Numerical calculation of thermal induced stresses in a hexagonal rod bundle

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CIRCE experiment overview

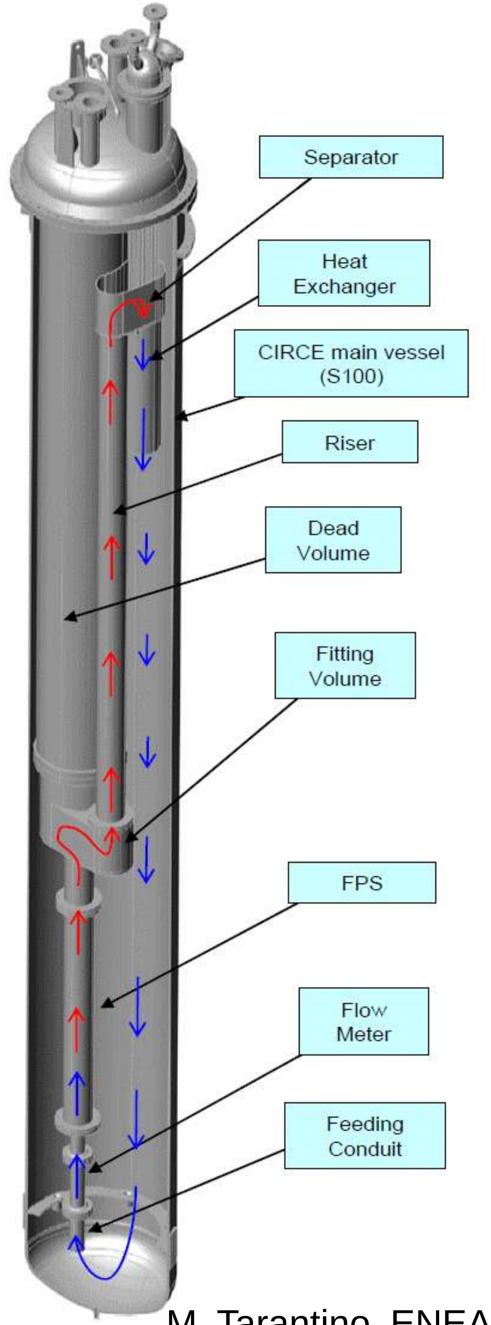
LBE pool Experiment is planned in the CIRCE Main Vessel at ENEA, Brasimone Italy in the framework of the IP Eurotrans project.

Vessel design:

• External diameter:	1.2 m
• Height:	8.5 m
• LBE inventory:	70.000 kg
• Temperature range:	200°C - 450°C

LBE pumping system:

- LBE circulation by Gas-Lift pump
- Available pressure head 0.4 bar

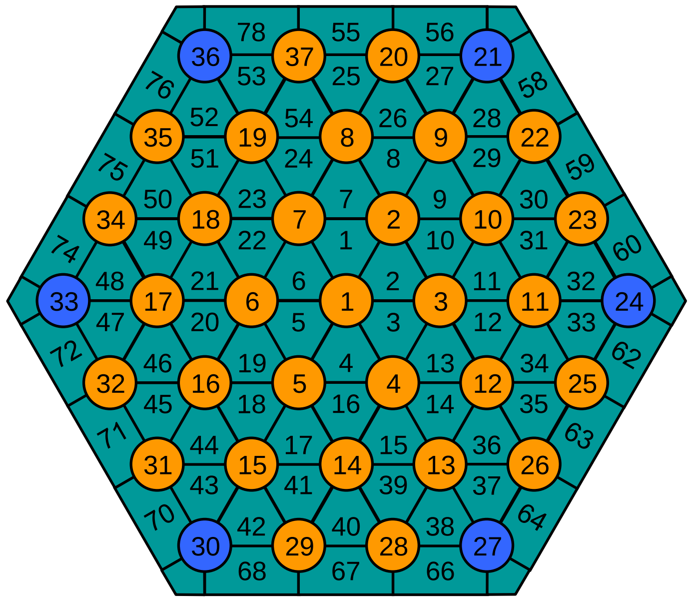


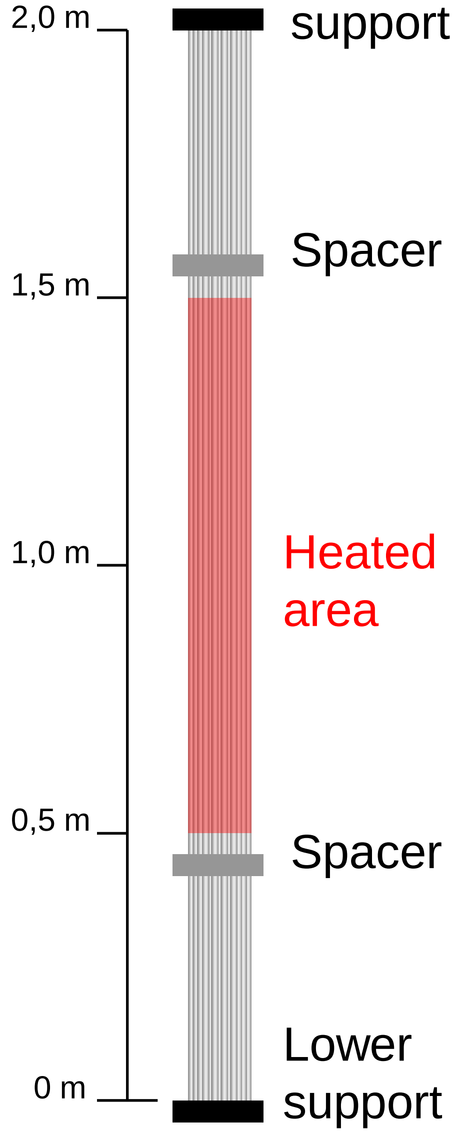
M. Tarantino, ENEA

CIRCE experiment: Heated rod bundle

Experimental design :

- 37pin hexagonal rod bundle structure with 31 heated pins and 6 cold outer pins
- Coolant entry temperature: 300°C
- Pin Diameter: 8.2 mm
- P/D ratio: 1.8
- Heated length: 1 m
- Nonheated inlet/outlet: 0.5 m
- Fluid velocity in bundle: 1 m/s
55 kg/s
- Thermal power: 100 W/cm²
480 W/cm
800 kW total
- 2 spacer in the non-heated area.



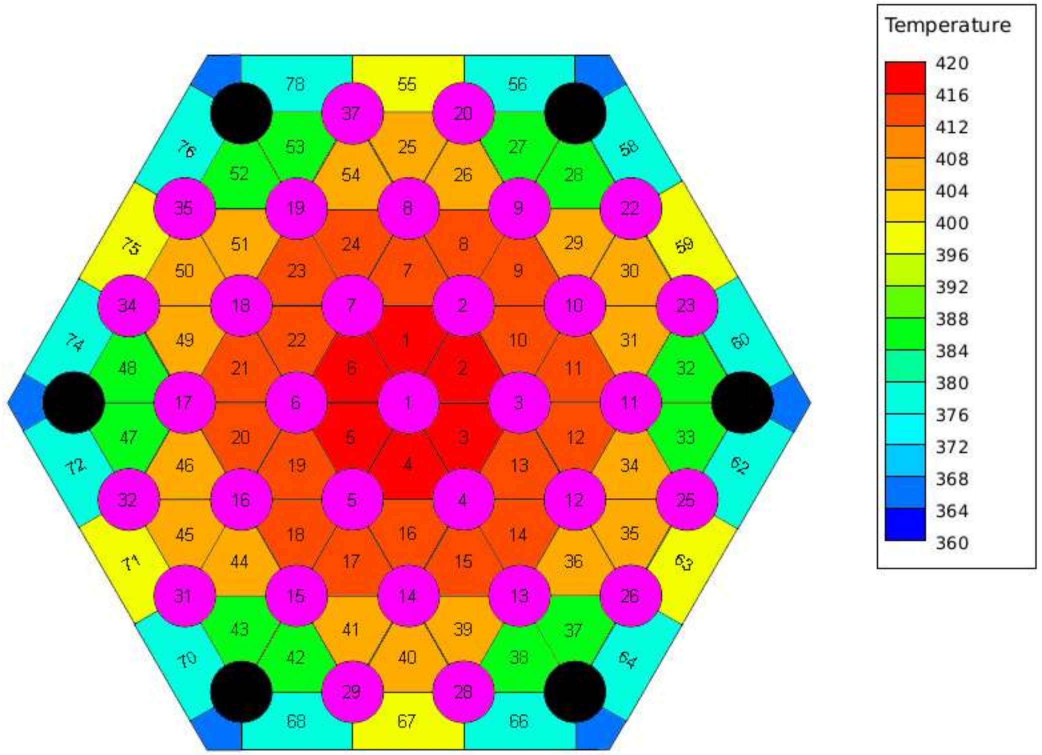


MATRA sub channel analysis:

31 Heated rods:

Sub channel temperatures at end of heated area:

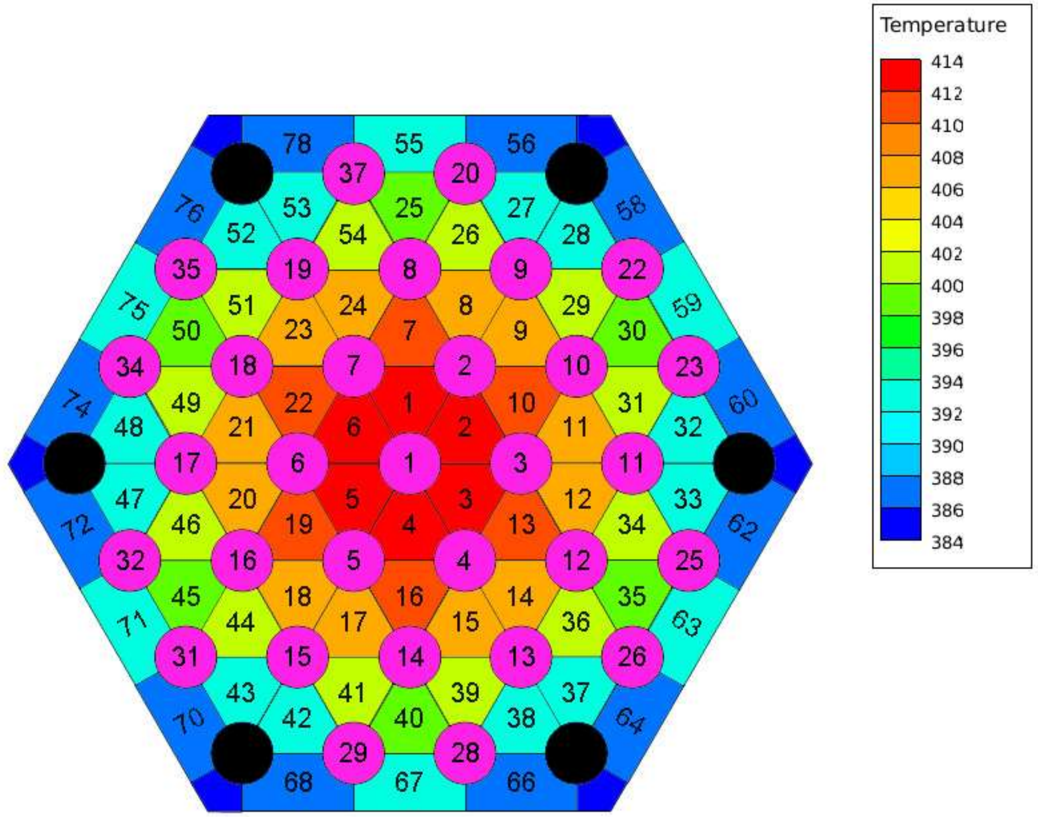
- T_{Exit} hottest Channel: 416°C
- T_{Exit} coldest Channel: 364°C
- Max ΔT in rod bundle 52°C
- Max ΔT around one rod:
  - rod 2 4 C
  - rod 8 9 C
  - rod 9 25 C
  - rod 20 29 C
  - rod 21 22 C



MATRA sub channel analysis:

31 Heated rods:

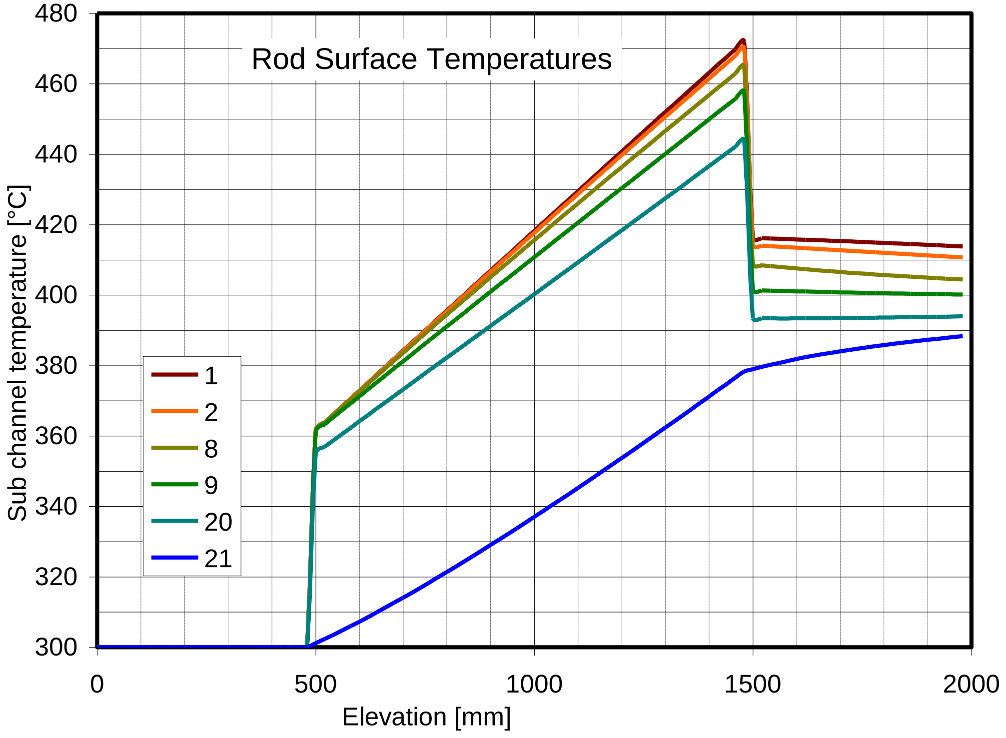
Sub channel temperatures at Channel exit:

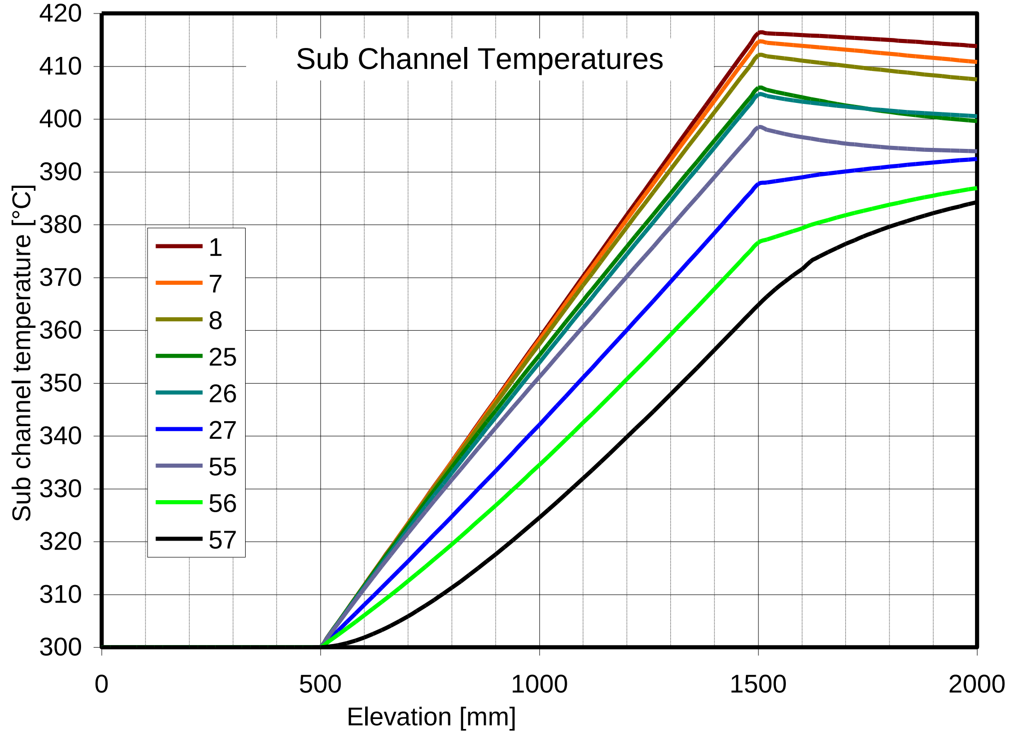


- T_{Exit} hottest Channel: 414°C
- T_{Exit} coldest Channel: 384°C
- Max ΔT in rod bundle 30°C
- Max ΔT around one rod:
  - rod 2 6 C
  - rod 8 11 C
  - rod 9 15 C
  - rod 20 14 C
  - rod 21 8 C

MATRA sub channel analysis:

31 Heated rods





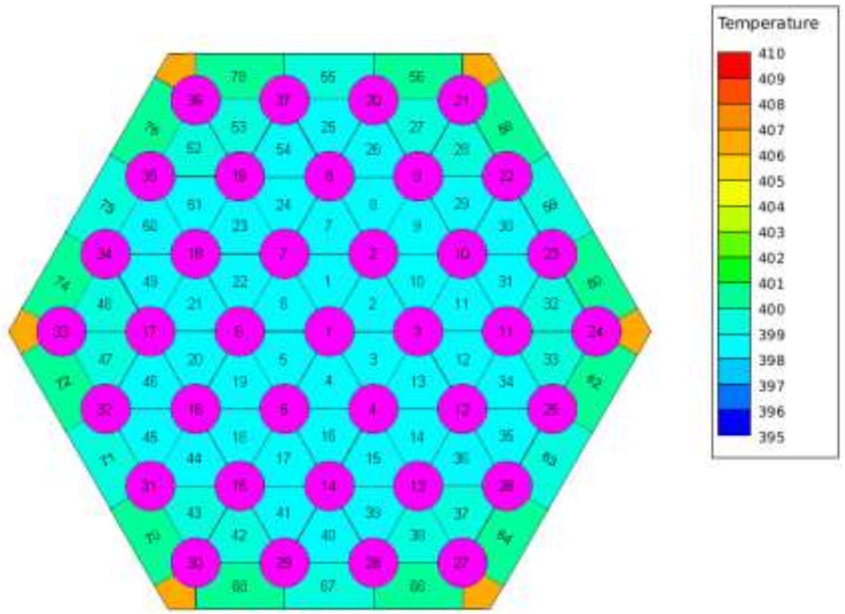
Temperature distribution as function of elevation for rods (left) and sub channels (right)

MATRA sub channel analysis:

Comparison with 37 heated rods:

Sub channel temperatures at end of heated area:

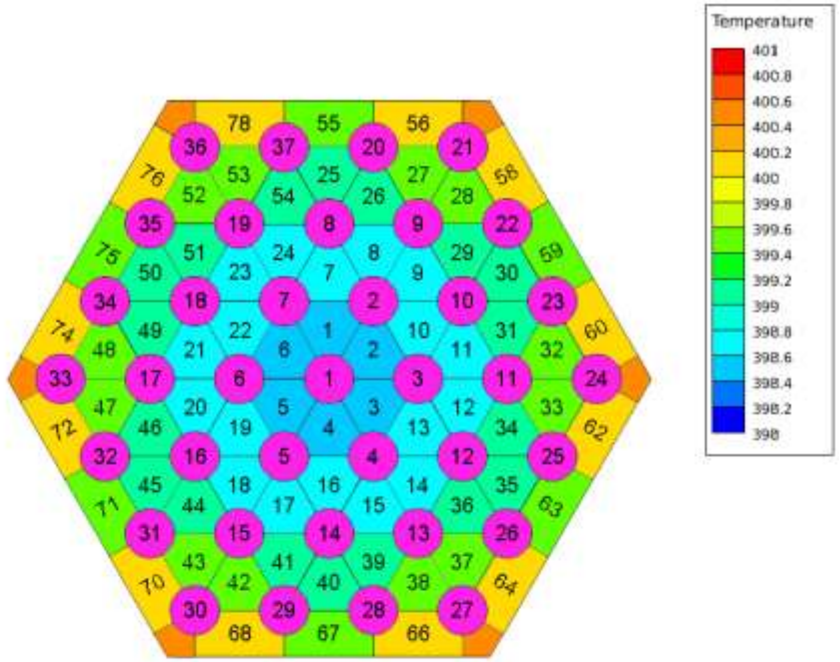
- T_{Exit} hottest Channel: 406°C
- T_{Exit} coldest Channel: 399°C
- Max ΔT in rod bundle 7°C
- Max ΔT around one rod: ~6 C



Sub channel temperature results at Channel exit:

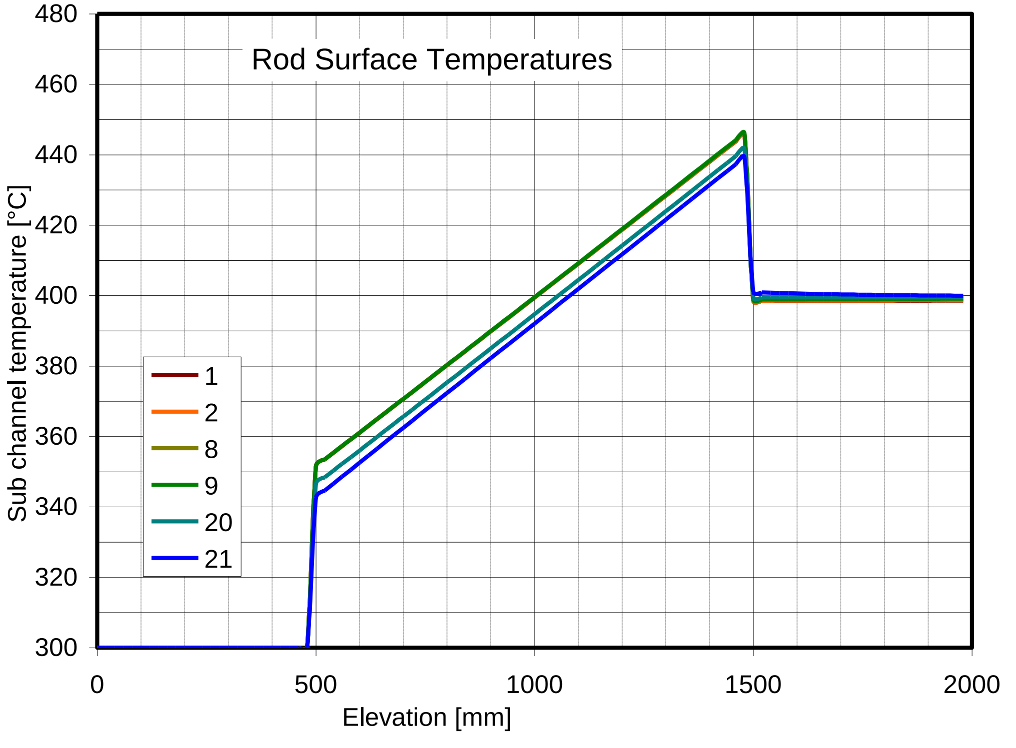
1. T_{Exit} hottest Channel: 401°C

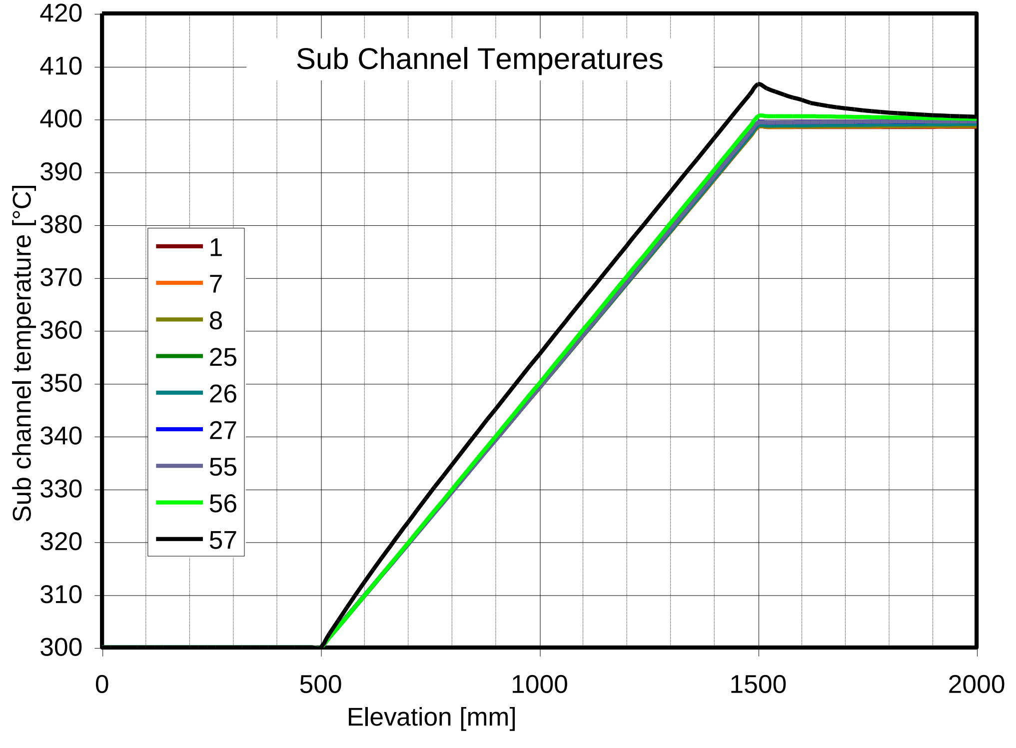
- T_{Exit} coldest Channel: 398°C
- Max ΔT in rod bundle 3°C
- Max ΔT around one rod: ~1 C



MATRA sub channel analysis:

37 Heated rods



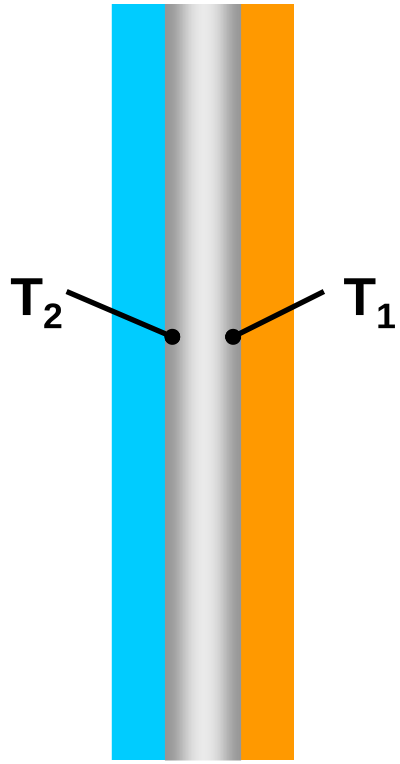


Temperature distribution as function of elevation for rods (left) and sub channels (right)

Temperature influence on rod geometry

Temperature distribution in the rods:

Large temperature differences in sub channels leads to ΔT in the rods at a given height.



Maximum temperature differences around heater #20

- Given heat flux, MATRA subchannel data, Subbotin-correlation

T [K]

60

- Temperature differences up to ΔT=60 K exceeding MATRA results

Temperature influence on rod geometry

Estimation of circumferential heat flux

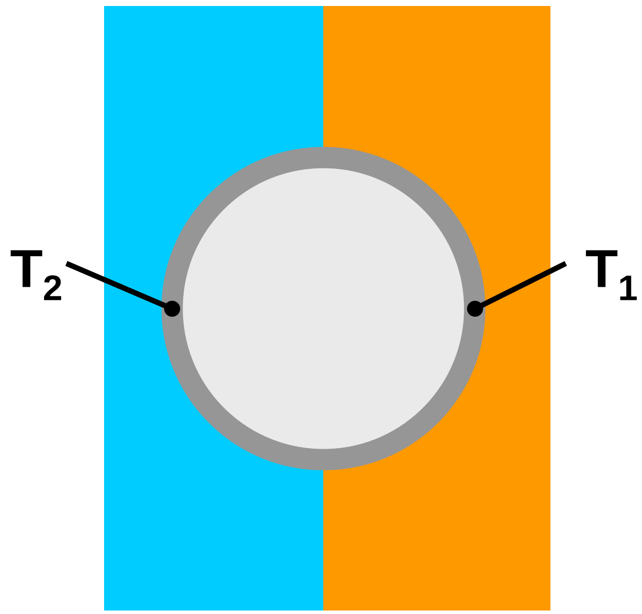
- MATRA assumes uniform heater surface temperature
- Heat flux across the heater for ΔT=60K:

$$\dot{q} = \lambda \frac{dT}{dx} \left[\frac{W}{mK} \frac{K}{m} \right]$$

$$\dot{q}_l = \lambda \frac{dT}{dx} s \left[\frac{W}{mK} \frac{Km}{m} \right]$$

$$\dot{q}_l = \lambda \frac{\Delta T}{\pi r} s \approx \frac{15 \cdot 60 \cdot .5}{3 \cdot 4} \left[\frac{W}{mK} \frac{Kmm}{mm} \right]$$

$$\dot{q}_l = 37 \left[\frac{W}{m} \right] = .37 \left[\frac{W}{cm} \right] \qquad << 480 \left[\frac{W}{cm} \right]$$



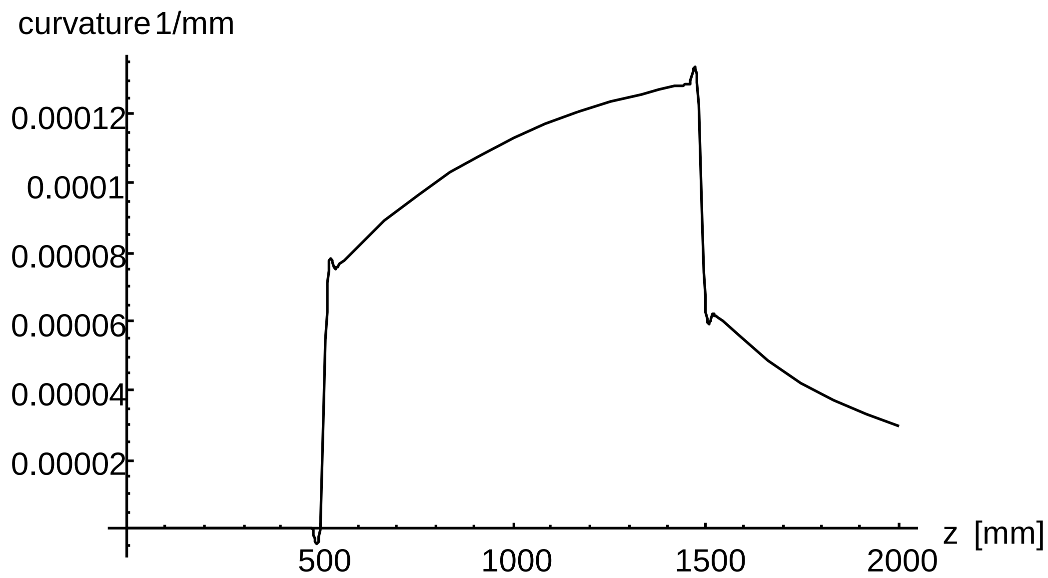
✓ circumferential heat flux is negligible

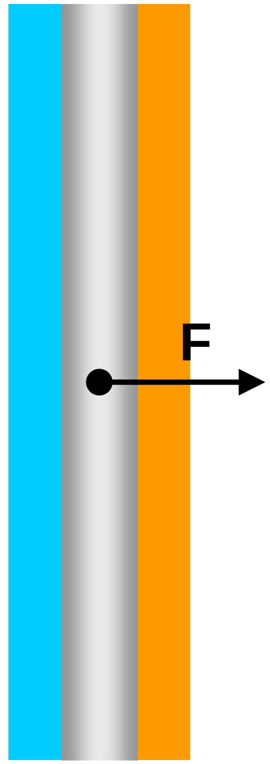
Temperature influence on rod geometry

Curvature of rod due to non-uniform temperature

- Conservative estimate neglecting stresses due to geometric constraints

$$\frac{1/c+d}{1/c} = \frac{1+\beta\,\Delta T}{1}$$





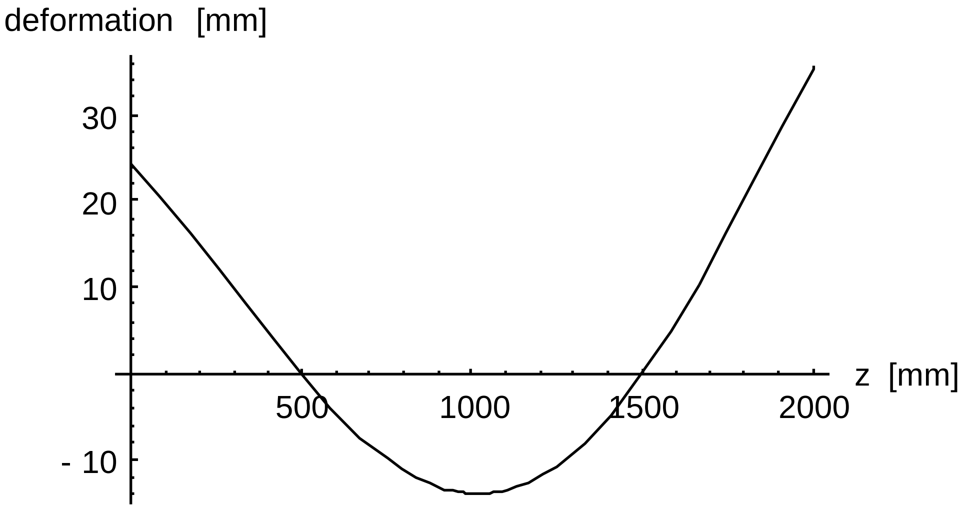
- Curvature radius 1/c of 8 - 30 m

Temperature influence on rod geometry

Deformation of rod due to non-uniform temperature

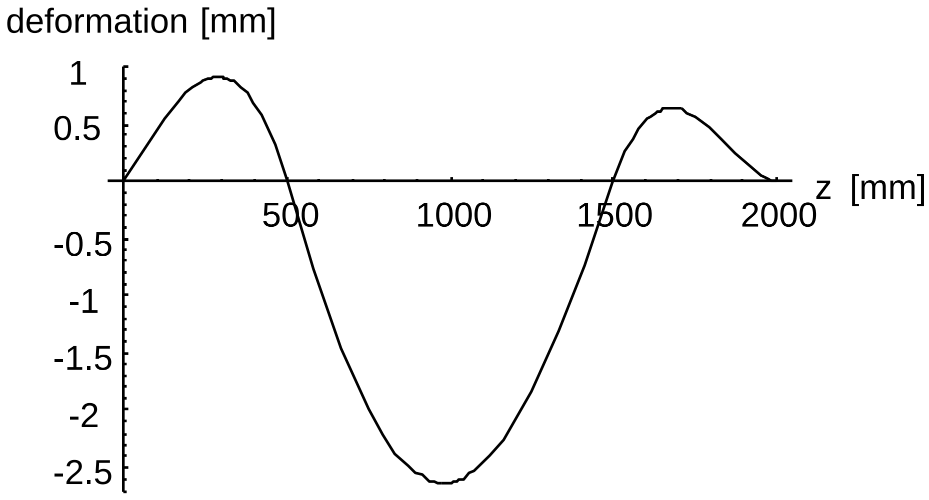
- Conservative estimate neglecting stresses due to geometric constraints

$$\frac{h''}{(1+h'^2)^{3/2}} = c$$



- Including geometric constraints

$$\frac{h''}{(1+h'^2)^{3/2}} = c$$



- Unacceptable deformation that could lead to blocking of subchannels

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Conclusions:

- Numerical calculations show unacceptable deformation of the heated rods for the first suggested design
- blocking of subchannels cannot be excluded

- Design of Circe experiment was changed in the way that all 37 rods are heated and an additional spacer will be positionned at the middle of the heated area so that deformations will remain in an acceptable range.