

Thermal analyses

Coolant analysis

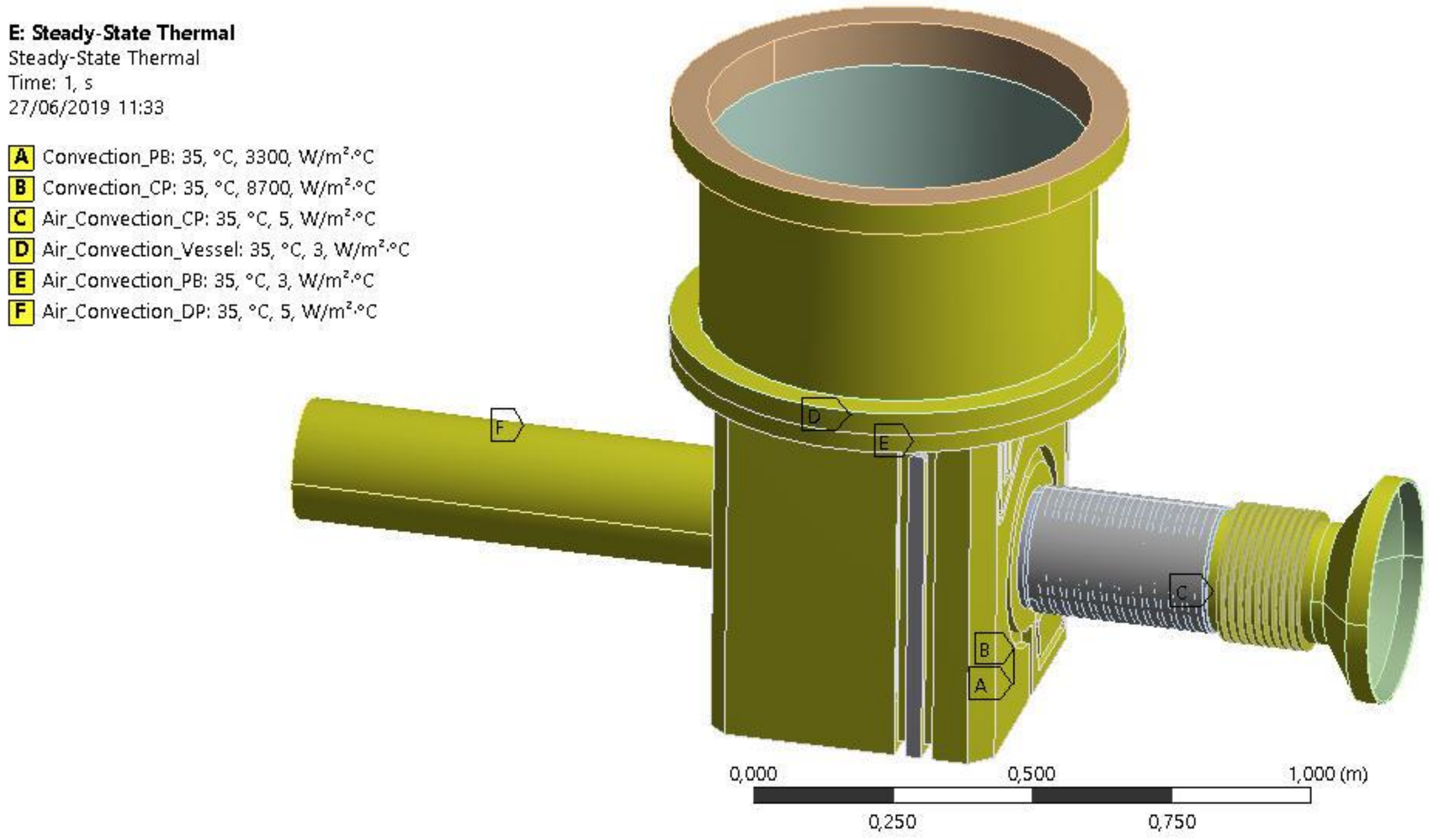
- Power removed, temperatures and pressure drop are determine from cooling parameters.

Magnitude measured	Value
Mass flow	0.3 [kg/s]
Inlet temperature	35ºC
Power removed by cooling system	3.032 kW
ΔT	2.5ºC
Power removed by convection in PB	2.250 [kW]
Power removed by convection in the Connecting Pipe	782 [W]
Power removed by convection & conduction	301 [W]
Power removed by convection & conduction in Shielding blocks	2.97 [kW]
Average velocity of the fluid	1.70 [m/s]
Estimated pressure drop	46 [kPa]
Ambient temperature	35ºC

Thermal analyses

Boundary Conditions

- Convection mechanisms applied.

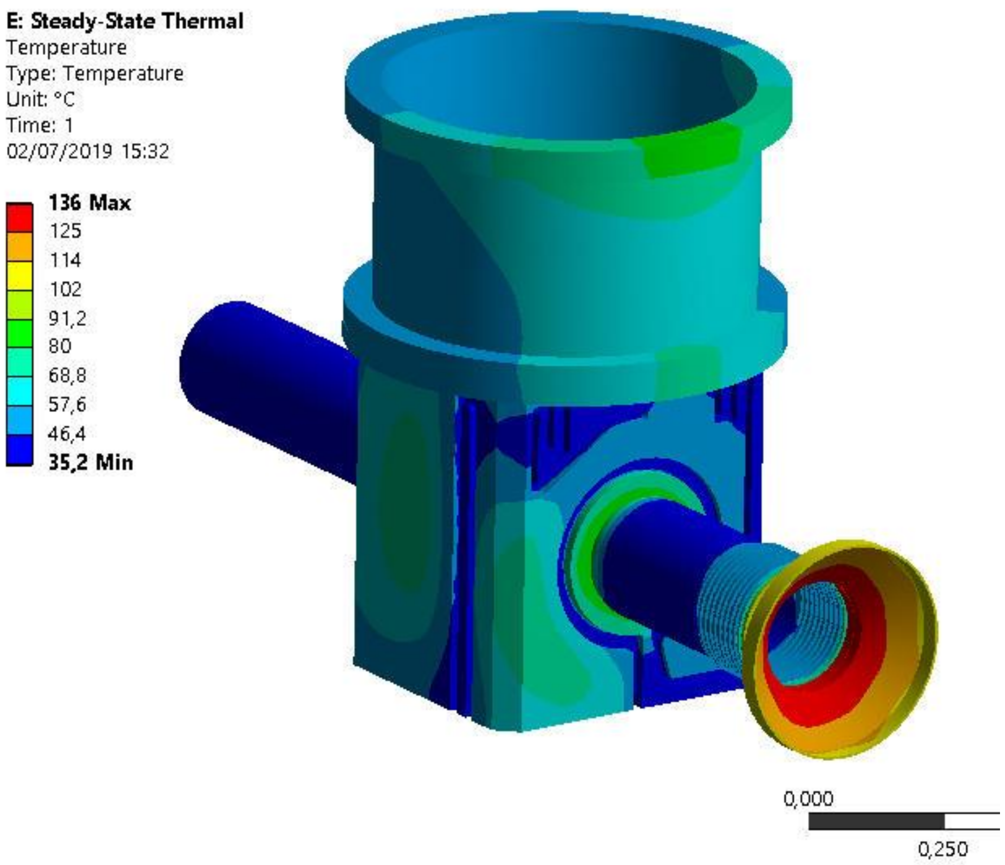


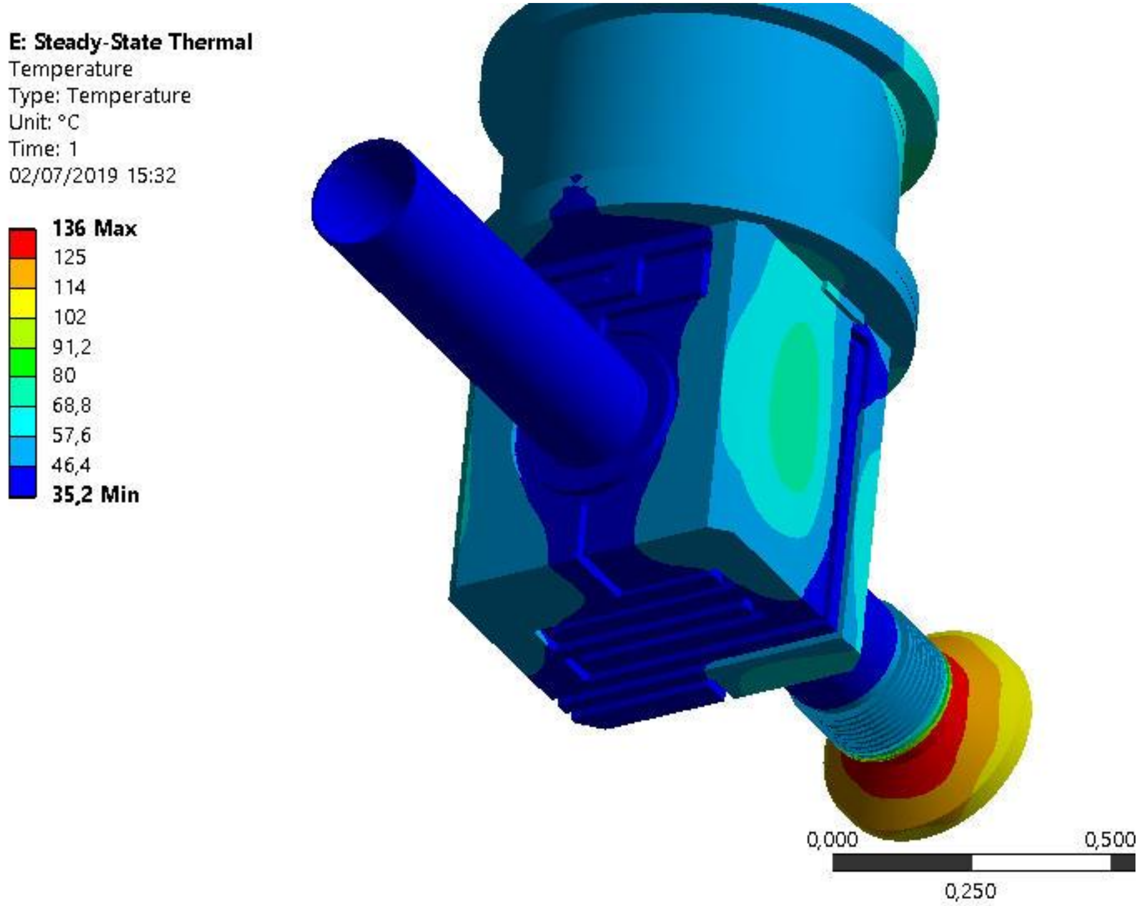
Thermal results of PB and Vessel

Thermal analyses

Temperature Maps

- Maximum temperature is 136 ºC after the bellow weld

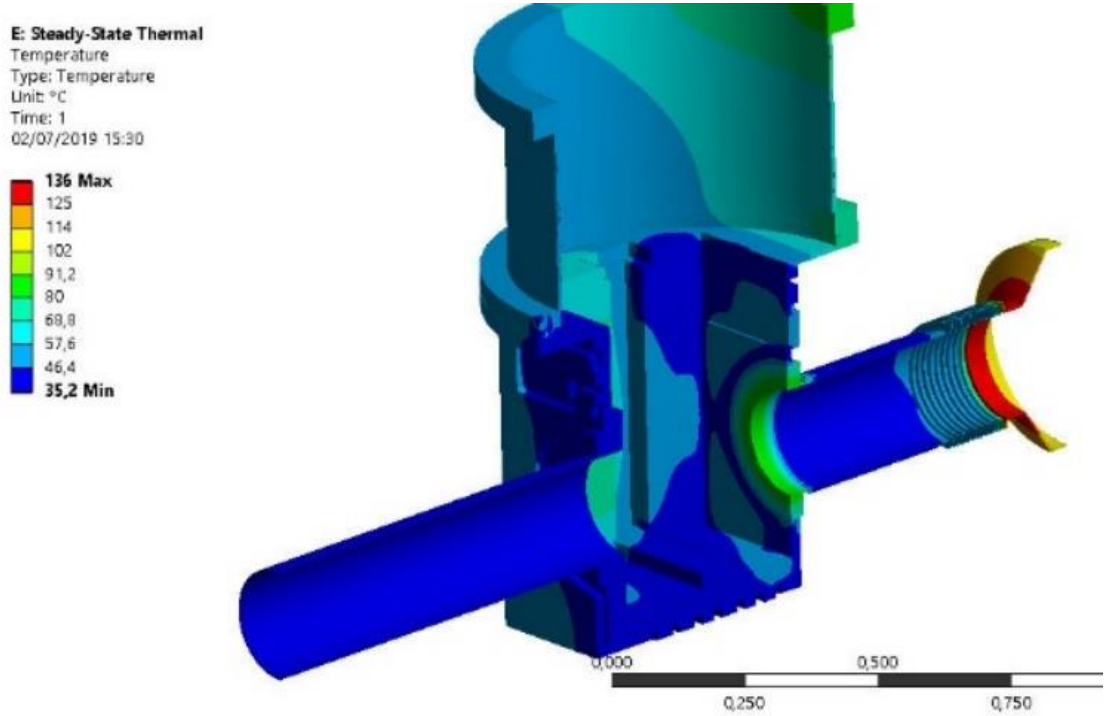


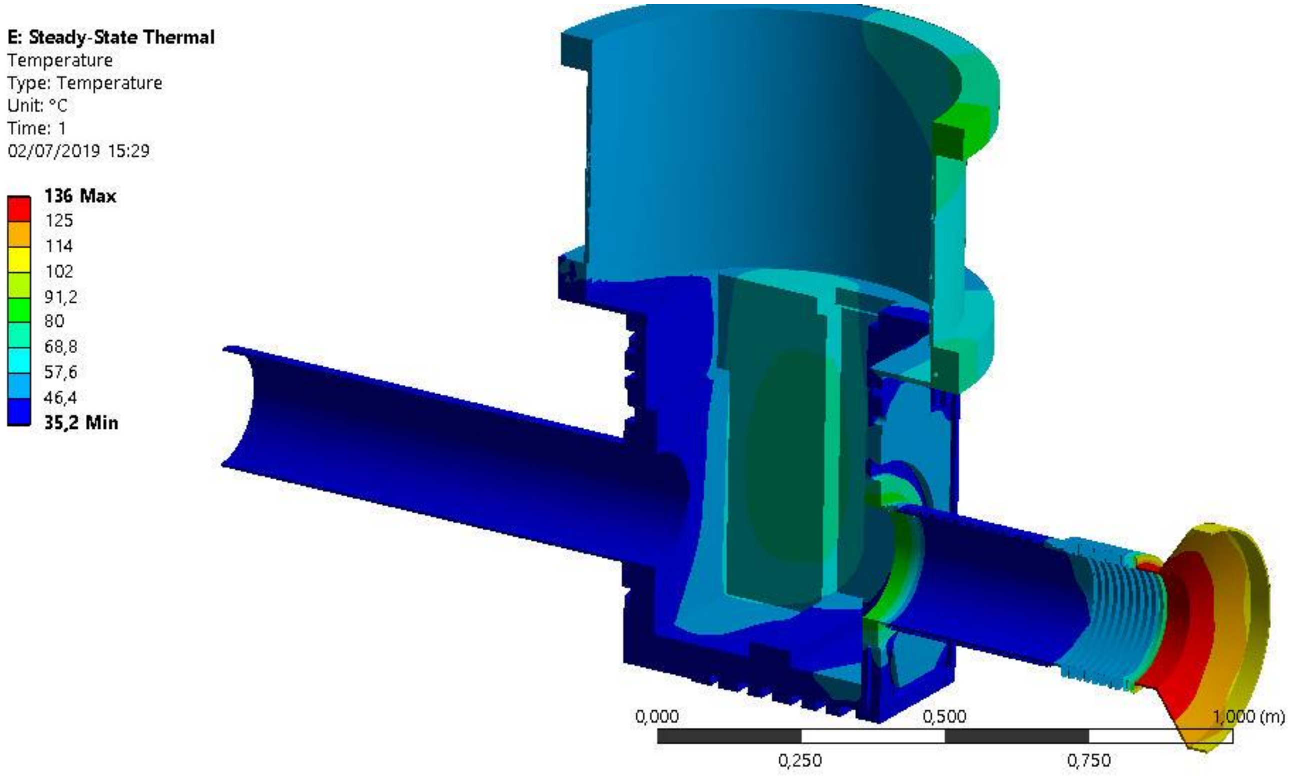


Thermal analyses

Temperature Maps

- Far below from SS316L change of properties (>400ºC).

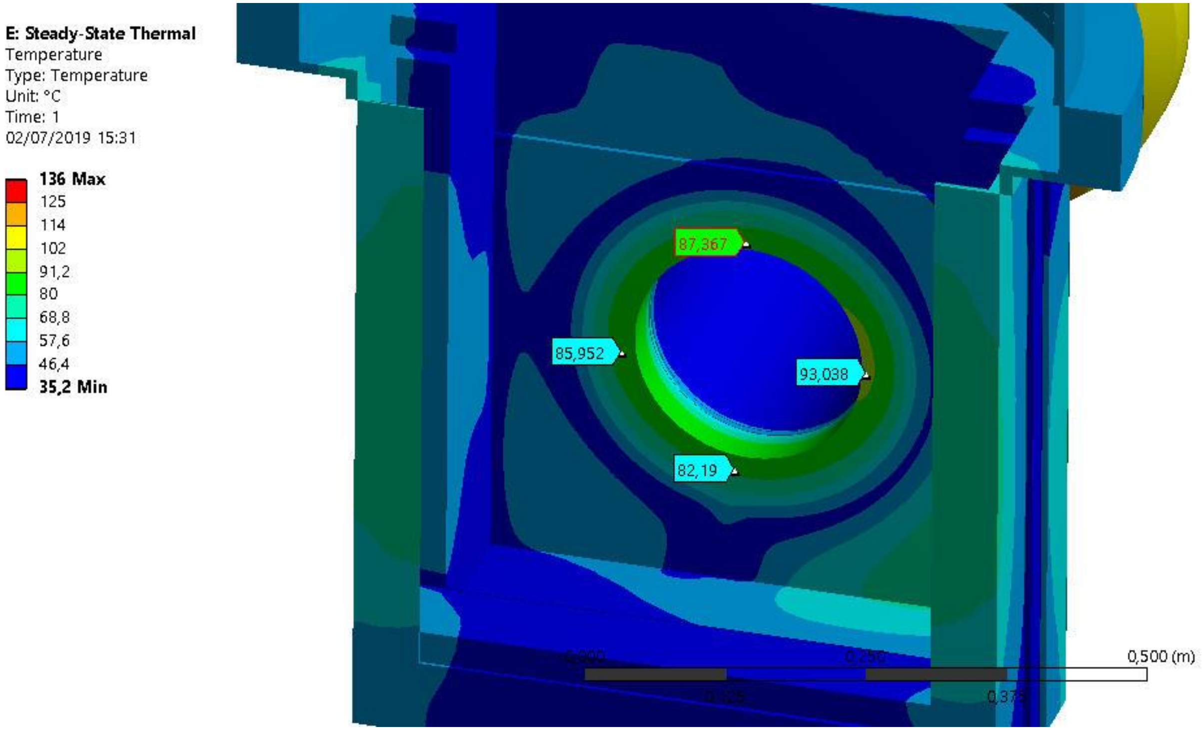




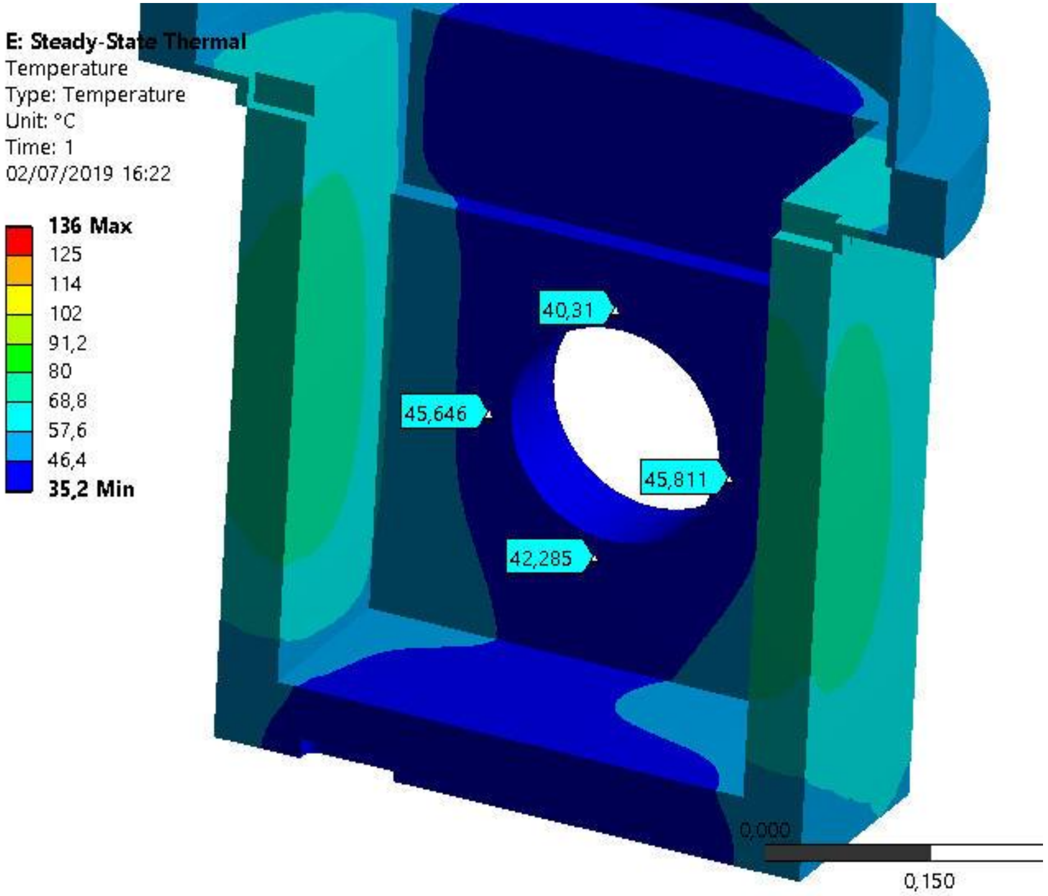
Thermal analyses

Sealing surfaces

- Maximum temperature difference is only 12ºC.



Target side surface

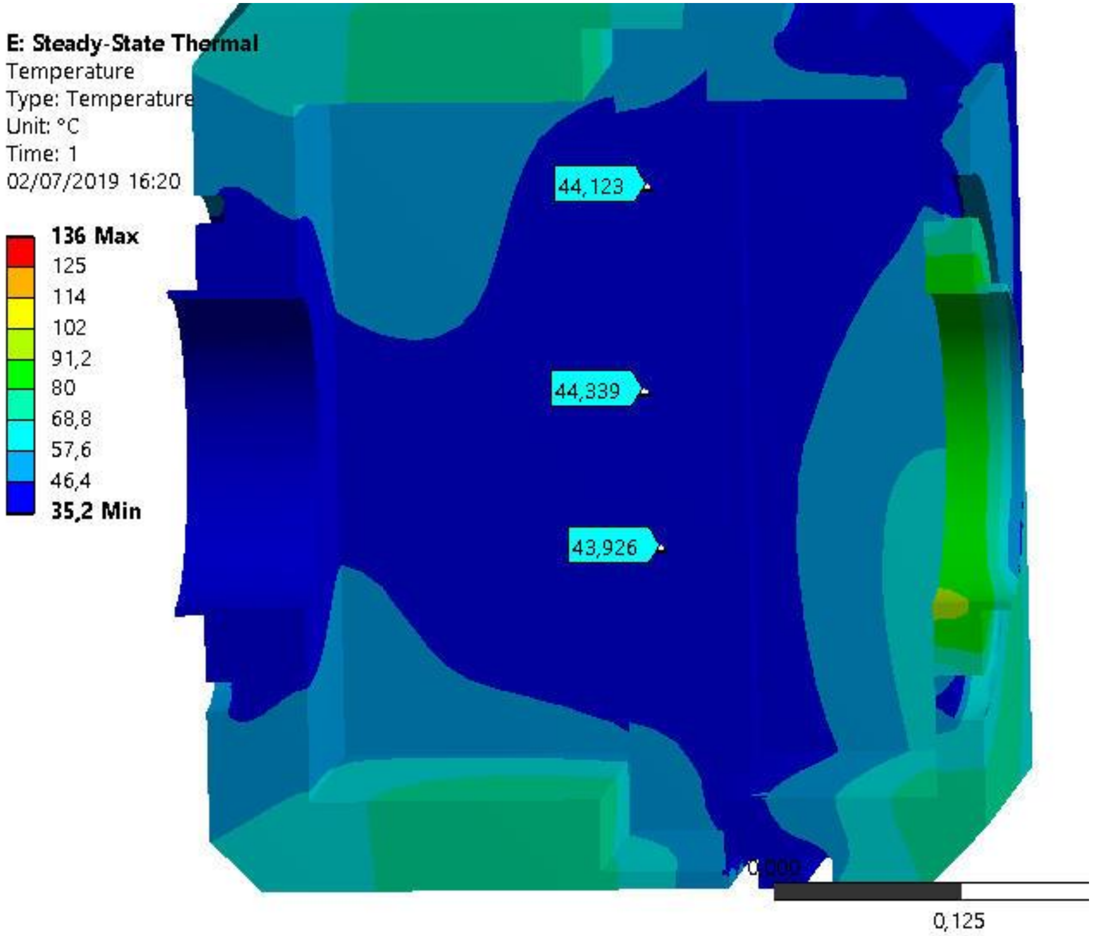


Accel. side surface

Thermal analyses

PB bottom surface for PBI

- Less than 1ºC.



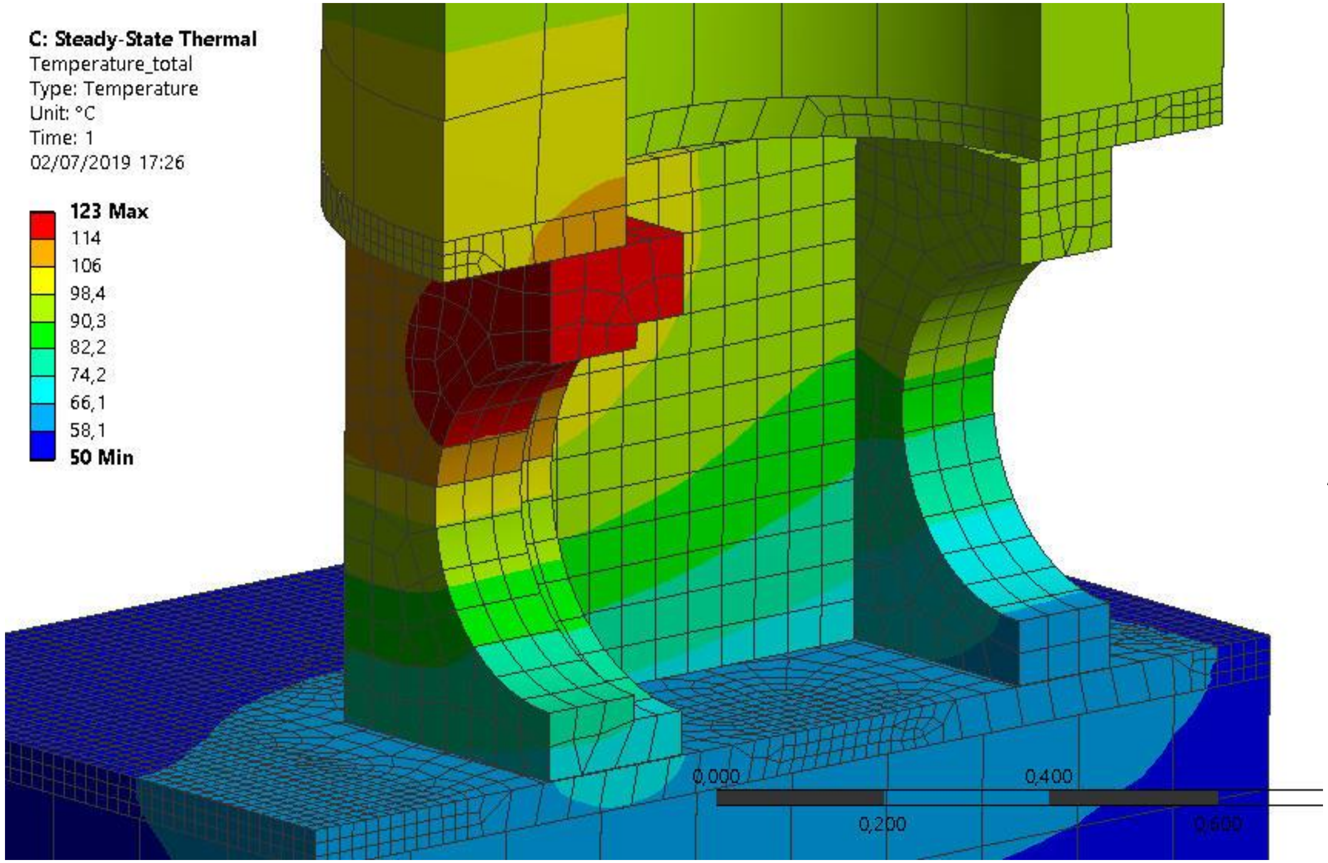
Thermal results of Shielding blocks

Thermal analyses

Temperature maps

- 123 ºC max.
- No remarkable deformation of mechanical stresses.

TARGET SIDE



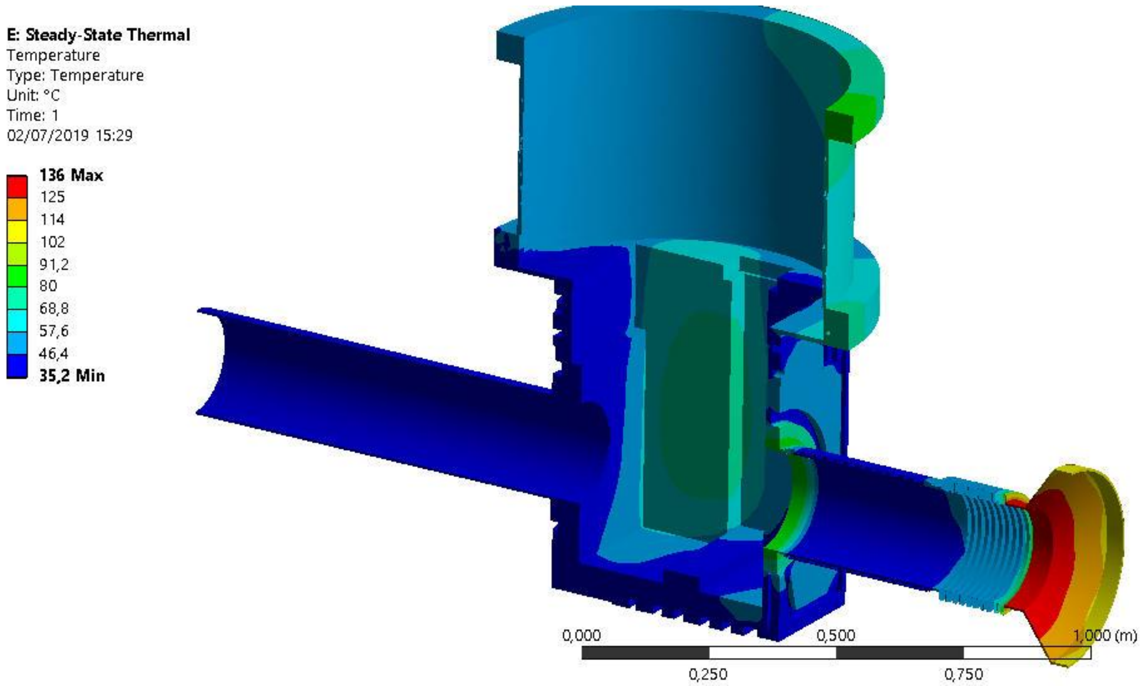
ACCELERATOR SIDE

Conclusions

Thermal analyses

Conclusions

- **Cooling design is validated** to evacuate all power deposited in the PB, Vessel and Connecting Pipe.
- **Reduction of diameter** from 420 to 210 mm, and thickness from 10 to 5mm of CP has proven to be a good choice, since **power has been reduced** to less than a half (from 2KW to 880W).
- **Thermal deformations** in **PBW Seal** surfaces are **controlled** (<12ºC). It will be possible to perform a proper sealing.
- **Bottom** surface has also well **controlled** temperatures (<1ºC).
- **Maximum temperatures** of **136ºC** after the bellow won't compromise functioning.
- Power deposition in the vessel is negligible.
- Design of cooling channels feasible to be manufactured.



Prototyping

Thermal analyses

Prototyping the CP

- Scaled prototyped has been built.
- Proven the capability to withstand 5 bar pressure.
- Deformations of the cover (jacket) around the pipe are less than 30 microns. There is no bypass in the design.
- Coolant flows easily through the helical channels, cooling both the pipe and the cover.

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