PICO-40L thermal model

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Outline

- Intro
- Motivation
- Thermal model
- Threshold
- Conclusion

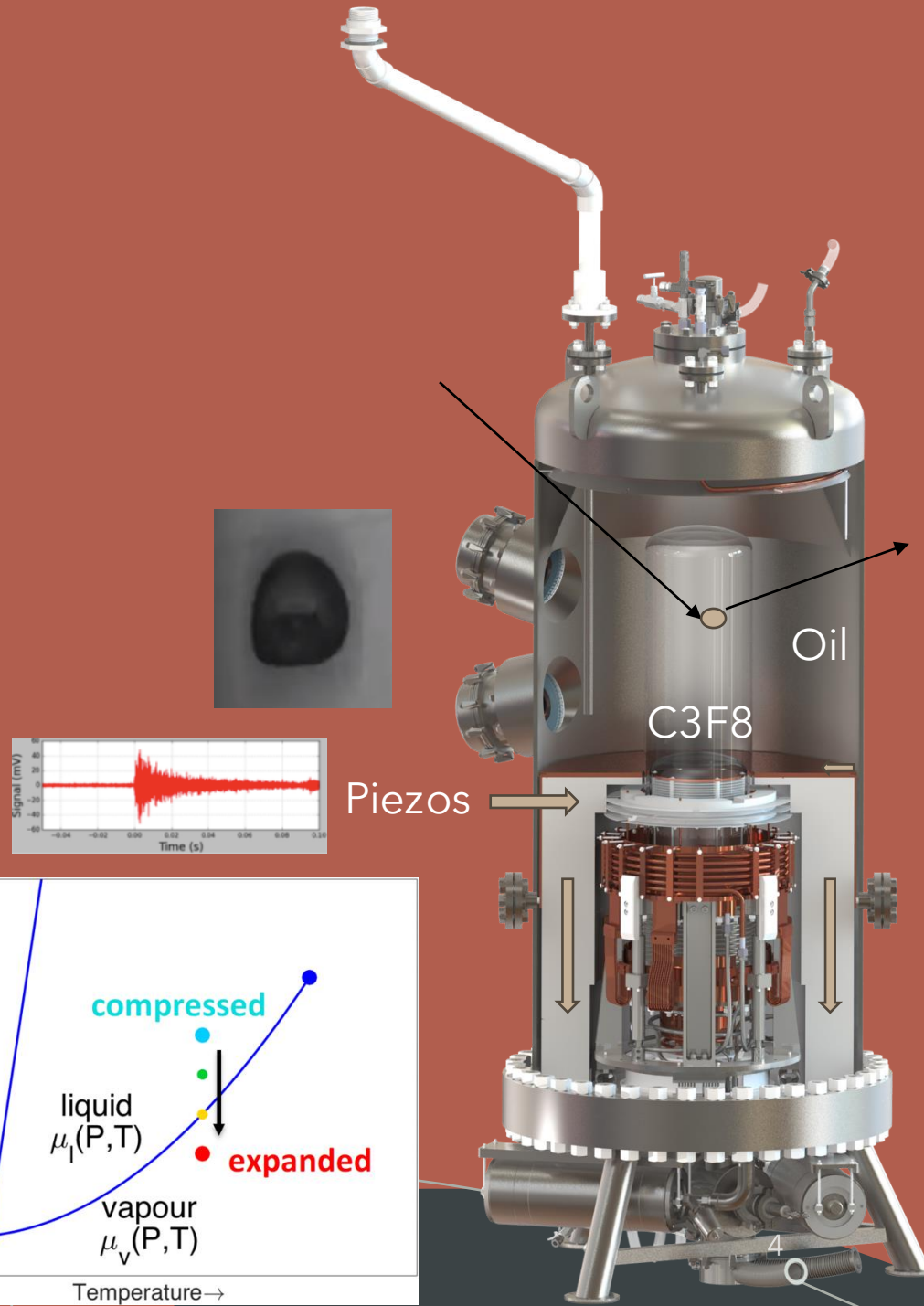
PICO-40L Experiment

- Bubble chamber detector
  - C3F8 as the active fluid → Metastable (superheated, ⇣ P)
  - Interaction: particle-nucleus→ nuclear recoil →bubble(s)
  - Seitz model : localized energy deposit → threshold

- Collaboration: technological achievement
  - Background rejection : insensitive to electron & gamma
    - less localized than nuclear recoils→ protobubble collapses immediately
  - Acoustic discrimination: Piezo→ distinct sign.; α vs neutron

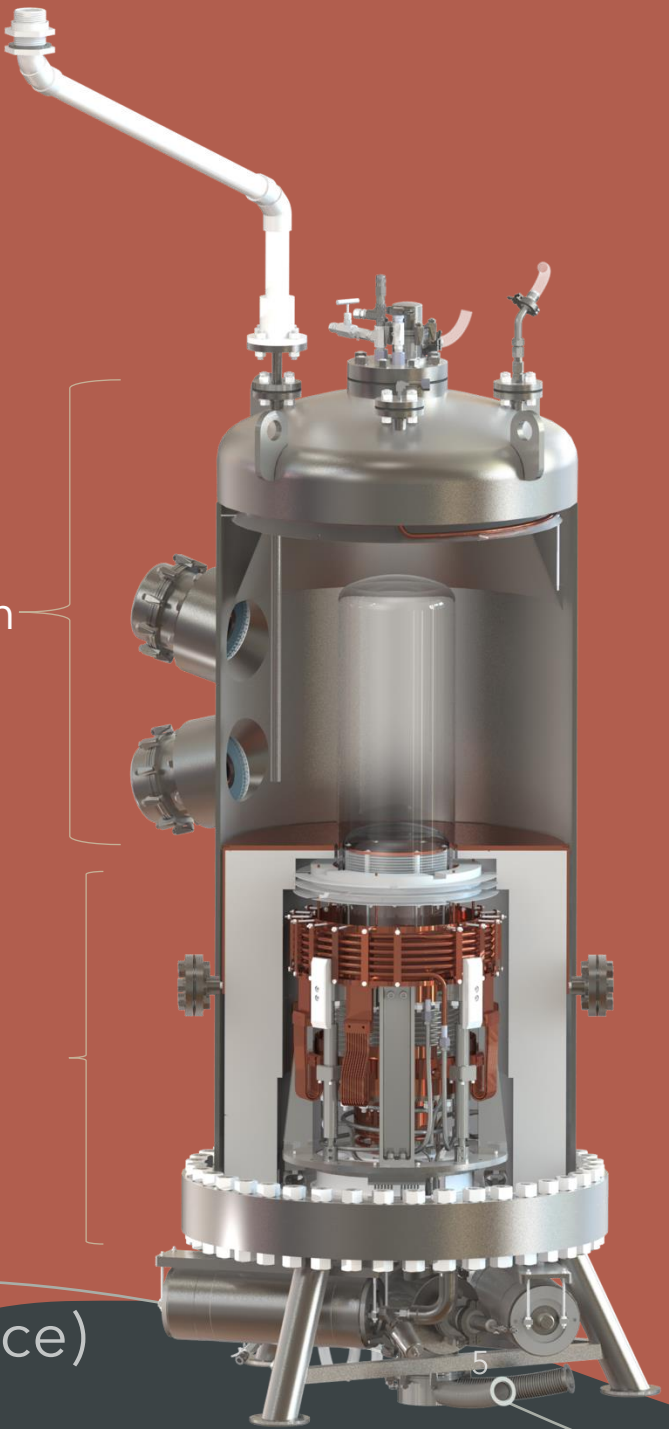
PICO-40L Experiment

- Camera
  - Primary trigger
  - Bubble position reconstruction
- Fast pressure transducer : dytran
  - Secondary trigger
  - Bubble multiplicity
  - Event type: bulk vs wall



Thermal concept

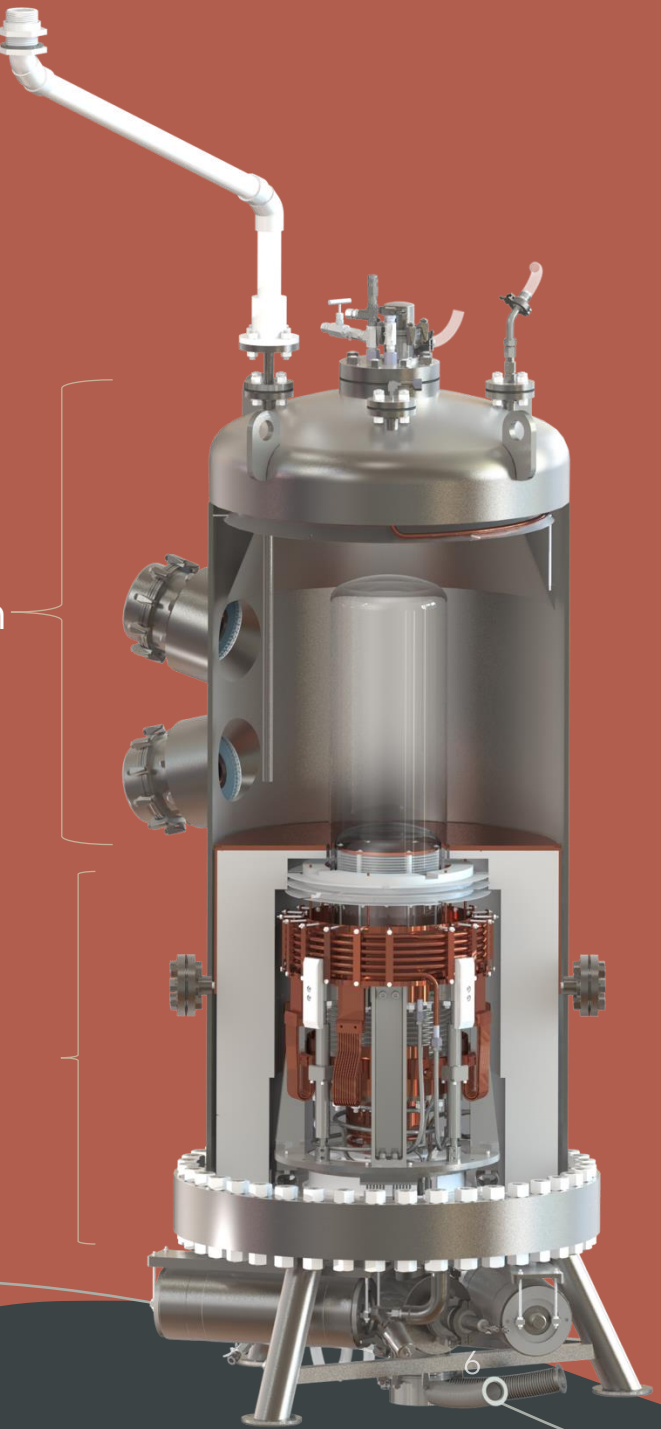
- Warm region: water bath → regulate T
- Transition region: imperfect
  - HDPE sheets & Heater plates
  - Thermal simulation & RTD to understand
- Cold region: Cooling coil
- Need for a cold and warm region: why?
  - C_3F_8 in contract with the bellows
  - Nucleation sites: Bellows (presence) vs Glass (~ absence)



Thermal concept

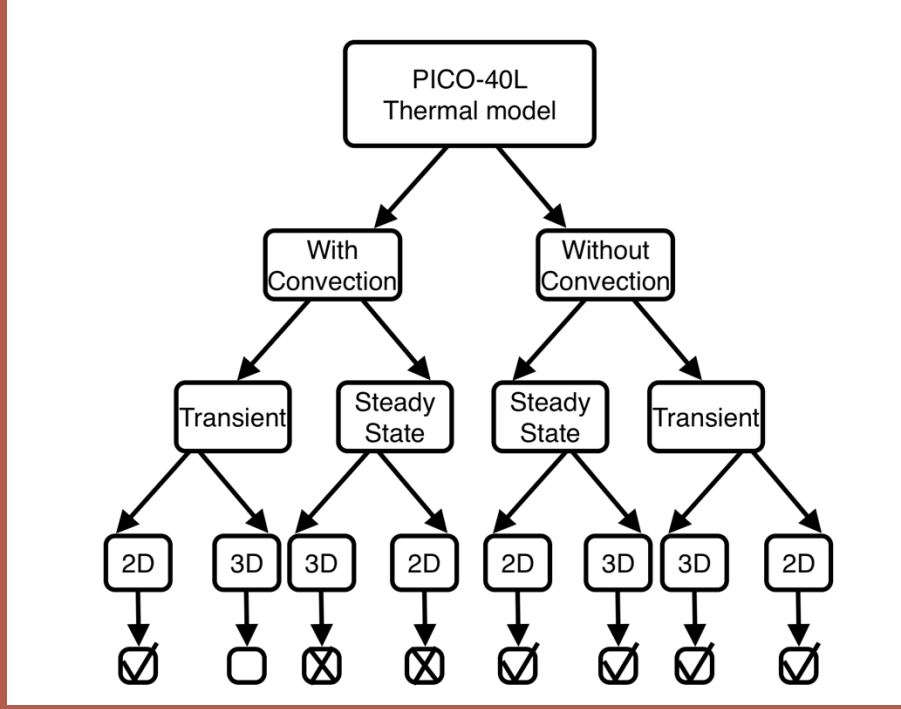
- Question that needed to be answered
  - P & T° : profile along the Z-axis
  - Threshold → Q(P,T)
  - No RTDs in the active fluid

- COMSOL simulation vs RTD data
  - Which model best describes reality

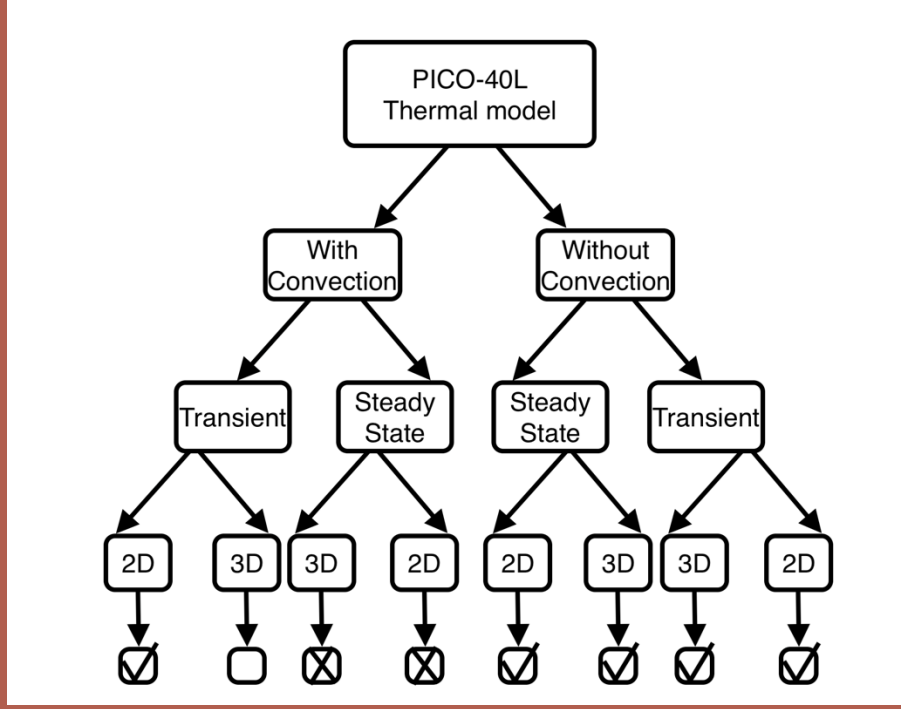


Thermal model : diagram

- Convection
  - More realistic regarding the time needed to reach a steady state
  - Boussinesq approximation : velocity field of the fluid
- No convection
  - When the system stabilizes, it is possible that the convective flow can be neglected.
  - Maximum time to reach equilibrium

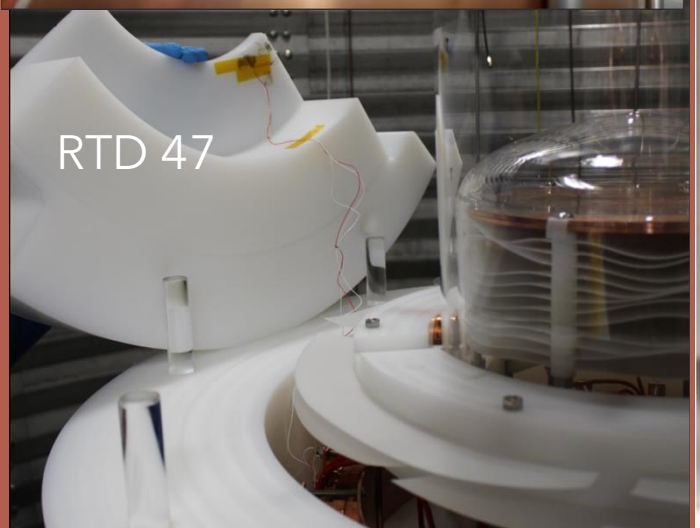


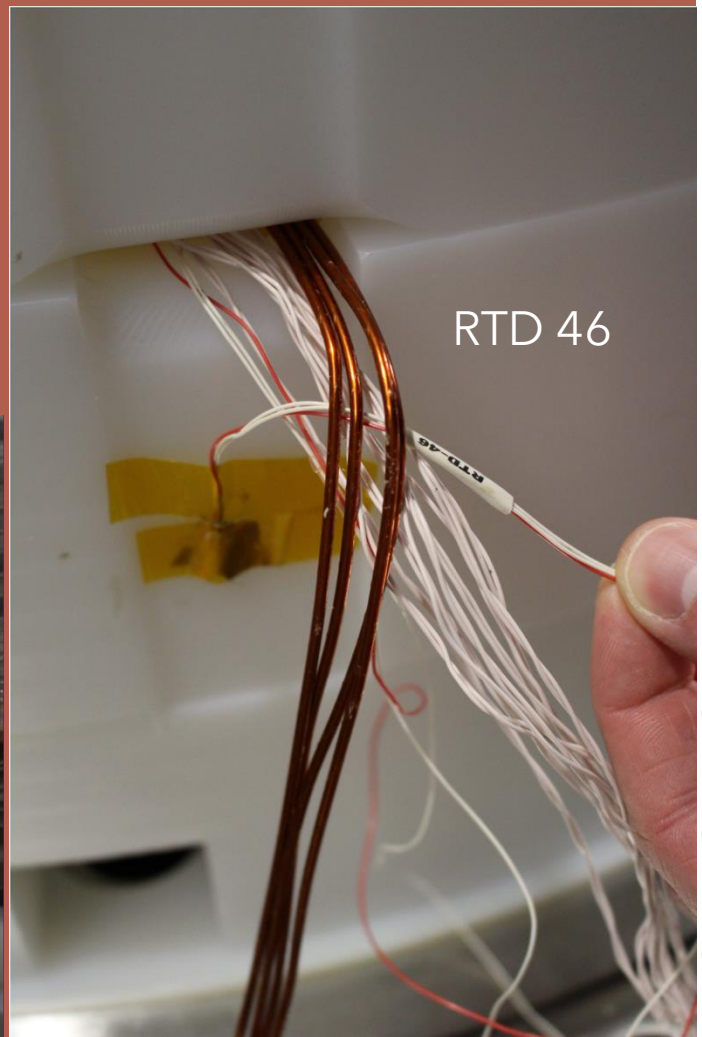
Thermal model : diagram

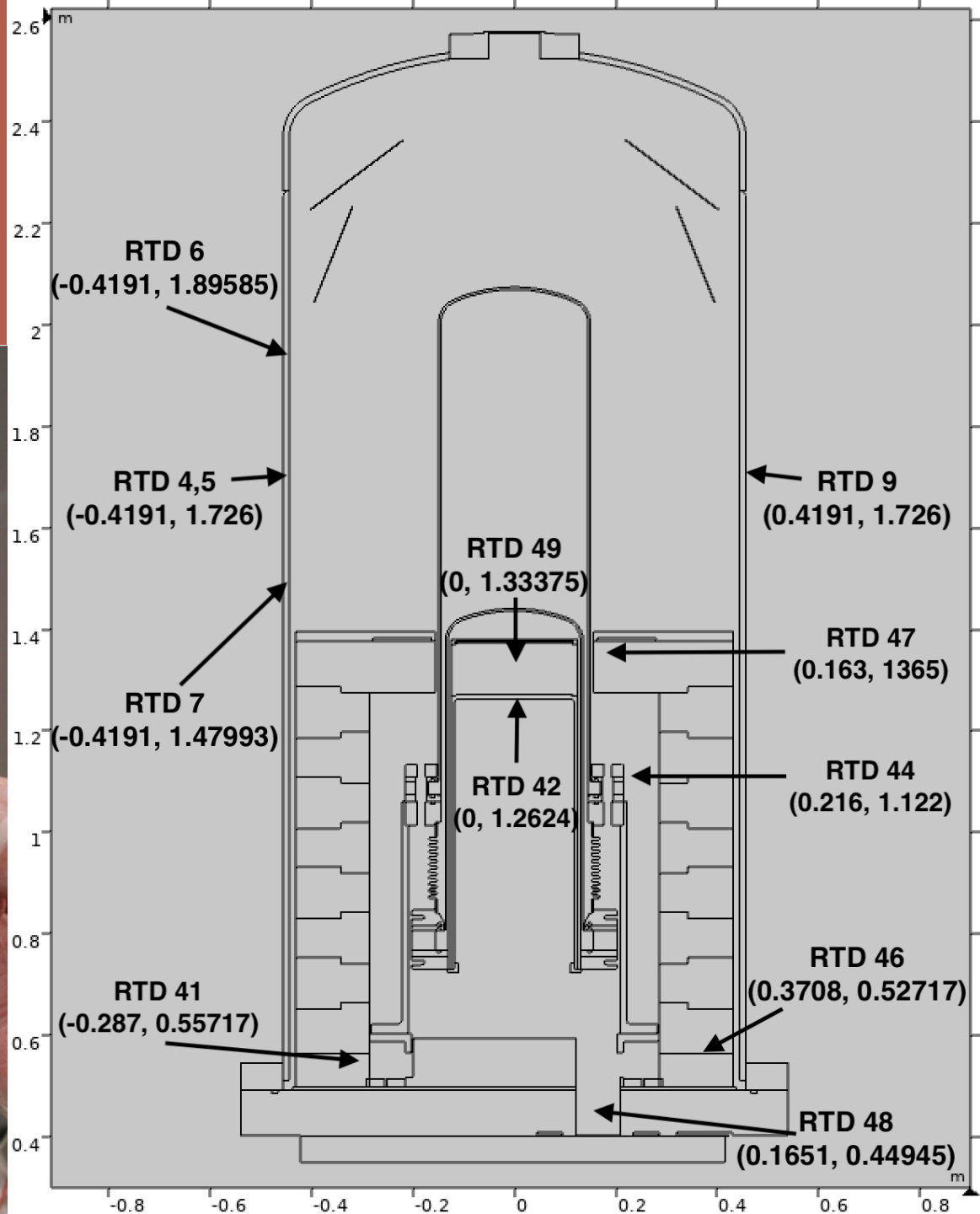


- Transient
  - T over time: COMSOL vs RTD
  - Compression and expansion cycle
- Steady state
  - When the system reaches stability
- 2D
  - Reduce computation time but constitutes a simplification
- 3D
  - Limits possible errors due to the use of symmetry (2D)

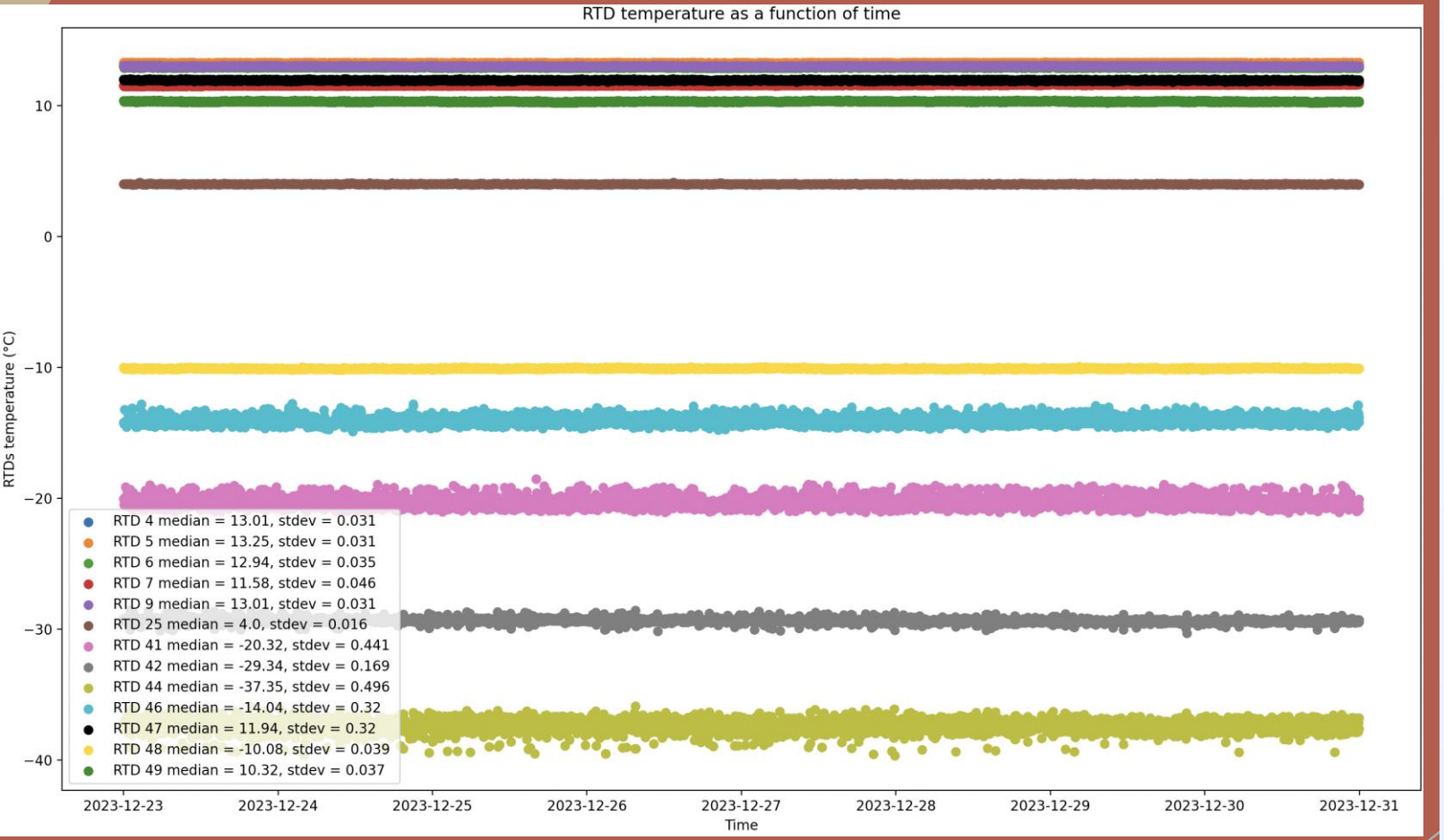
RTDs : positions

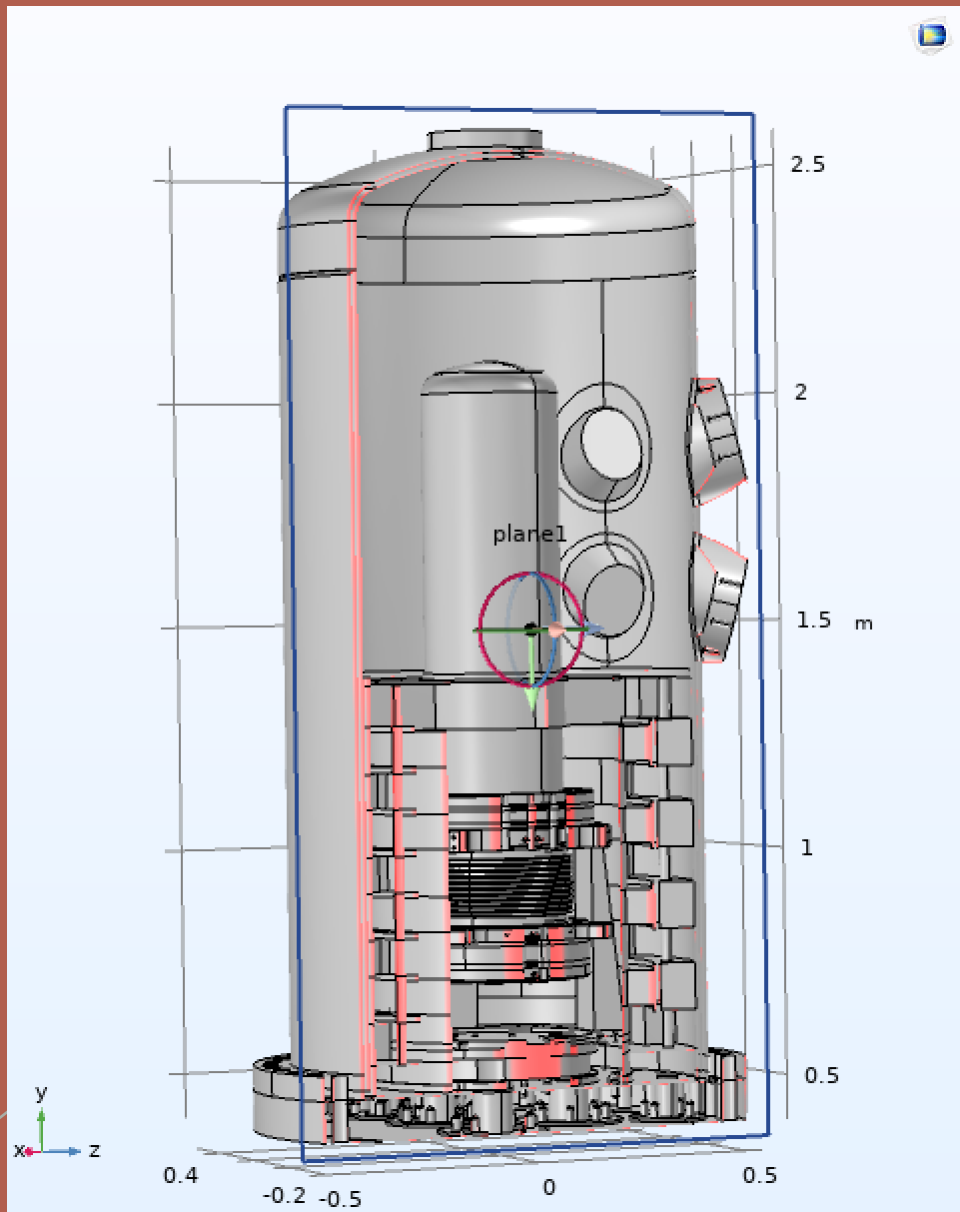






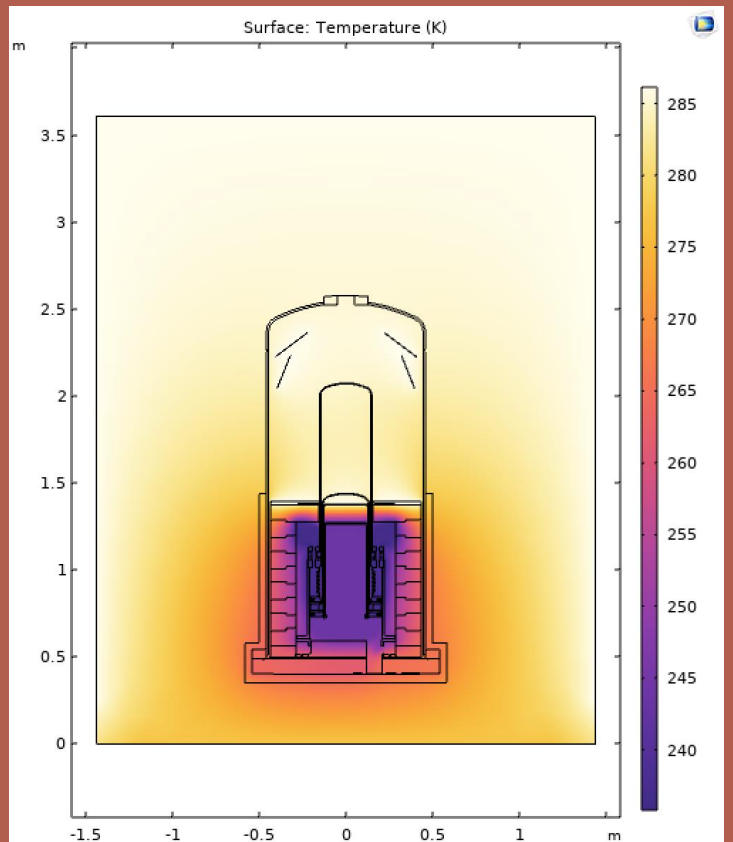
RTDs: steady-state data

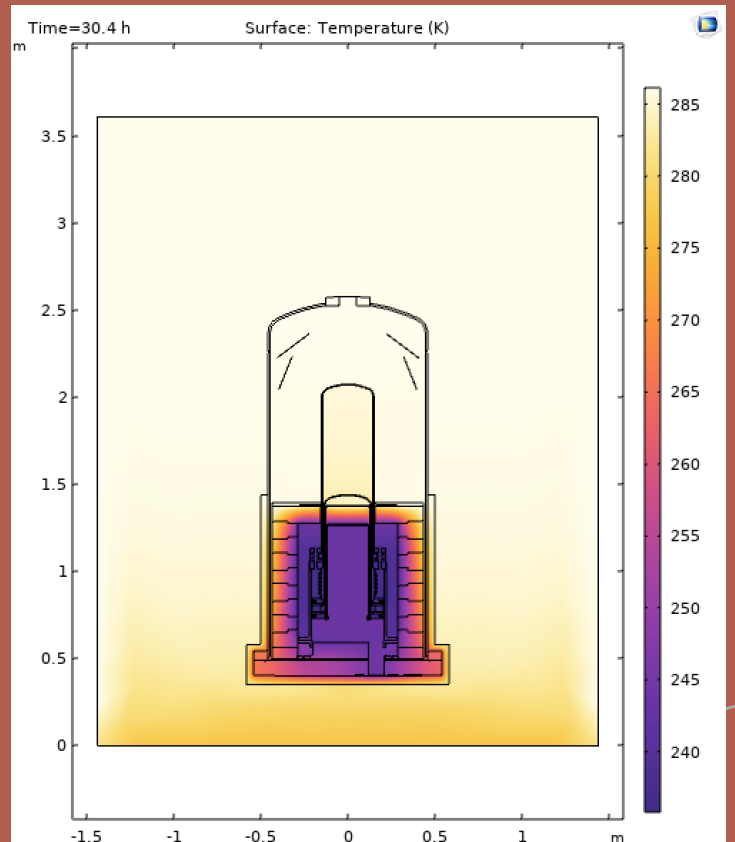




RTD vs COMSOL data

- SS No convection vs Convection trans



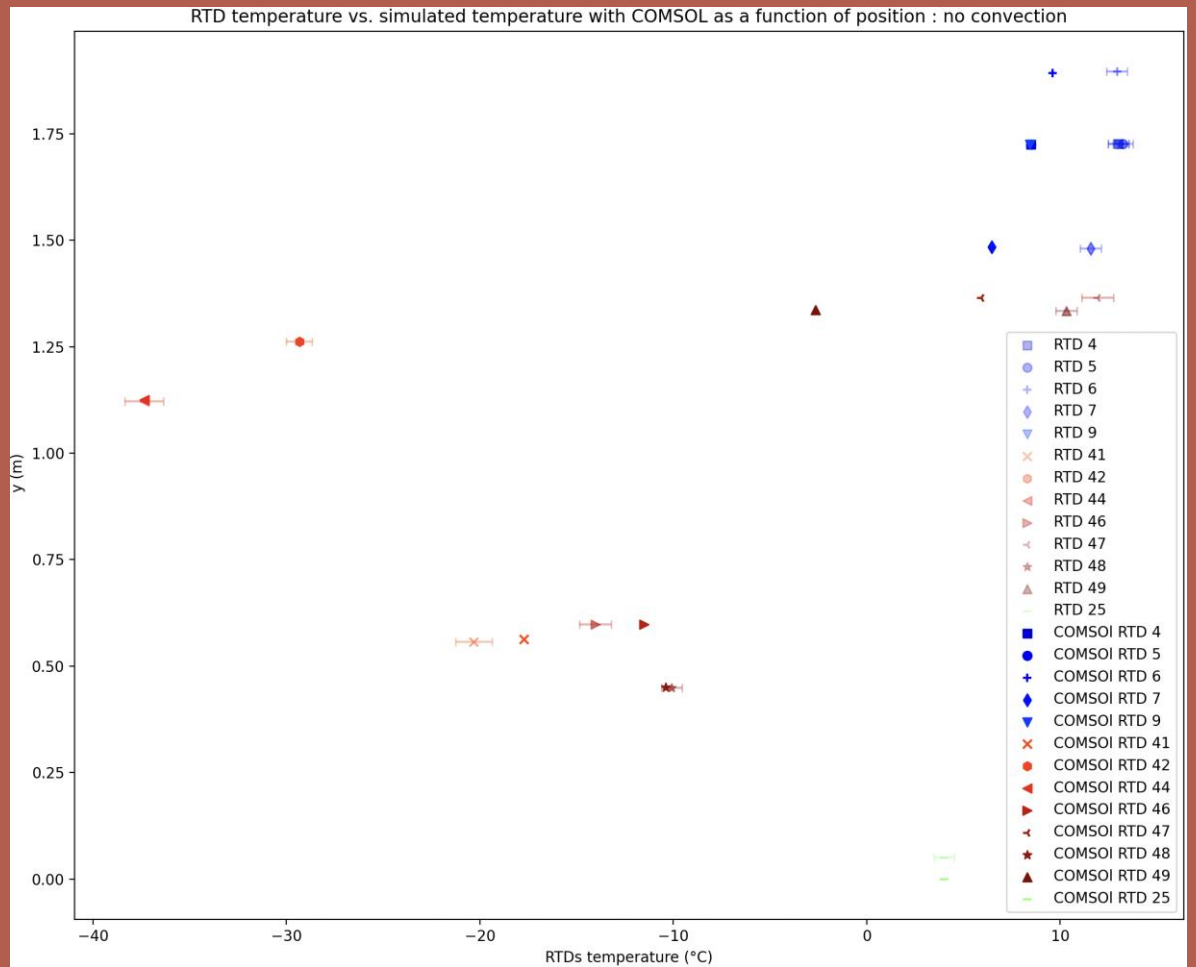


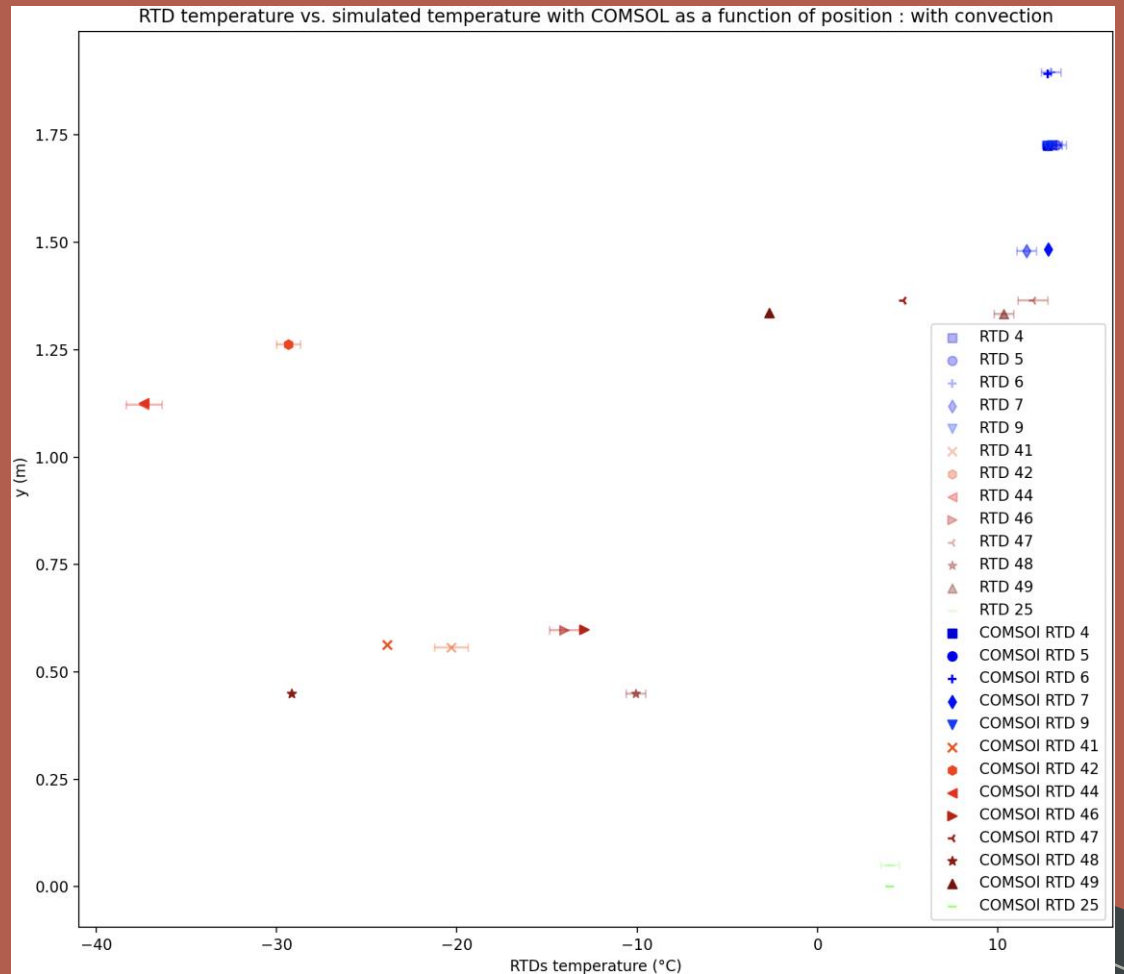
Slight temperature difference near the wall and the bottom of the PV.

*** Heat transfer occurs from the oil to the glass wall since the oil is warmer. ***

The bottom of the PV is colder when convection is taken into account.

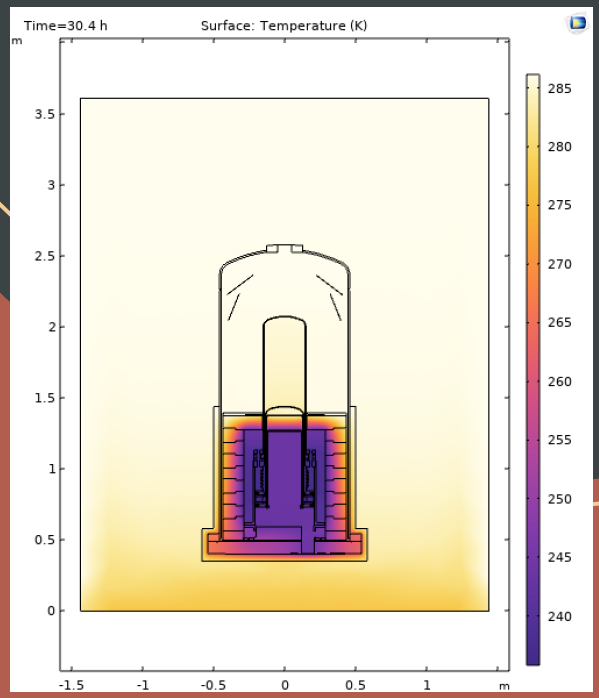
RTD vs COMSOL data

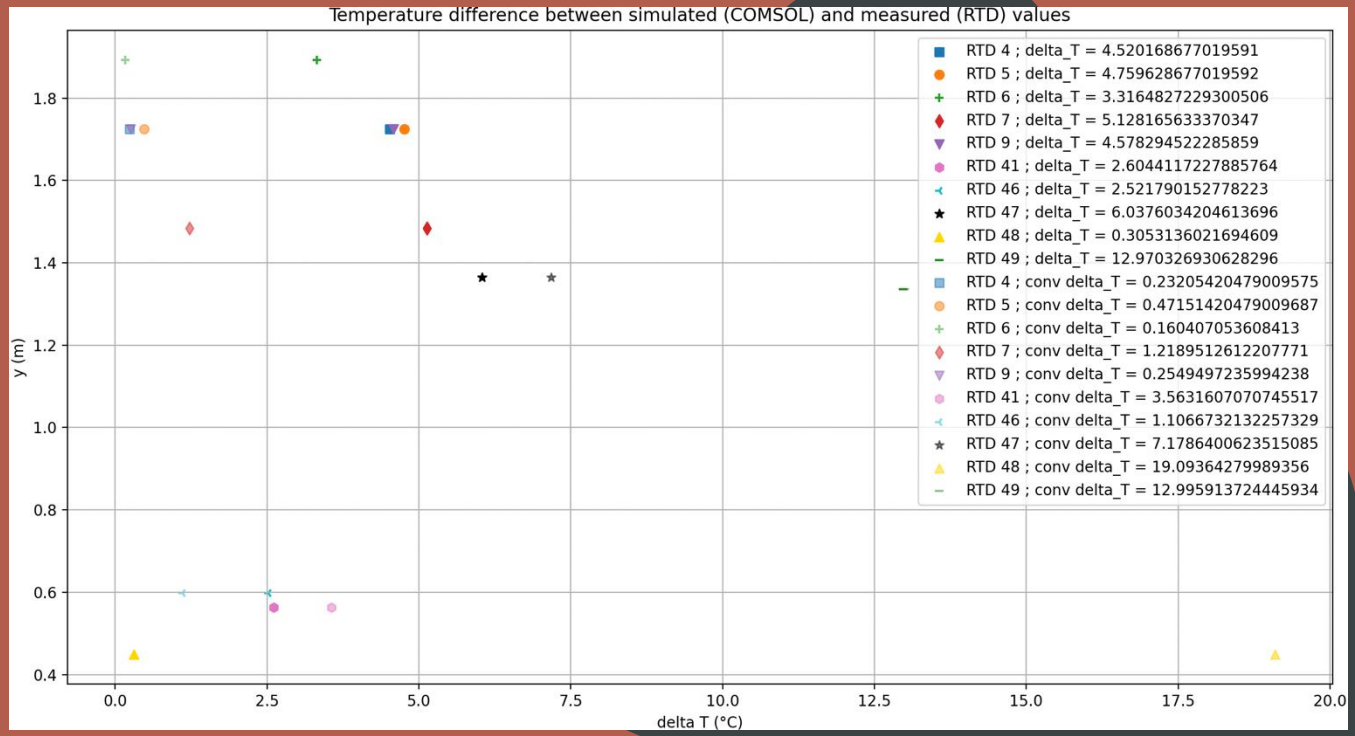




Temperature difference between models

- The model that takes convection into account best describes reality.
- Significant change in T with a slight spatial shift : RTD47, RTD49



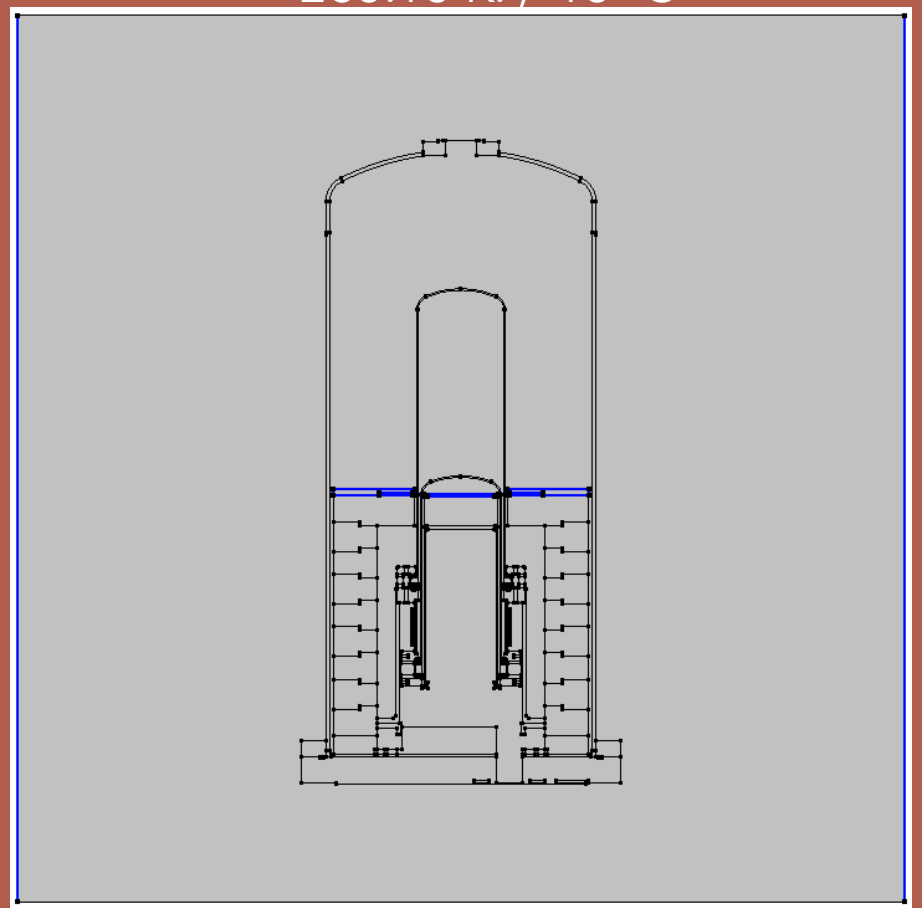


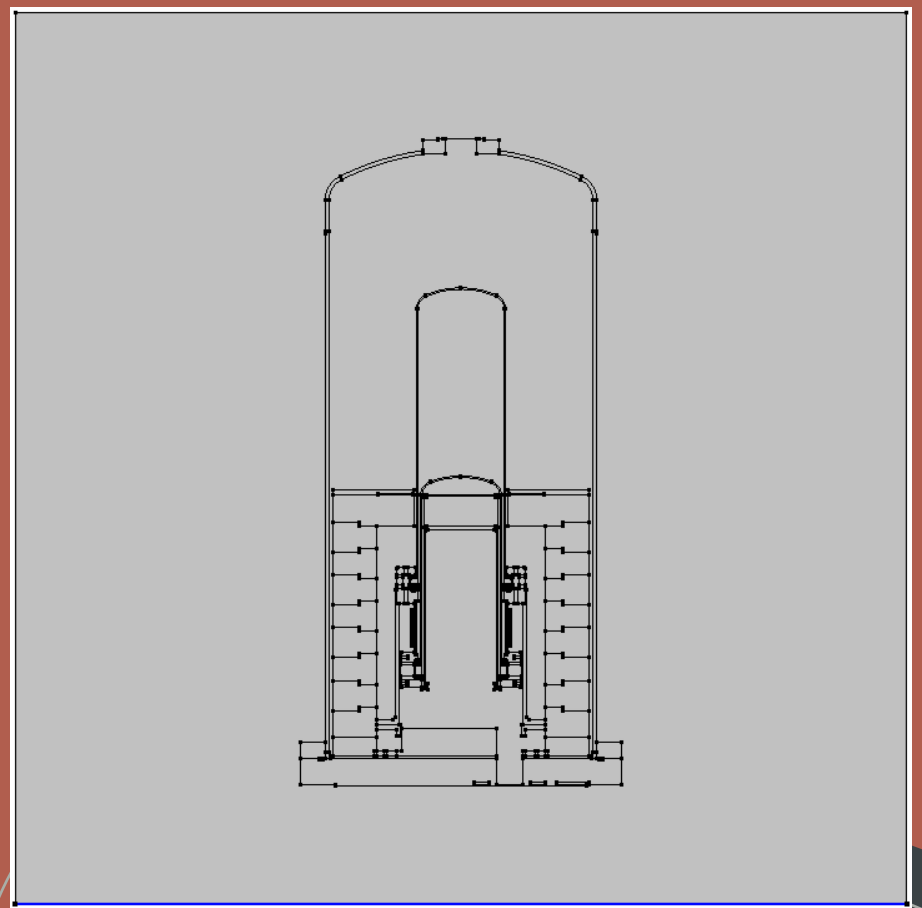
Initial & Boundaries condition

Water Tank Wall & Heater plate
286.15 K. ; 13 ^{0}C

Ti =293.15 K

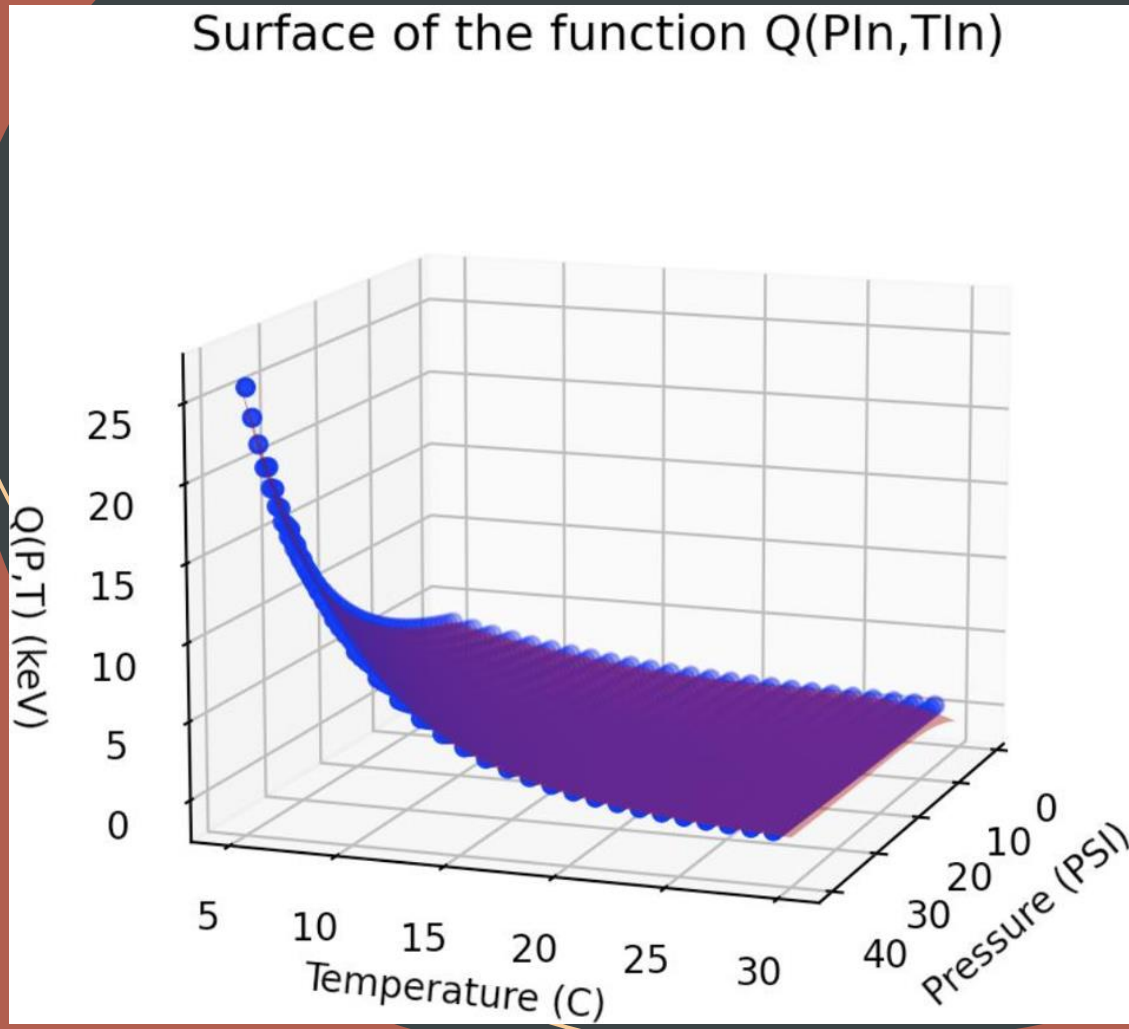
Water Tank Floor
277.15 K. ; 4 ^{0}C





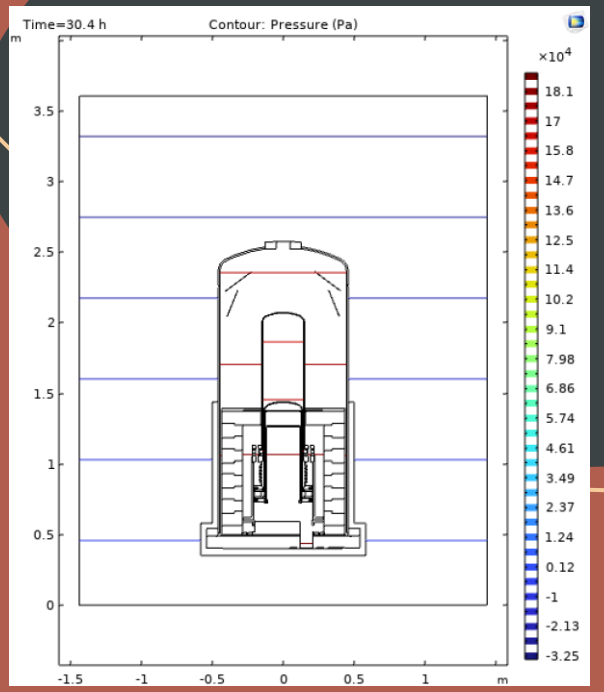
Seitz Threshold : C_3F_8

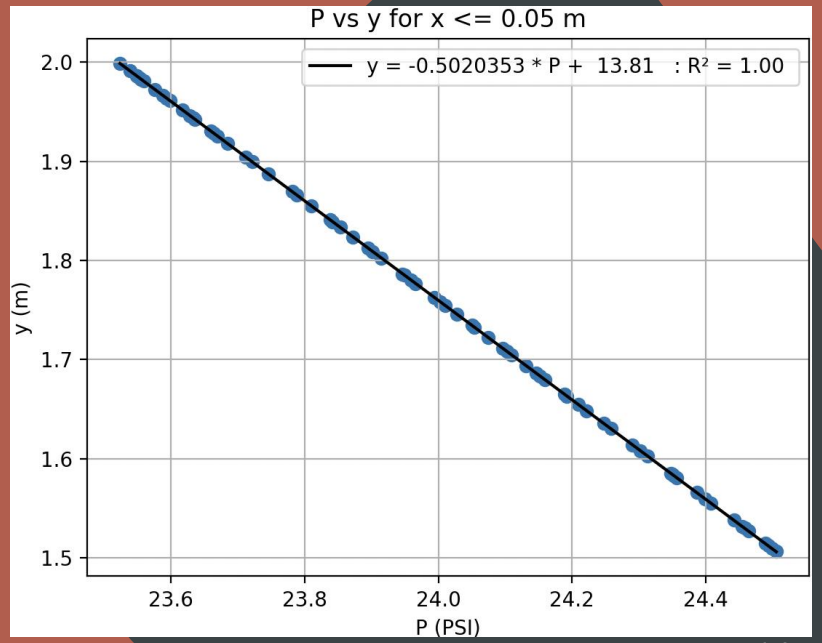
Q(P,T) = 5.7447 + 0.2538*P -0.7725*T + 0.0086*p^2 + 0.0695*T^2 -0.0468*p*T - 0.0018*p^2*T+0.0047*p*T^2 + 0.0002*p^3 -0.0046*T^3 +0.0002*p^2*T^2 - 0.0002*p*T^3 -4.1545e-05*p^3*T+ 3.9234e-06*p^4 + 0.0002*T^4 + 4.7669e-06*x*y**4 -4.5610e-07*p^4*T -4.0602e-06*p^2*7^3 + 1.8094e-06*p^3*T^2 + 6.3598e-08*p^5 -2.4525e-06*p^5



Pressure

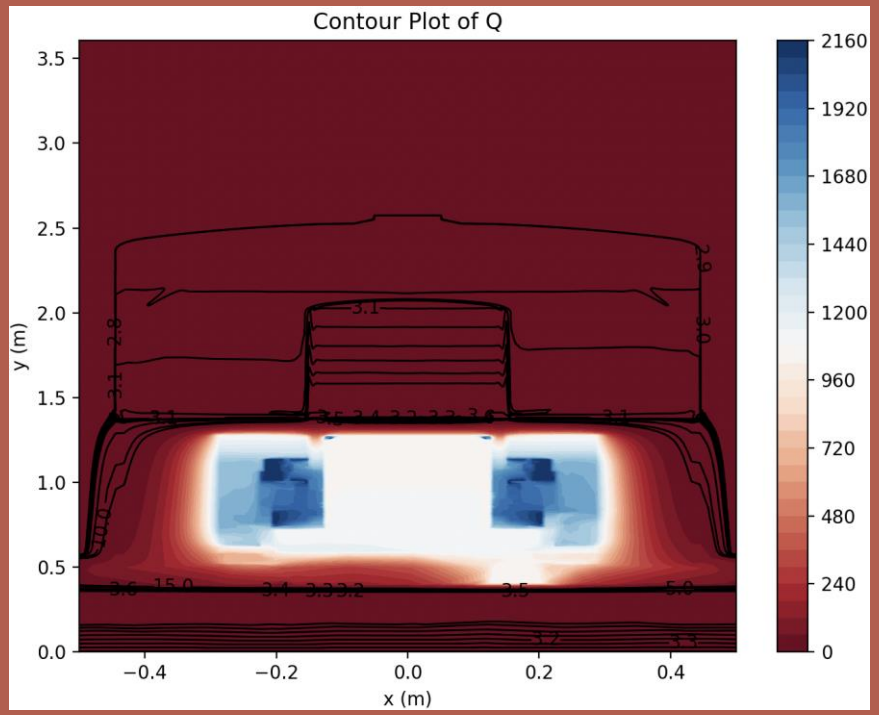
- Water Bath
- Pressure Vessel
- Fused Quartz

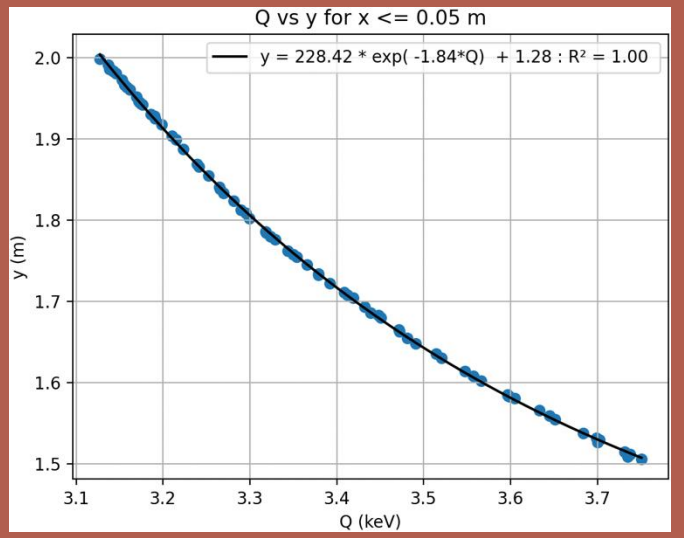


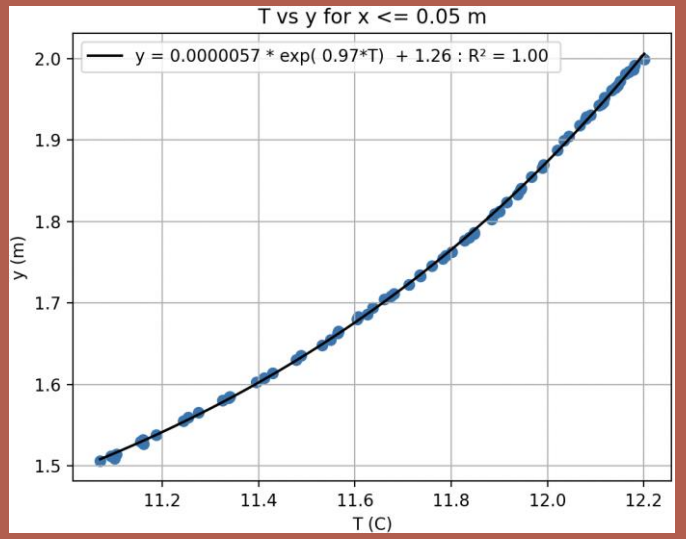


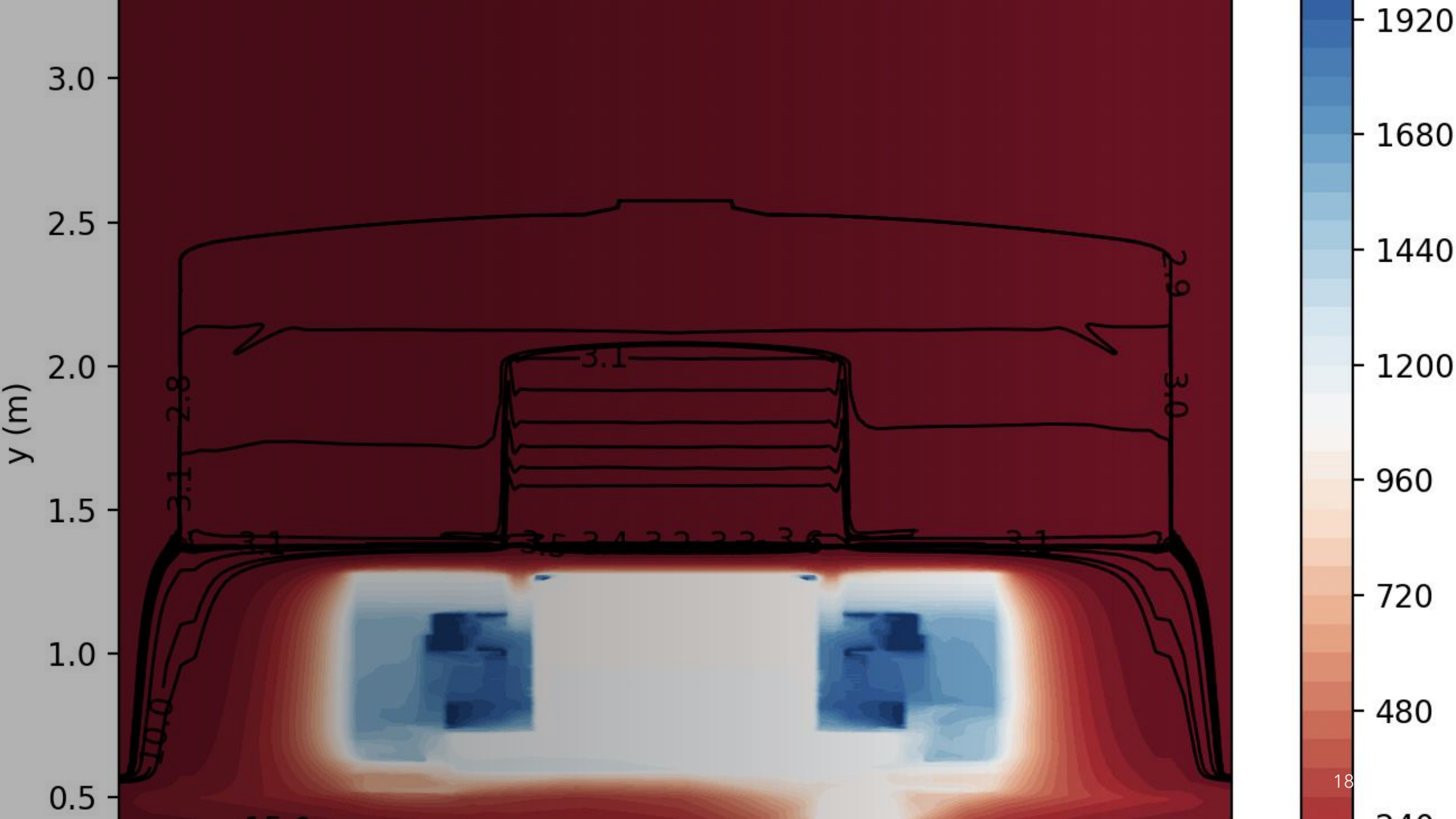
Threshold

- The correction on T and Q(P,T), in C_3F_8, is defined by the equations








y (m)
3.0
2.5
2.0
1.5
1.0
0.5
2.1
2.8
3.1
2.9
3.0
3.1
3.5
2.4
2.2
2.2
3.6
3.1
1920
1680
1440
1200
960
720
480

Conclusion

Done

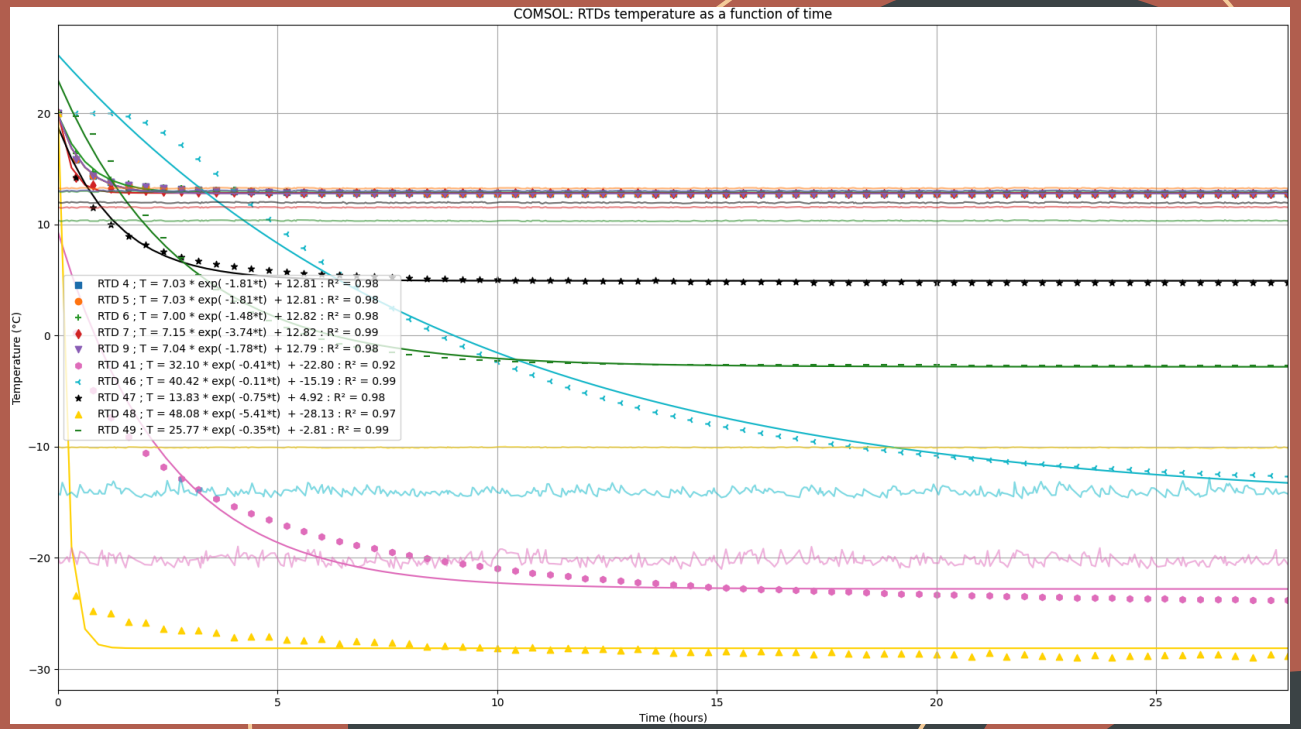
- Models considered: with and without convection ; Steady state and transient
- Strong correlation between simulated and real RTDs

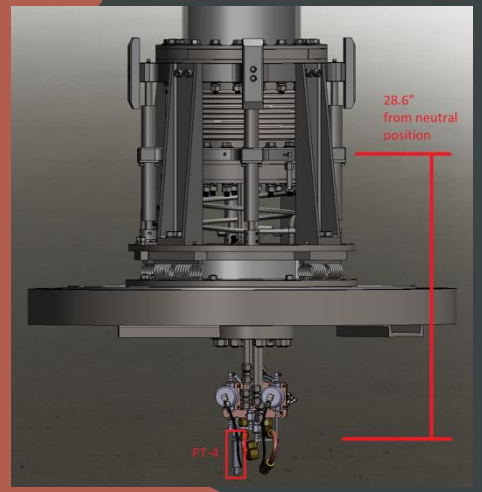
Need to be done

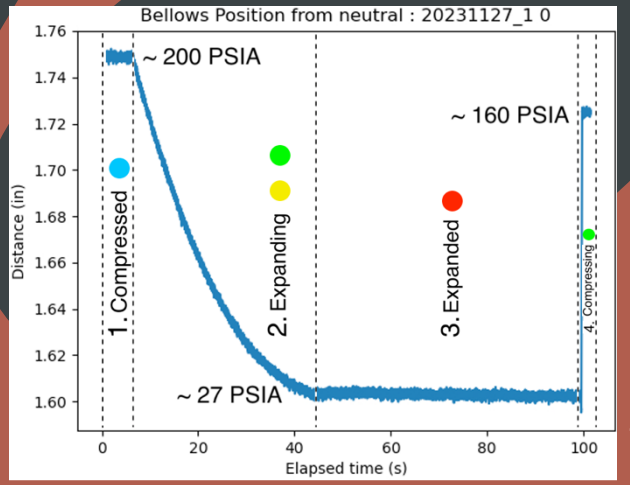
- Final check : values implemented → pressure, temperature

Annex

- Bellows
- Bellows & cycle
- T vs t







Annex : Seitz model

- Conditions for nucleation (Q_s > = W_min)
  - W_min = 4 pi /3 * sigma * r_c^2
  - E_r > Q_s
  - Energy must be deposited within r_c ~ 25 nm at 30 psia and 13 C

$$r_c \approx \frac{2\sigma}{P_v - P_l}\frac{\rho_l}{\rho_l - \rho_v}$$

- Q_s
  - Contain three principal terms
  - W_c : combat the pressure of the liquid to allow the protobubble to expand
  - W_v : to evaporate the liquid and transform it into gas
  - W_s : Energy to form the surface of the critical sphere
  - W_irr : irreversible processes such as acoustic wave emission (about 2%)

$$\begin{aligned} E_c &= W_c + W_v + W_s + W_{irr} \\ &= \frac{4\pi}{3} r_c^3 (P_l - P_b) + \frac{4\pi}{3} r_c^3 \rho_b (h_b(T) - h_l(T)) + 4\pi r_c^2 (\sigma - T\frac{\partial \sigma}{\partial T}) + W_{irr} \end{aligned}$$

Annex : heat transfer → advection-diffusion equation

Conduction Advection Generation Transient

- $$\boxed{\frac{1}{r}\frac{\partial T(r,z,t)}{\partial r}+\frac{\partial^2 T(r,z,t)}{\partial r^2}+\frac{\partial^2 T(r,z,t)}{\partial z^2}}-\boxed{\frac{\rho C_p v_r}{k}\frac{\partial T(r,z,t)}{\partial r}-\frac{\rho C_p v_z}{k}\frac{\partial T(r,z,t)}{\partial z}}+\boxed{\frac{\dot{g}}{k}}=\boxed{\frac{\rho C_p}{k}\frac{\partial T(r,z,t)}{\partial t}}$$
- where $v_r \; and \; v_z$ are given by the Boussinesq approximation of the Navier-Stokes equations;
  - Where, C_p is the Heat capacity
  - ρ the density
  - k the thermal conductivity
  - $\dot{g}$ heat generation term
  - v_r and v_z are the velocity components
  - T the temperature
- The velocity $\vec{u}\ (v_r, v_z)$ is given by the Navier-Stokes (N-S) equation or the approxi. choosen
- Ignored terms
  - Friction $\mu\phi$, ~ dilatation $\beta T \frac{\partial p(r,z,t)}{\partial t}$ and compressibility fluid $\beta T v \cdot \nabla p$, radiation term

PICO

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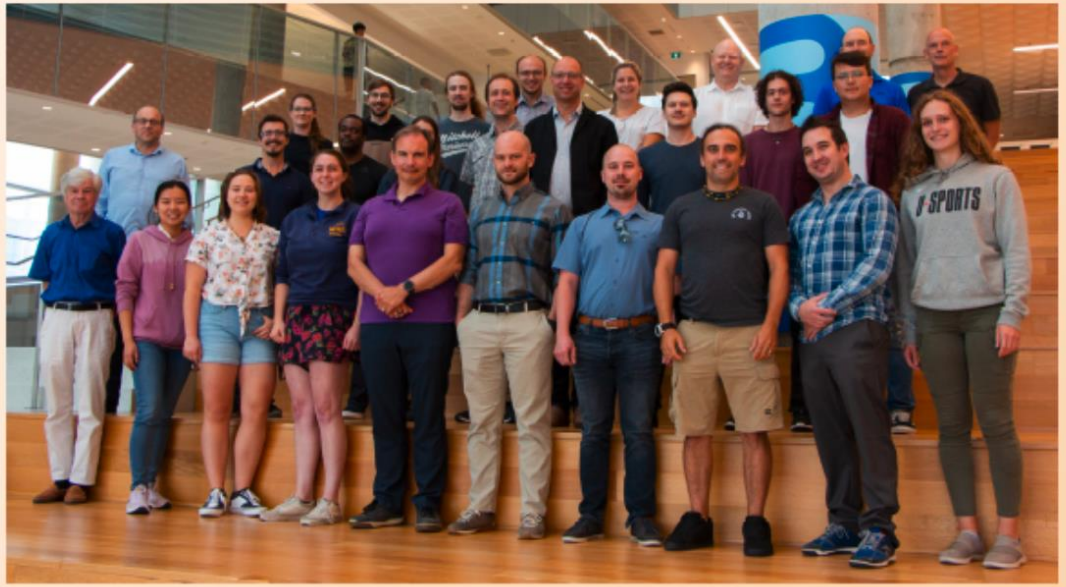

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