Mu2e Proton Beam Dump Heat Removal System

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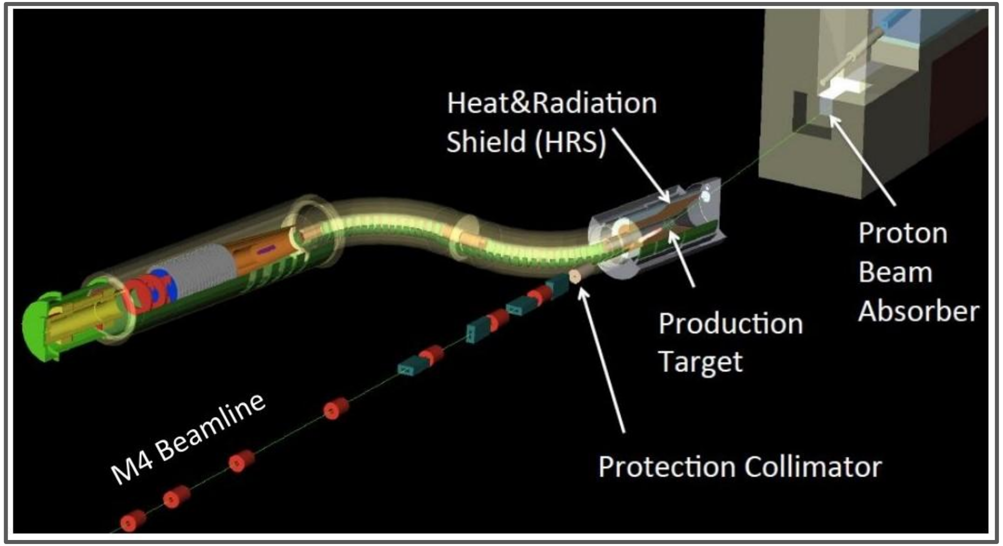
Proton Beam Dump

The Proton Beam Dump is a component made of **seven steel plates** surrounded by a steel baffle and **concrete** that absorbs the proton beam.

It needs a **Heat Removal System** where air circulates in forced circulation because the **concrete** temperature **should not go over 95 ° C**.



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Task description

Verification of the **operative conditions** of the **Heat Removal System** of Mu2e Proton Beam Dump

- 165 CFM vs 250 CFM
- Arbitrary power distribution generated by MARS code
    - Accident condition (6.7 kW)
    - Normal operation (1.7 kW)

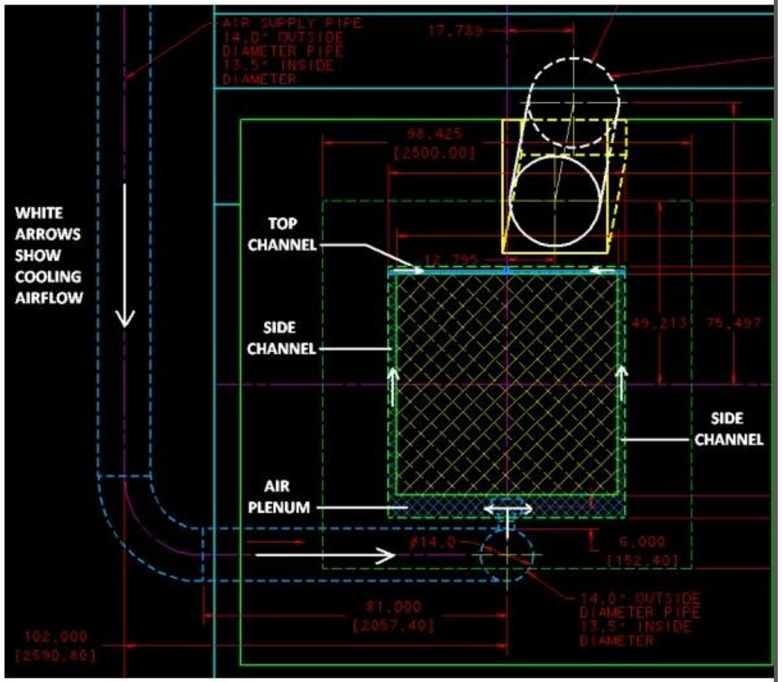

Figure 4.180. Airflow path through absorber – upstream view.

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Checking the results of the Excel file

Correction of **minor errors** in turbulent flow correlations

- P.K. Swamee and A.K. Jain formula
- Colebrook formula

Rewriting of the **sheet formulas** in clearer **VBA language**

Flow path number		1	2	3	4	5	6	7-1	7-2
		Building supply duct	Crossover line from building air duct to supply header	Supply header	Individual feed pipe	Horizontal gap under the core	Vertical gap between core and wall (half right)	Horizontal gap on top of the core 1 - lateral flow	Horizontal gap on top of the core 2 - longitudinal flow
Use the smaller heat transfer coefficient	W/(m^2-K)	3.6	3.6	2.2	8.1	1.2	2.8	2.5	6.9
Tsurface - Taverage bulk air	C	0.000	0.000	0.000	0.000	75.259	70.939	42.959	0.000
Calculate the surface temperature (CHECK INPUT)	C	20.000	20.000	20.000	20.000	109.065	156.744	232.680	255.442

Results with **165 CFM**: **very small heat transfer coefficients**

Flow path number		1	2	3	4	5	6	7-1	7-2
		Building supply duct	Crossover line from building air duct to supply header	Supply header	Individual feed pipe	Horizontal gap under the core	Vertical gap between core and wall (half right)	Horizontal gap on top of the core 1 - lateral flow	Horizontal gap on top of the core 2 - longitudinal flow
Use the smaller heat transfer coefficient	W/(m^2-K)	4.9	4.9	3.0	10.9	1.7	3.9	3.5	9.3
Tsurface - Taverage bulk air	C	0.000	0.000	0.000	0.000	54.290	51.290	31.362	0.000
Calculate the surface temperature (CHECK INPUT)	C	20.000	20.000	20.000	20.000	86.803	128.352	197.475	223.128

Results with **250 CFM**: **slightly bigger heat transfer coefficients**

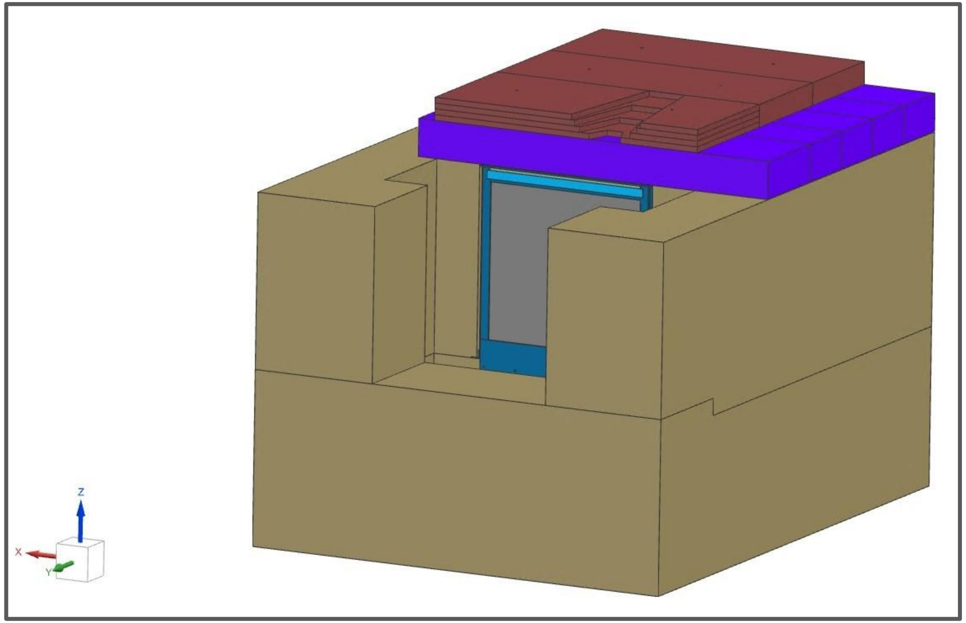
CAD Elaboration

Presence of **both solid and fluid** components file CADs

Merging of the solid CAD and the fluid CAD in one file

Checking for **coincidence of the to-be-coupled surfaces**

Refinement of details (removal of holes, small imperfections) to facilitate the meshing process



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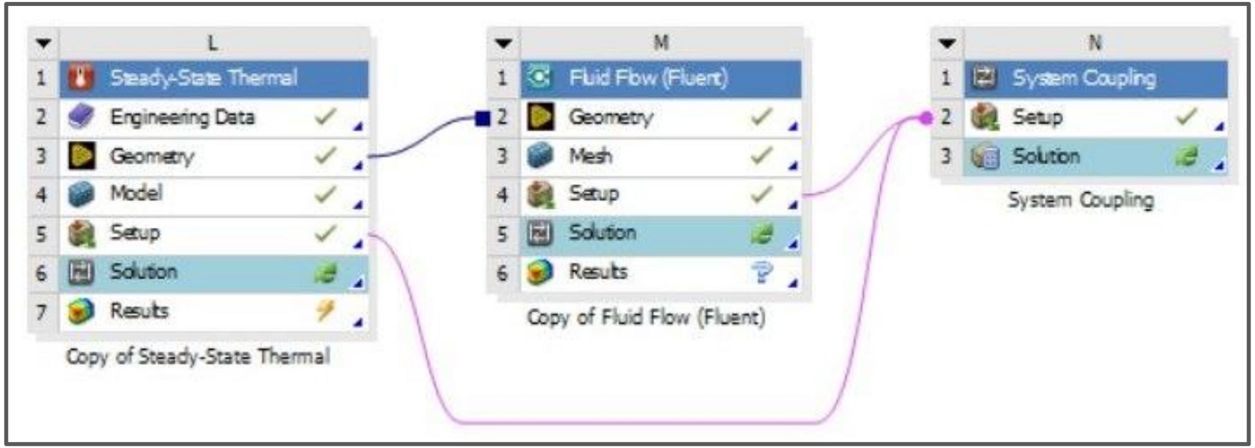
ANSYS Coupled Simulation

Necessity of a coupled simulation to get the **most accurate results**

Decision of the **blocks** to put inside of the simulation

ANSYS offers the System Coupling block that couples **different phases**



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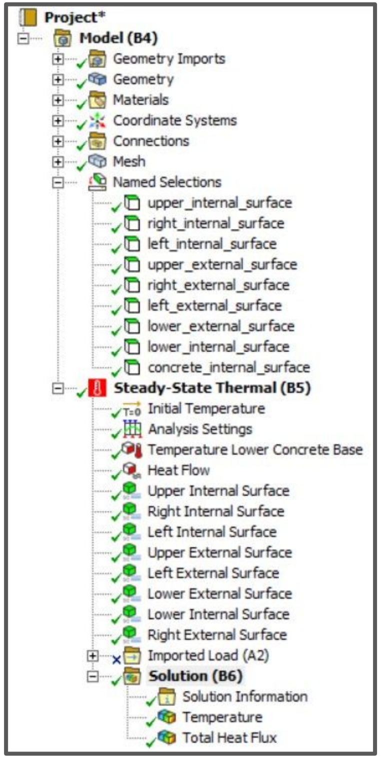
Boundary conditions - Heat transfer

Imposed 15 C temperature on the bottom surface of the lower concrete block

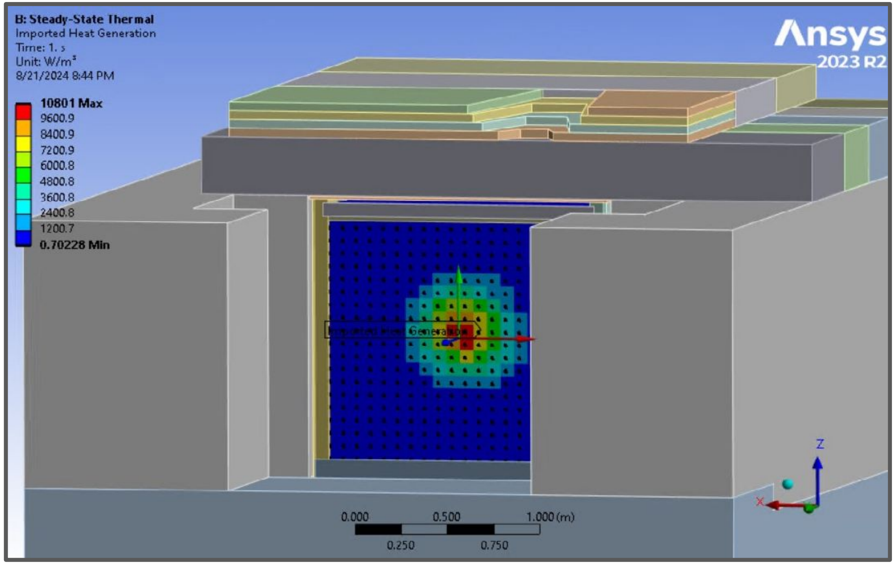
Perfect insulation as default conservative assumption

System Coupling Surfaces: the eight coupled surfaces

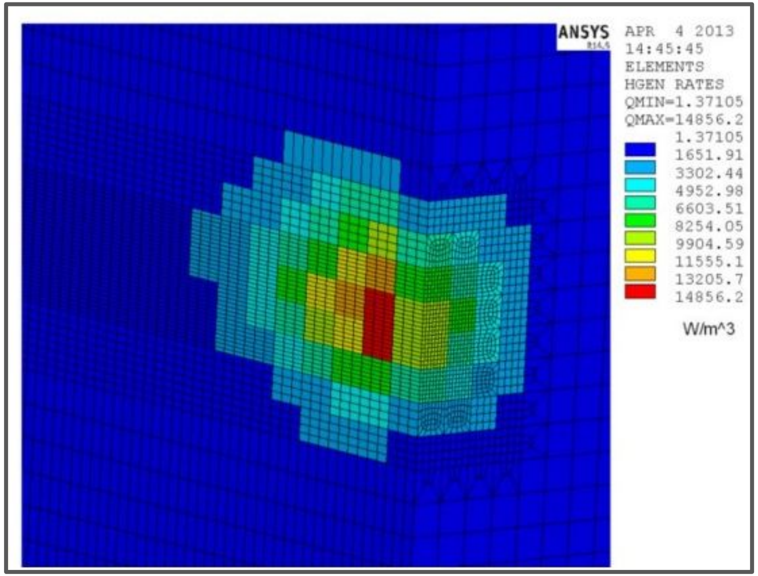


Boundary conditions - Heat generation

Heat generation from MARS distribution with **1.325 kW of power deposited locally**



Mapped heat distribution (**obtained**)



Mapped heat distribution (**previous**)

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Boundary conditions - Fluid

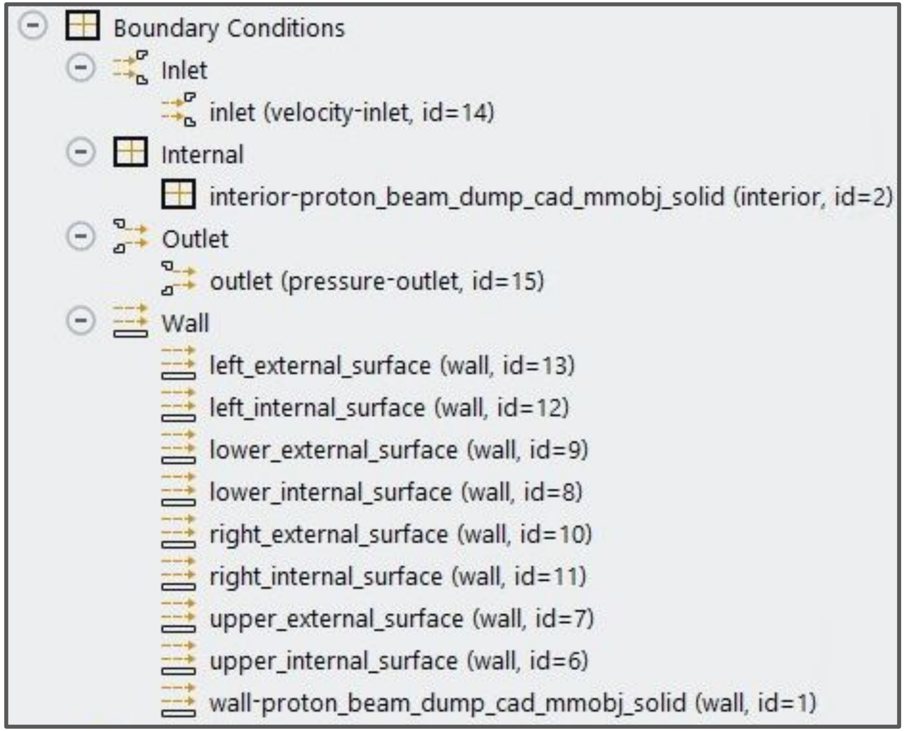
Imposed **inlet velocity**

Imposed **outlet gauge pressure**

Fluid properties: **air**

Energy equation: **on**

Thermal boundary conditions: **via System Coupling surfaces**



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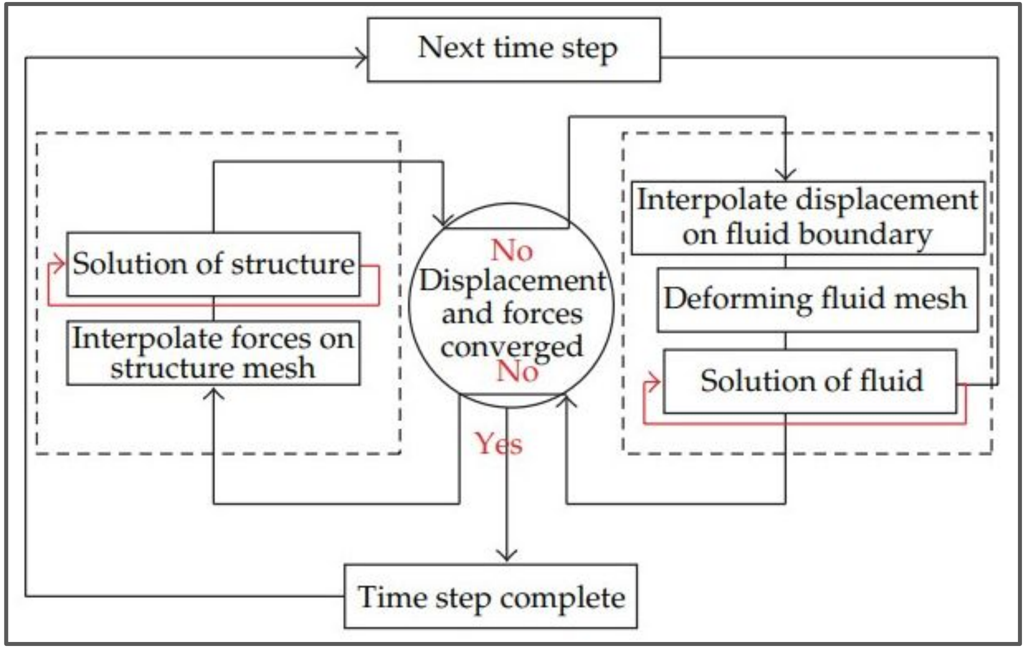
Two-way data transfer

Two-way data transfer

Data is initialized in the uncoupled simulation and **transferred on the coupled interfaces**

More coupling iterations to get the **converged and common value**



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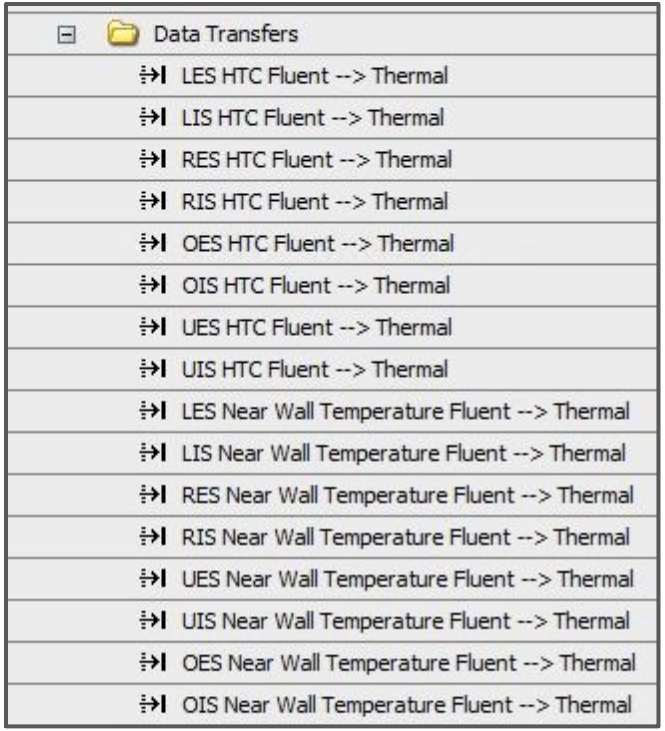
Coupling conditions

To make the coupled convection work, for each surface two transfers are needed :

- **Heat Transfer Coefficient** from Fluent simulation to **Convection Coefficient** of Thermal Steady-State simulation
- **Near Wall Temperature** from Fluent simulation to **Convection Reference Temperature** of Thermal Steady-State simulation



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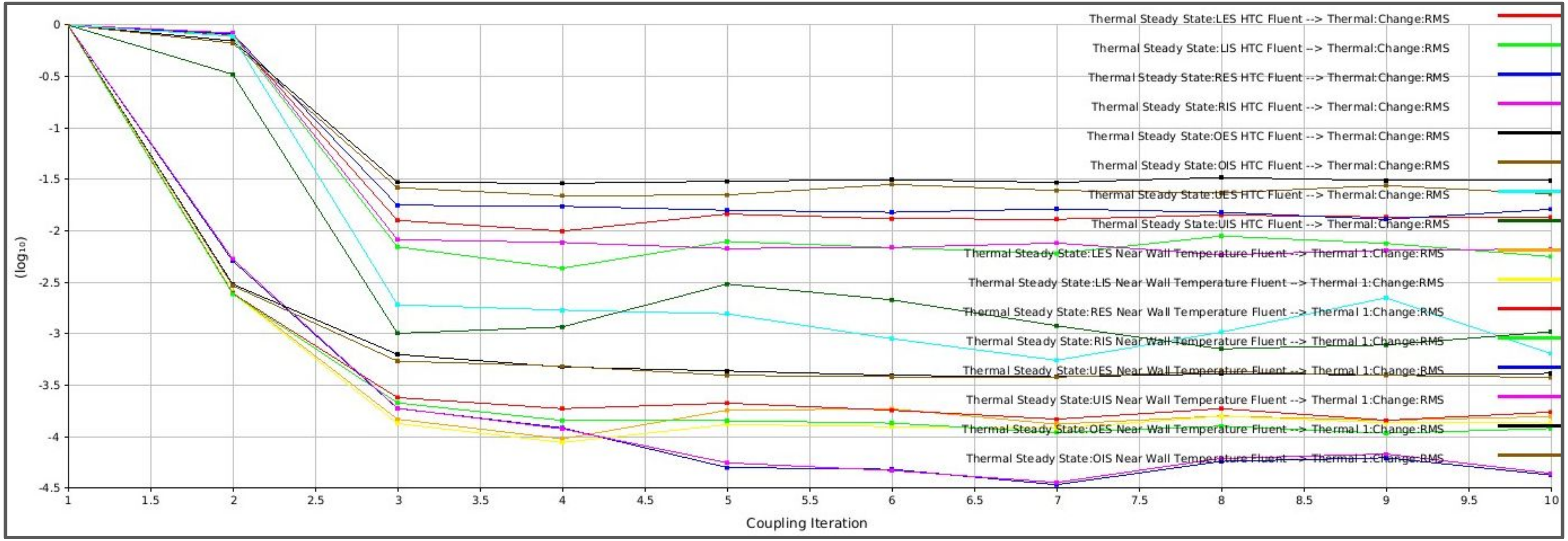
Running and convergence

The simulation **runs** and **converges**



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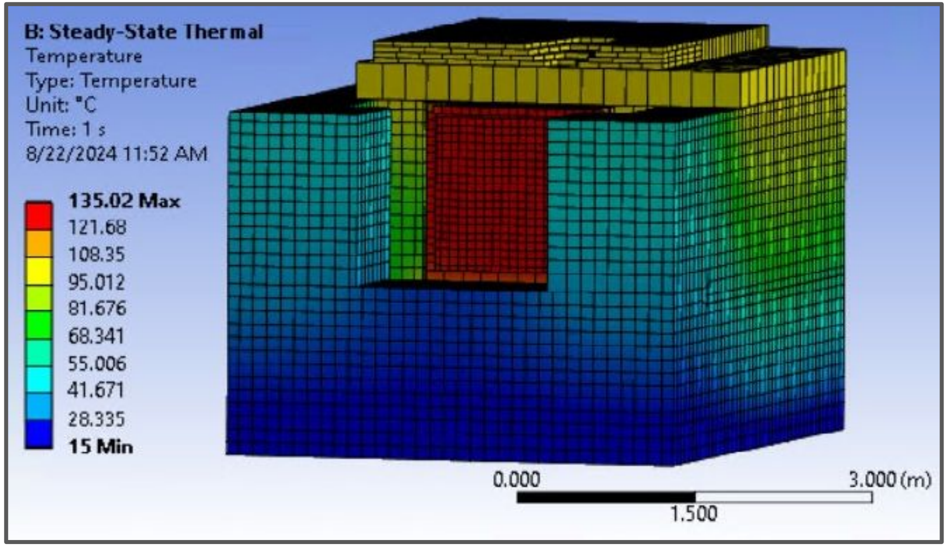
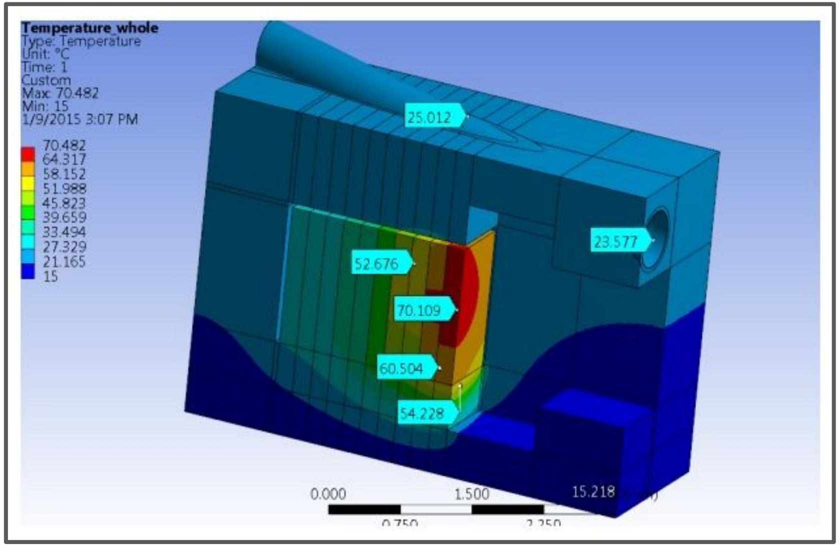
Presentation of the preliminary results



Steady-state thermal results (**obtained**)



Steady-state thermal results (**previous**)

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Verification of the results

The results are **not fully coherent** with the previous Excel calculations and separate ANSYS simulations: **more work to be done**

Slow Fluent convergence noted due to complex geometry and coarse mesh

Convergence threshold on residuals had to be increased from the default value due to otherwise very high computational time required

```
+-----------------------------------------------------------------------+
|                       COUPLING ITERATION = 10                          |
+-----------------------------------------------------------------------+
| Thermal Steady State                 |                                 |
|   Interface: interface-1             |                                 |
|     LES Near Wall Temperature Fluent |           Converged             |
|       RMS Change                     |    2.04E-04           1.57E-04  |
|       Weighted Average               |    2.93E+02           2.93E+02  |
|     LES HTC Fluent --> Thermal       |           Converged             |
|       RMS Change                     |    1.56E-02           1.36E-02  |
|       Weighted Average               |    4.16E+00           4.11E+00  |
|   Interface: interface-2             |                                 |
|     LIS HTC Fluent --> Thermal       |           Converged             |
|       RMS Change                     |    1.07E-02           5.64E-03  |
|       Weighted Average               |    4.09E+00           4.07E+00  |
|     LIS Near Wall Temperature Fluent |           Converged             |
|       RMS Change                     |    1.82E-04           1.36E-04  |
|       Weighted Average               |    2.93E+02           2.93E+02  |
|   Interface: interface-3             |                                 |
|     RES HTC Fluent --> Thermal       |           Converged             |
|       RMS Change                     |    1.88E-02           1.63E-02  |
|       Weighted Average               |    4.05E+00           4.02E+00  |
|     RES Near Wall Temperature Fluent |           Converged             |
|       RMS Change                     |    2.25E-04           1.74E-04  |
|       Weighted Average               |    2.93E+02           2.93E+02  |
|   Interface: interface-4             |                                 |
|     RIS HTC Fluent --> Thermal       |           Converged             |
|       RMS Change                     |    1.24E-02           6.68E-03  |
|       Weighted Average               |    3.96E+00           3.94E+00  |
|     RIS Near Wall Temperature Fluent |           Converged             |
|       RMS Change                     |    1.84E-04           1.21E-04  |
|       Weighted Average               |    2.93E+02           2.93E+02  |
|   Interface: interface-5             |                                 |
|     OES HTC Fluent --> Thermal       |           Converged             |
|       RMS Change                     |    3.11E-02           3.09E-02  |
|       Weighted Average               |    4.91E+00           5.08E+00  |
|     OES Near Wall Temperature Fluent |           Converged             |
|       RMS Change                     |    5.90E-04           4.14E-04  |
|       Weighted Average               |    2.93E+02           2.93E+02  |
|   Interface: interface-6             |                                 |
|     OIS HTC Fluent --> Thermal       |           Converged             |
|       RMS Change                     |    2.86E-02           2.30E-02  |
|       Weighted Average               |    4.99E+00           5.18E+00  |
|     OIS Near Wall Temperature Fluent |           Converged             |
|       RMS Change                     |    5.12E-04           3.78E-04  |
|       Weighted Average               |    2.93E+02           2.93E+02  |
|   Interface: interface-7             |                                 |
|     UES HTC Fluent --> Thermal       |           Converged             |
|       RMS Change                     |    1.09E-03           6.44E-04  |
|       Weighted Average               |    4.34E+00           4.36E+00  |
|     UES Near Wall Temperature Fluent |           Converged             |
|       RMS Change                     |    4.98E-05           4.26E-05  |
|       Weighted Average               |    2.94E+02           2.94E+02  |
|   Interface: interface-8             |                                 |
|     UIS HTC Fluent --> Thermal       |           Converged             |
|       RMS Change                     |    3.42E-03           1.05E-03  |
|       Weighted Average               |    7.19E+00           7.45E+00  |
|     UIS Near Wall Temperature Fluent |           Converged             |
|       RMS Change                     |    5.60E-05           4.42E-05  |
|       Weighted Average               |    2.94E+02           2.94E+02  |
+-----------------------------------------------------------------------+
+-----------------------------------------------------------------------+
| Participant solution status          |                                 |
|   Thermal Steady State               |           Converged             |
|   Fluent                             |           Converged             |
+=======================================================================+
```

Future improvements and solutions

Fix the coupled convective heat transfer from the steel to the air due to convection

Remove the **fixed heat flux** between the steel plates and the baffle

Improve convergence speed by tweaking the relaxation factor and improving BC/mesh

```
x (mm),y (mm),z (mm),h (W/m3)
678.05,678.05,-190,1.28362848
685.55,678.05,-190,1.21412064
693.05,678.05,-190,1.24887456
700.55,678.05,-190,1.86764544
708.05,678.05,-190,2.06559168
715.55,678.05,-190,2.14643232
723.05,678.05,-190,2.92235136
730.55,678.05,-190,2.96617152
738.05,678.05,-190,3.5169456
745.55,678.05,-190,4.3517952
753.05,678.05,-190,3.5660544
760.55,678.05,-190,3.61667424
768.05,678.05,-190,3.43686048
775.55,678.05,-190,3.24269184
783.05,678.05,-190,3.45877056
790.55,678.05,-190,3.29482272
798.05,678.05,-190,3.92568192
805.55,678.05,-190,3.89923872
```

What to achieve in the end

Fully independent coupled two-way simulation that emulates exactly the behaviour of air, steel and concrete

Heat transfer coefficients for each of the coupled surfaces (to double-check them)

Understanding if **the constraints on the temperatures of the steel and the concrete** have been met for all the different operating conditions