National Physical Laboratory

A prototype calorimeter for HDR ^{192}Ir brachytherapy sources

Thorsten Sander, Hugo Palmans, Simon Duane

National Physical Laboratory, Teddington, UK

LNE-LNHB / BIPM Workshop on “Absorbed Dose and Air Kerma Primary Standards”, Paris, 9 - 11 May 2007

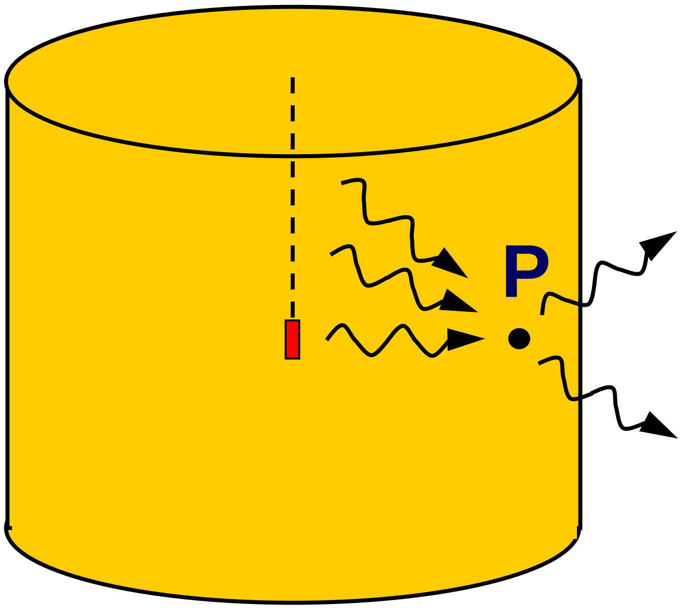
Overview

- Absorbed dose measurements for brachytherapy
- MC calculations for calorimeter design parameters
- MC calculated correction factors
- Heat transfer simulations
- Conclusions
- Future work

Proposed measurement method: calorimetry

- Objective: investigate feasibility of calorimetry for brachytherapy
- Alternative method to current air kerma based approach (using reference air kerma rate (RAKR), dose rate constant Λ and TG-43 to derive absorbed dose)
- Direct measurement of absorbed dose

$$D_{\text{point}} = \frac{E_{rad}}{m} = c_p \Delta T$$



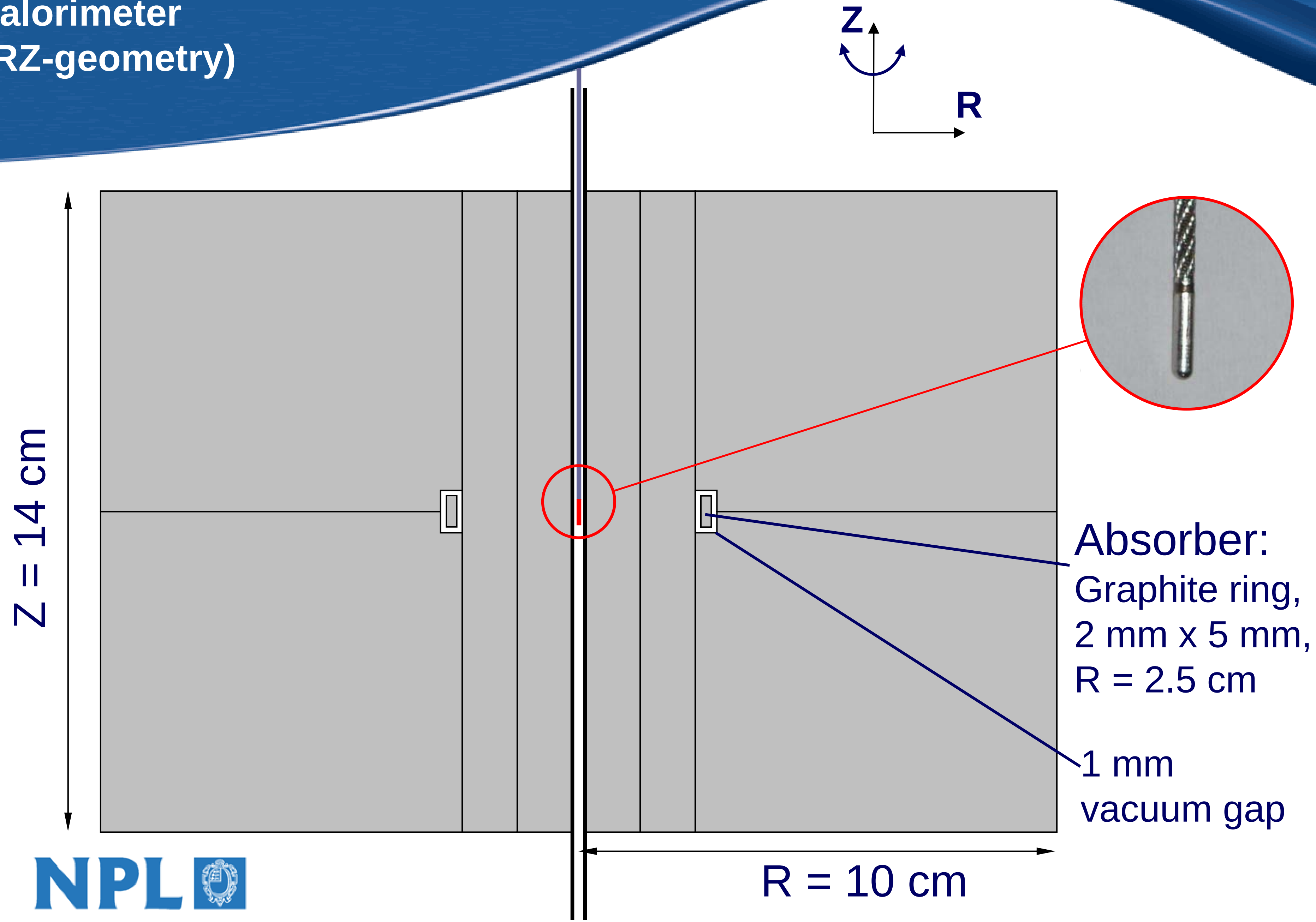
NPL

Problems in brachytherapy dosimetry

- High dose gradient over clinically relevant range (0.5 cm to 5 cm from source centre) resulting in heat flow down temperature gradients
- Self-heating of radioactive source
- Huge variety of brachytherapy source designs

NPL

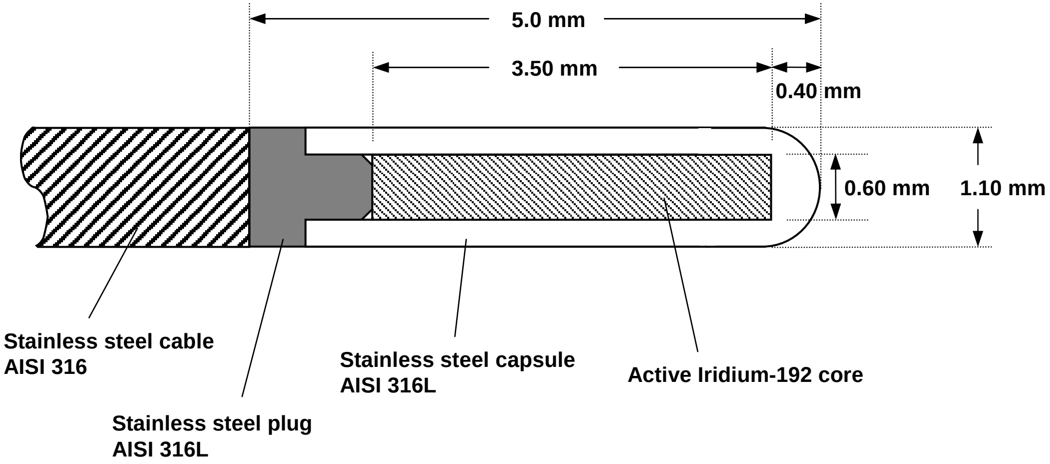
Schematic drawing of prototype calorimeter (RZ-geometry)



NPL

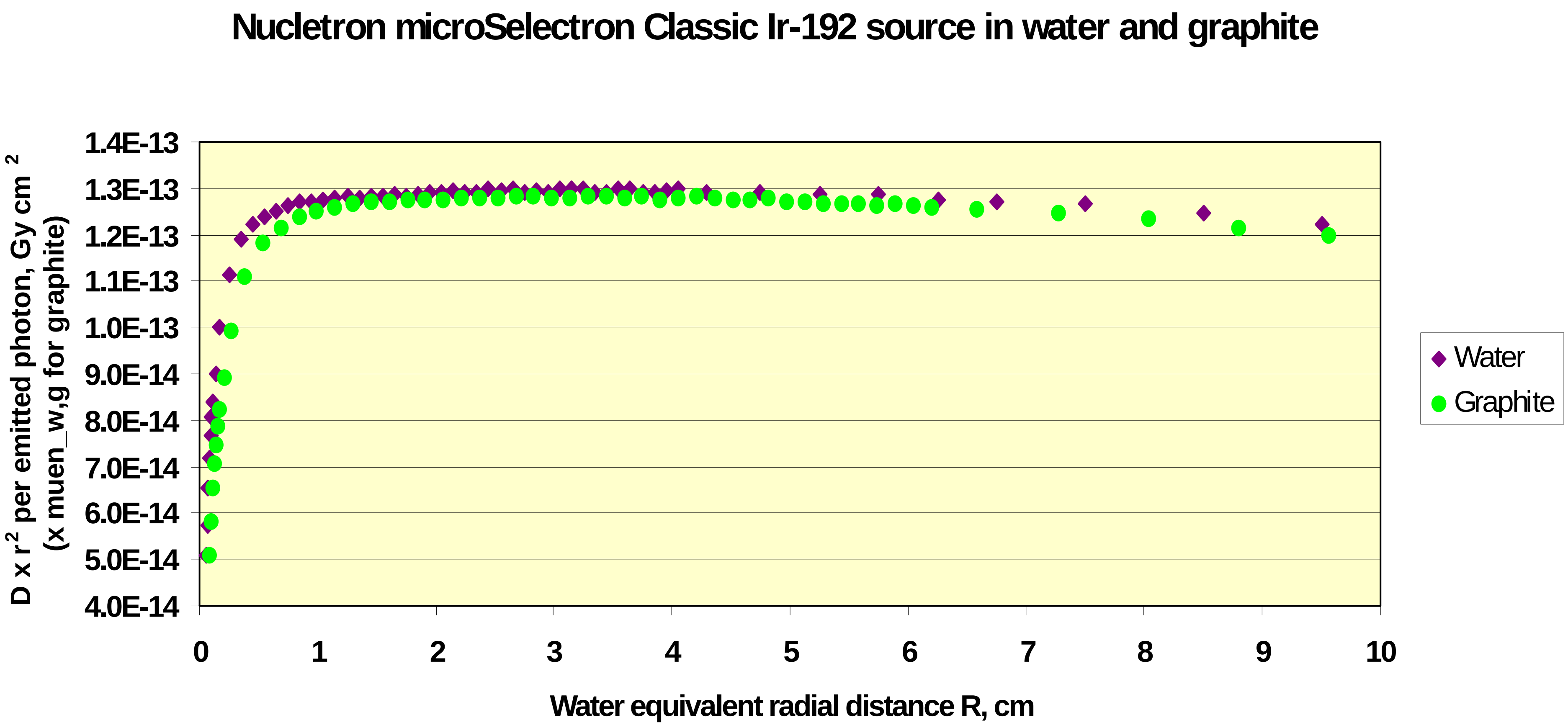
EGSnrc Monte Carlo simulations

- Various aspects of calorimeter modelled with DOSRZnrc
- Source (Nucletron microSelectron Classic):
  - Bare ^{192}Ir spectrum used for ^{192}Ir cylinder
  - AISI 316L stainless steel encapsulation



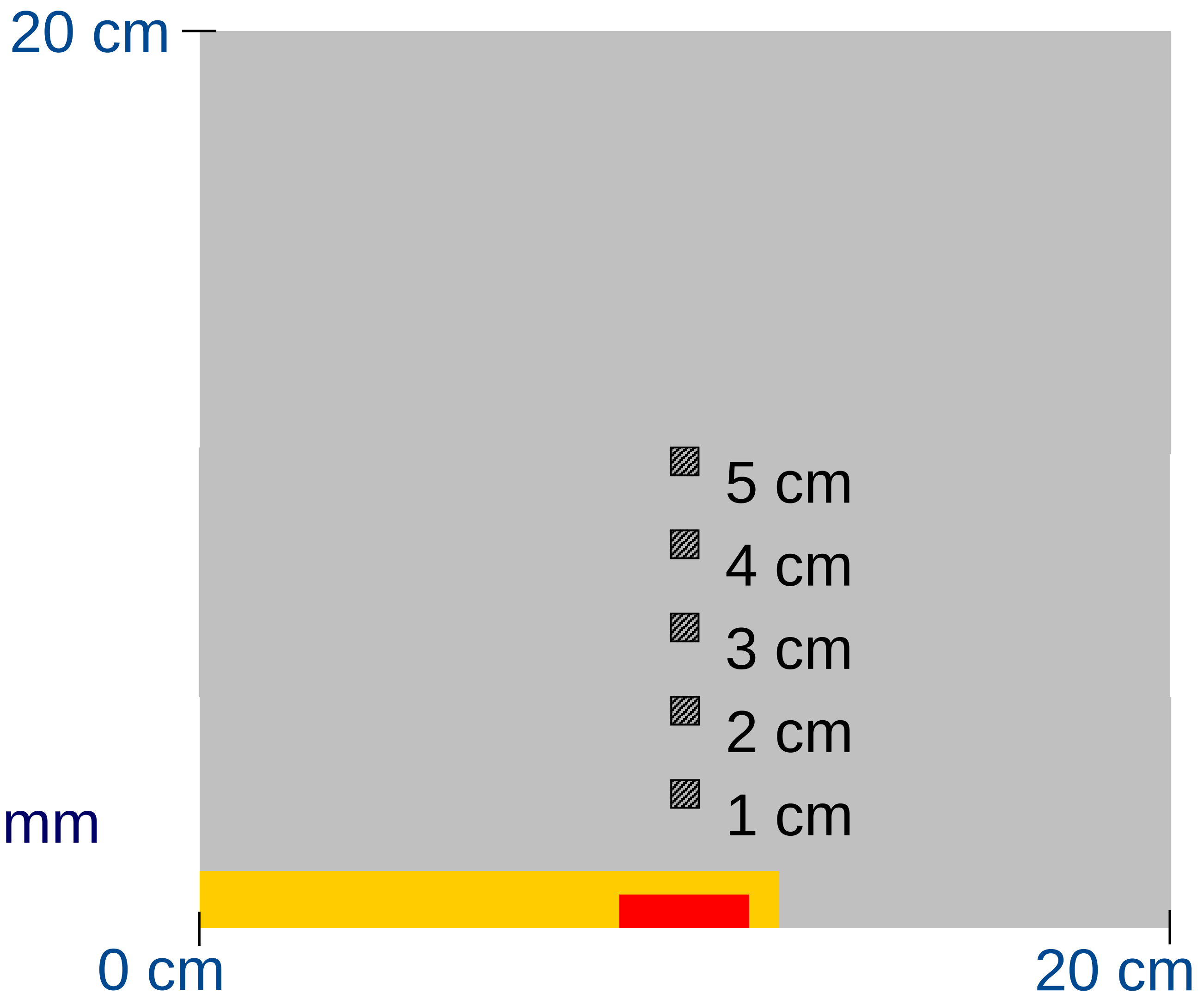
NPL

Build-up curves in water and graphite



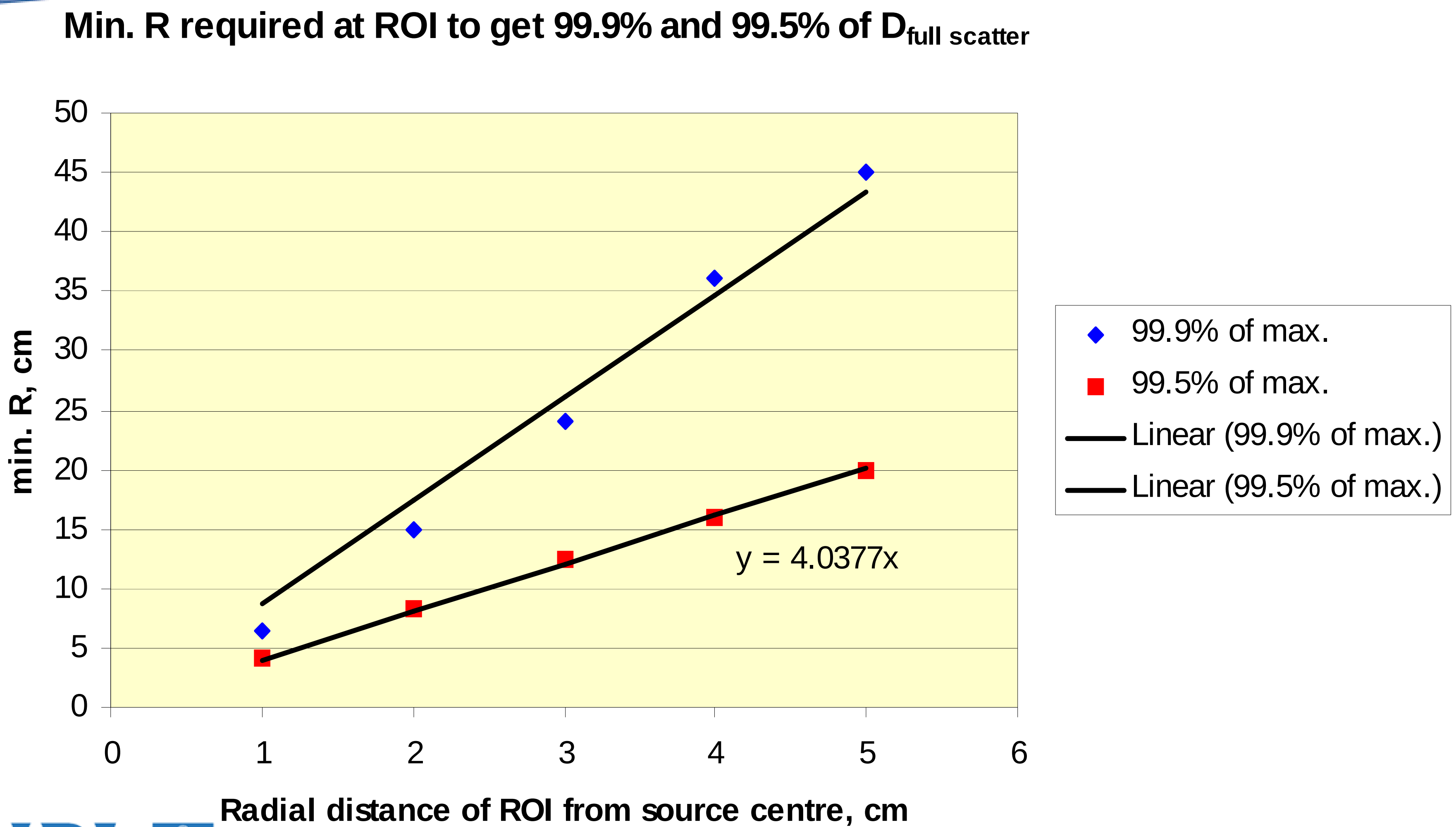
- $(\mu_{en}/\rho)^{w}_{g} = 1.11$ for mean ^{192}Ir energy
- Energy dependent → calculate fluence spectrum

Scatter build-up along R-axis

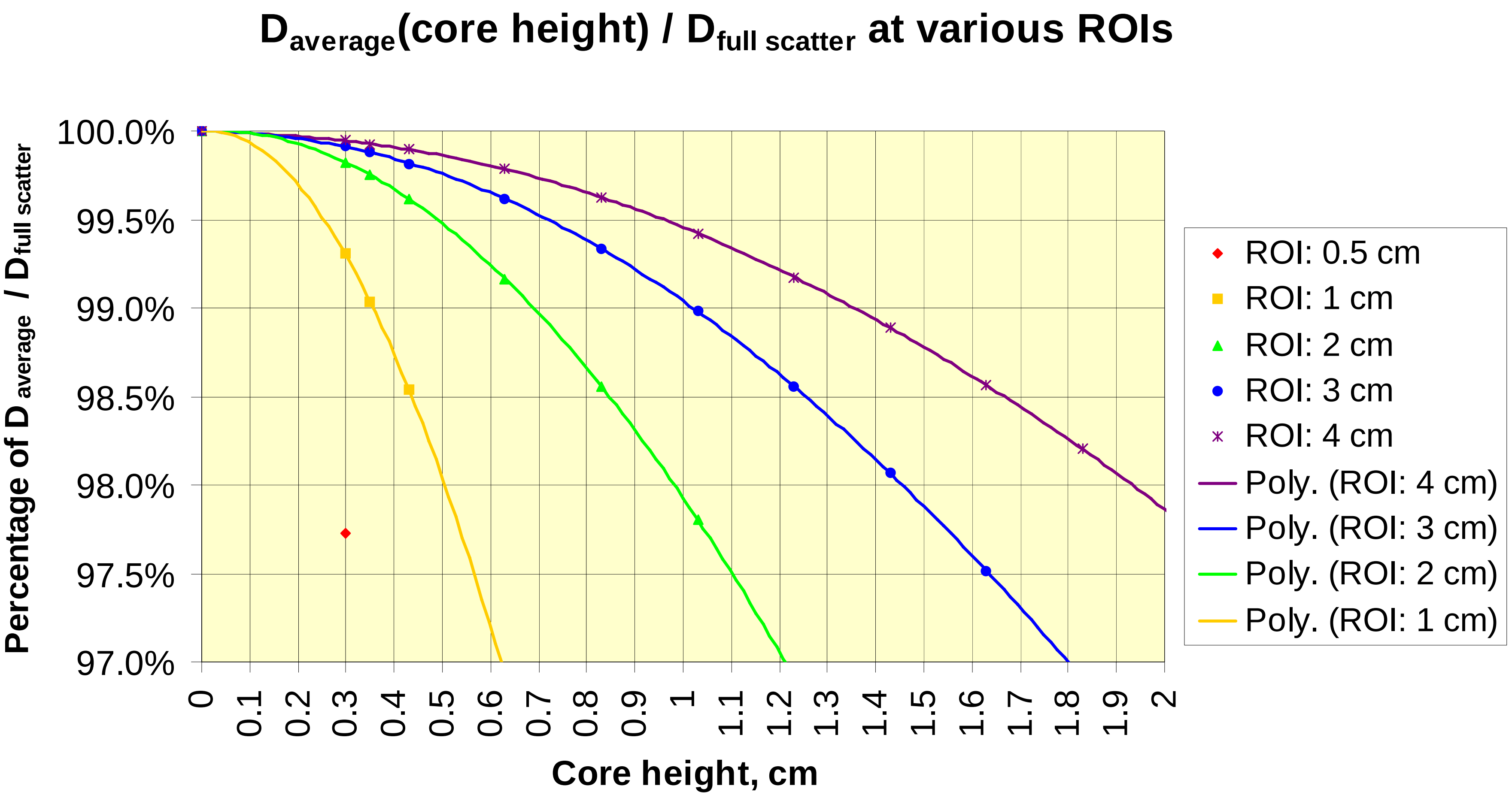


ROI = 1 mm x 1 mm

Scatter build-up in graphite



Variation of $D_{average}$ with core height



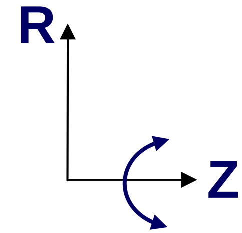
NPL

Summary of MC simulations

Source to core, cm (graphite)	Build-up	Min. R, cm	Min. Z/2, cm	Max. core height, cm	Dose gradient over 2 mm, %	Dose rate from 370 GBq source, Gy/s	ΔT in 120 s, K
1	✗	✓	✓	✗	✗	9.99E-02	1.68E-02
2	(✓)	8.1	5.4	0.5	23	2.52E-02	4.24E-03
2.5	✓	10.1	6.8	0.6	18.5	1.60E-02	2.69E-03
3	✓	12.1	8.1	0.75	15	1.12E-02	1.88E-03
4	✓	16.2	10.9	1.05	11	6.21E-03	1.04E-03
5	✓	✗	✗	✓	✓	✗	✗

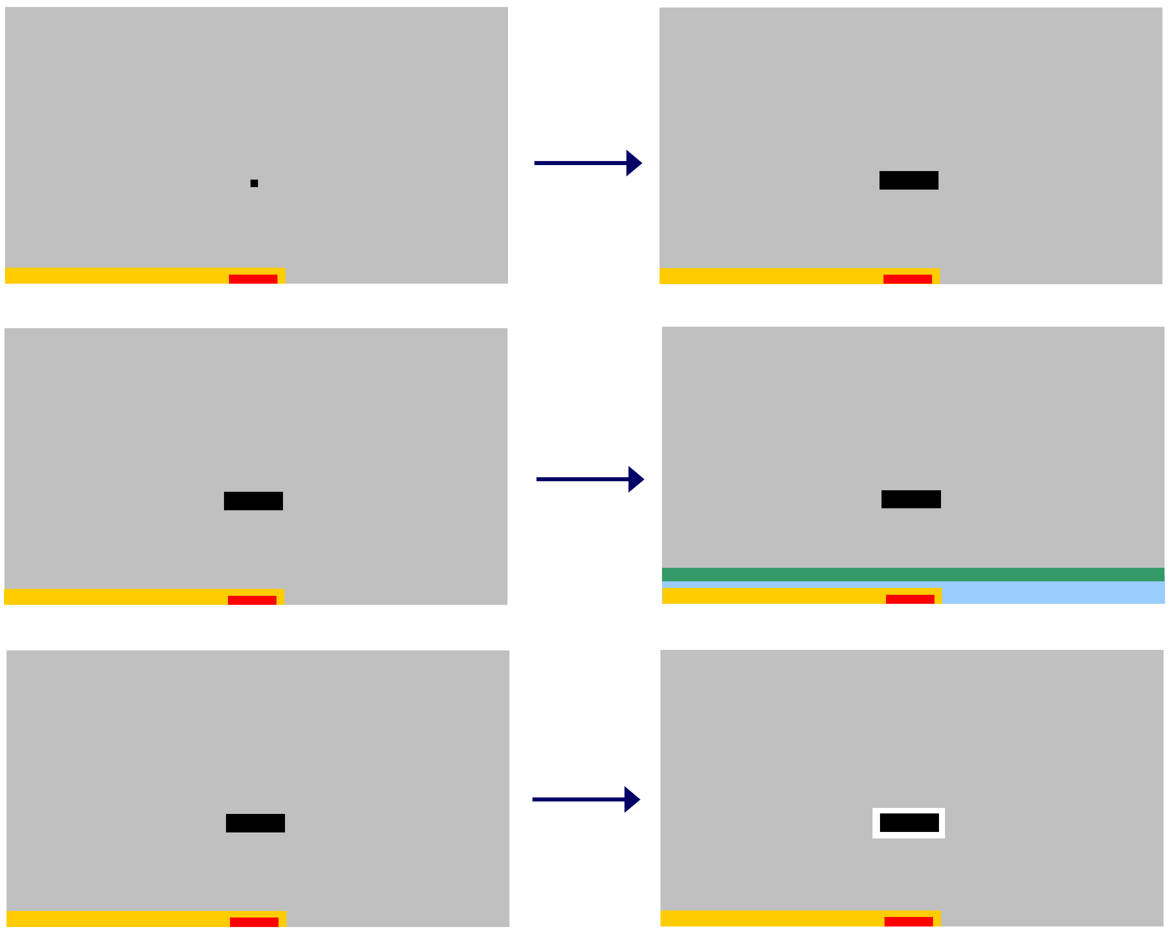
NPL

Calorimeter correction factors



'point' = 0.1 mm x 0.1 mm

core = 2 mm x 5 mm



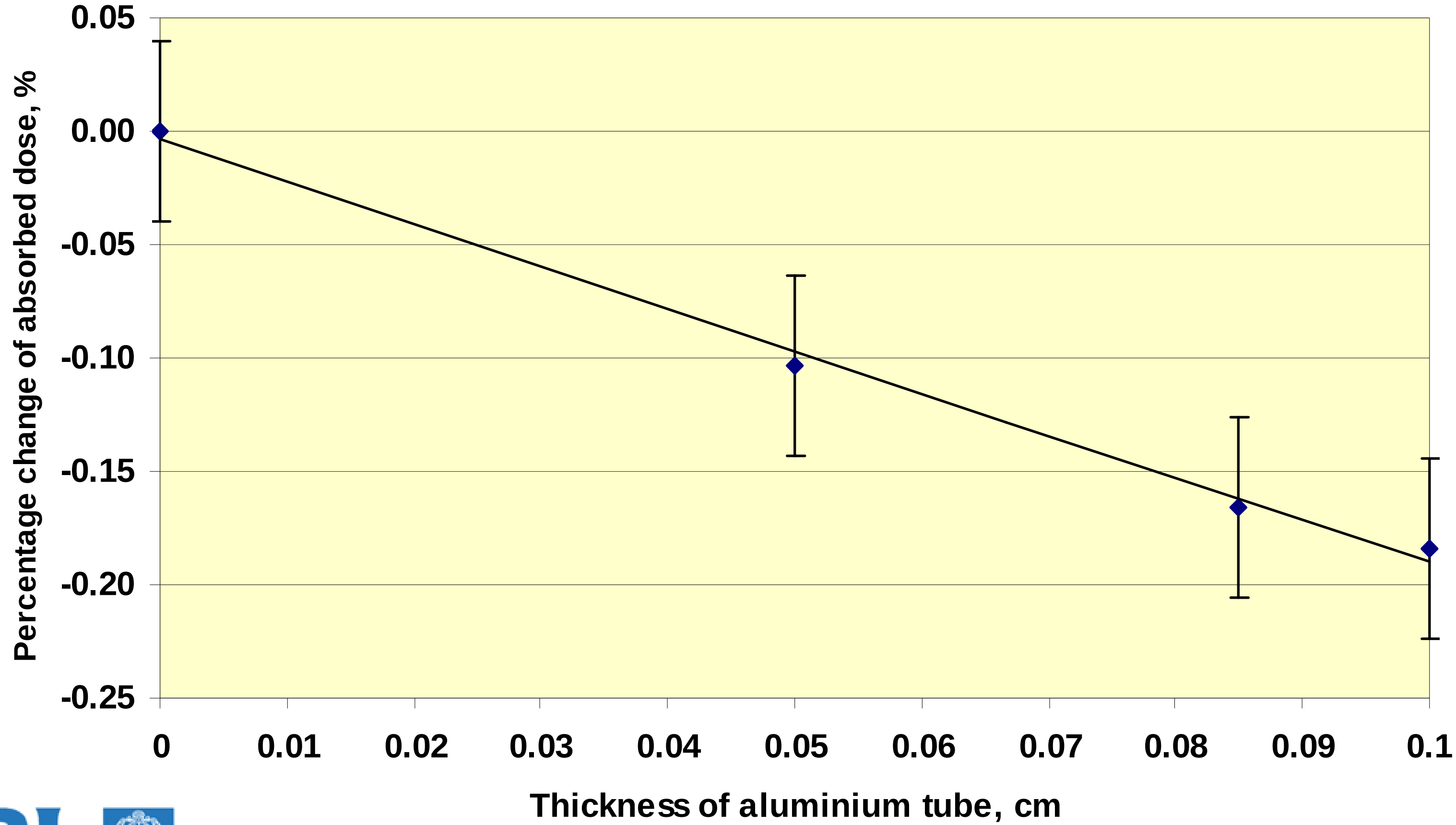
$$k_{\mathrm{vol}} = \frac{D_{\mathrm{point}}}{D_{\mathrm{core}}} = 1.0033$$

$$k_{\mathrm{inh}} = \frac{D_{\mathrm{core,\ graphite}}}{D_{\mathrm{core,\ graphite+air+metal}}}$$

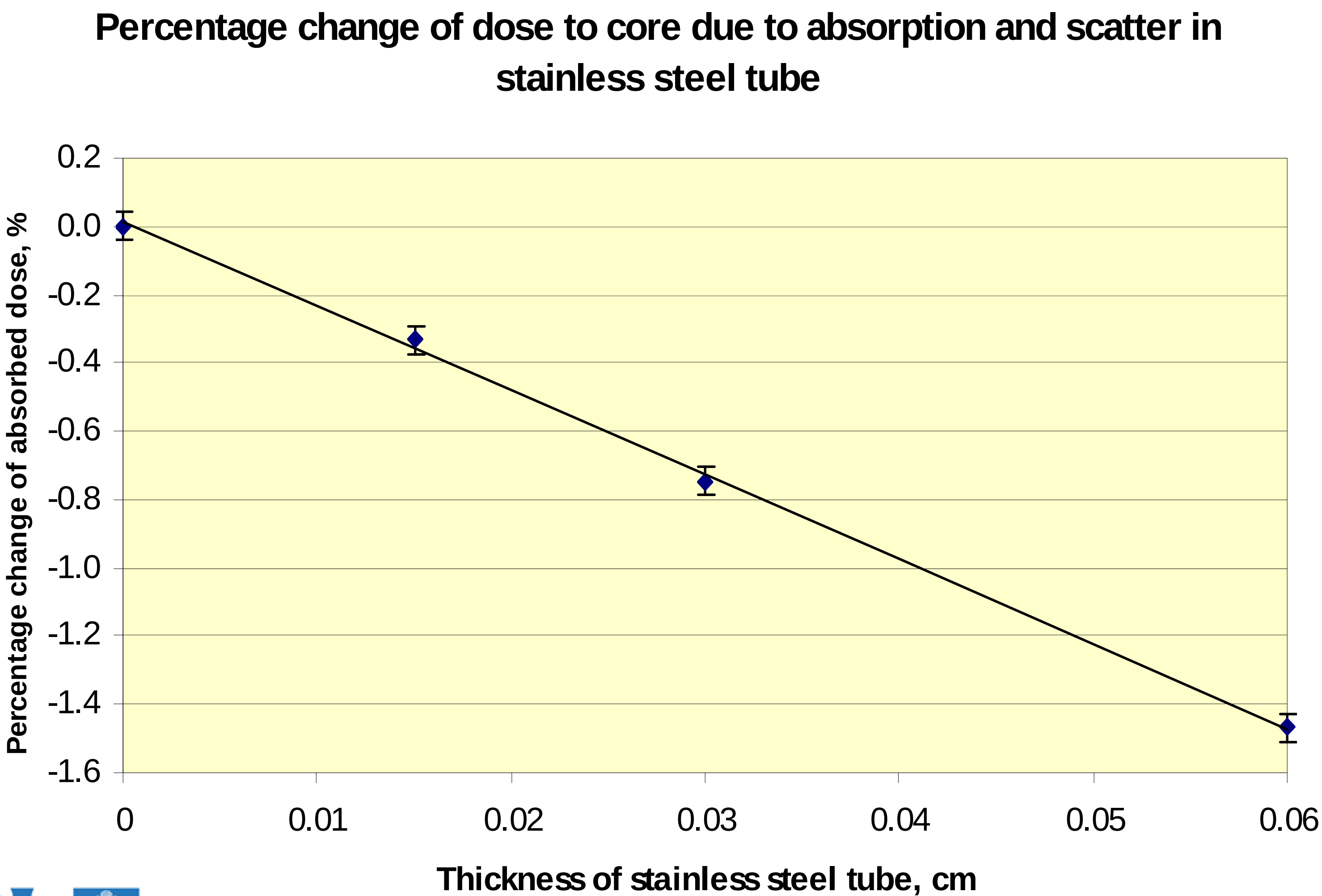
$$k_{\mathrm{gap}} = \frac{D_{\mathrm{core,\ graphite}}}{D_{\mathrm{core,\ graphite+vacuum\ gap}}}$$

Inhomogeneity correction due to aluminium tube

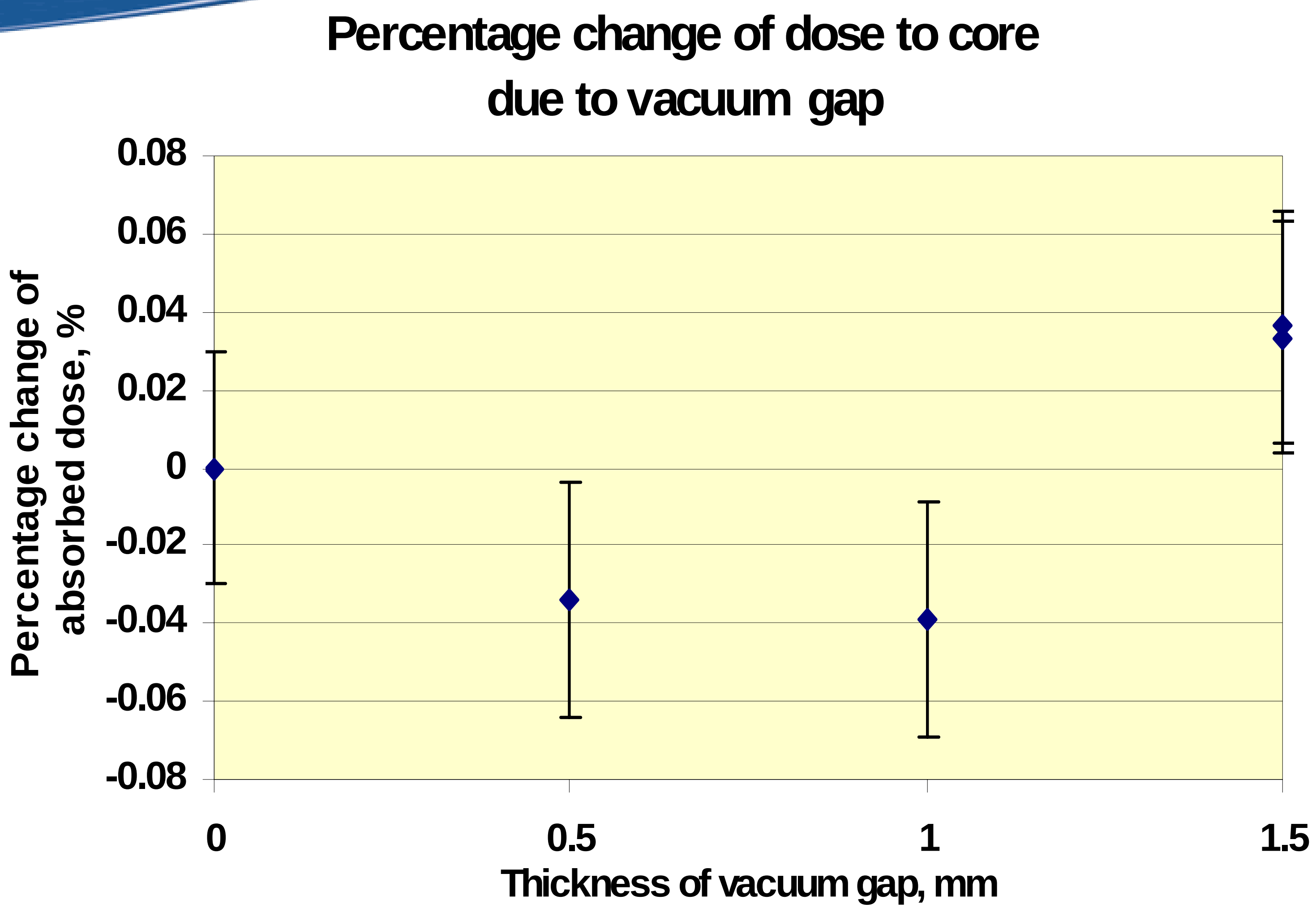
Percentage change of dose to core due to absorption and scatter in aluminium tube



Inhomogeneity correction due to stainless steel tube

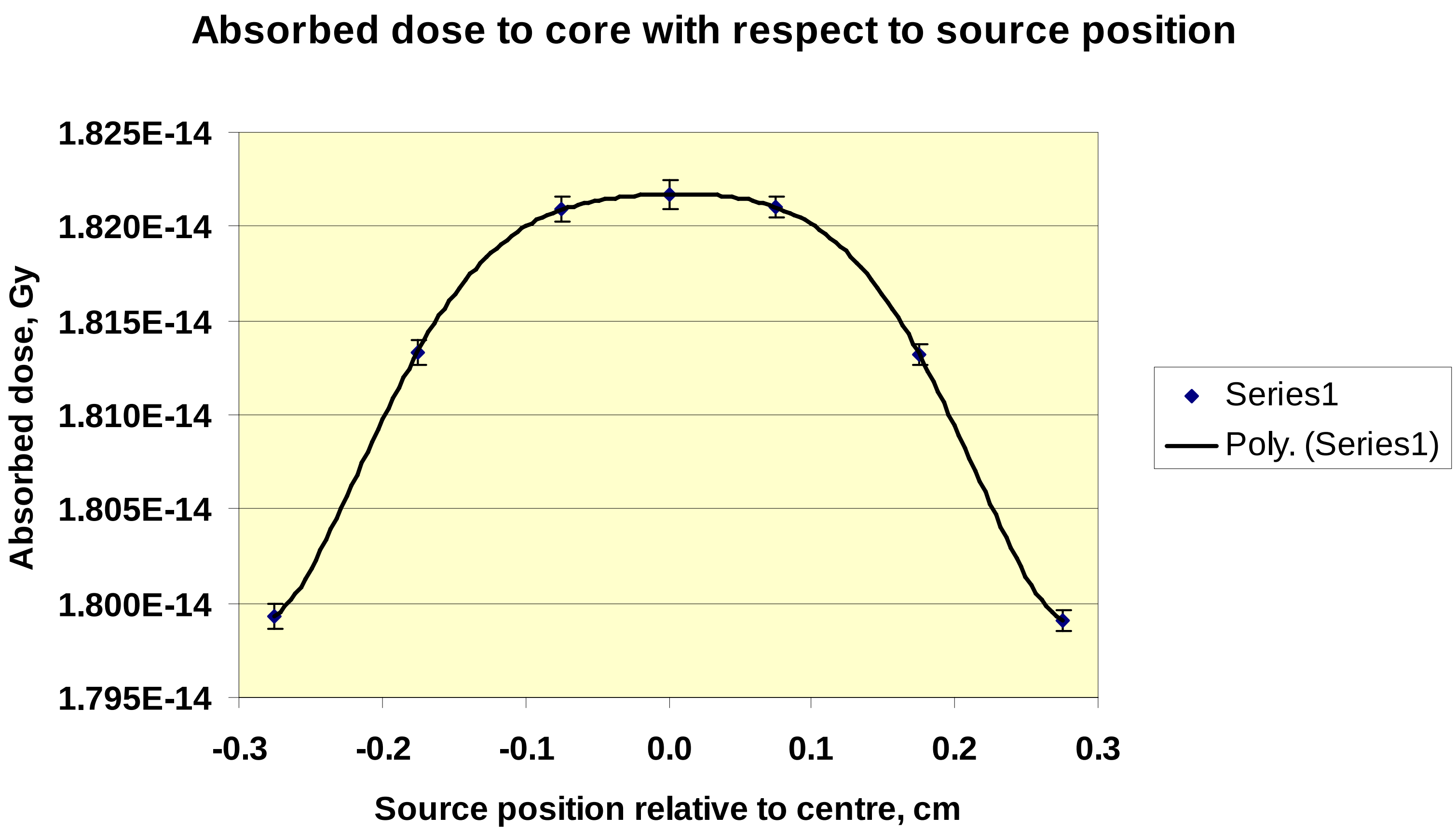


Gap correction factor



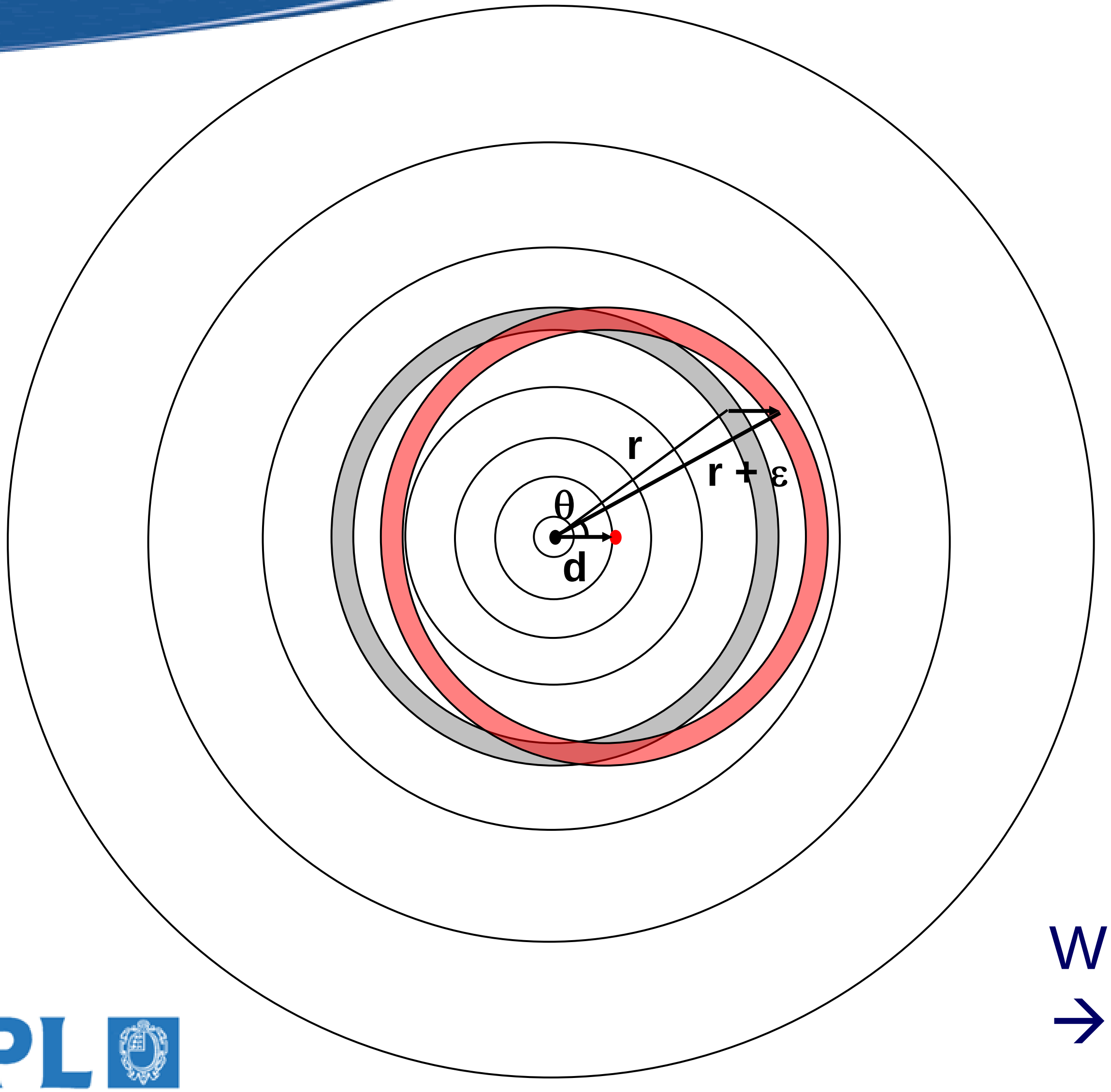
Displacement correction factor, Z-axis

$$k_{\text{disp,Z}} = \frac{D_{\text{central}}}{D_{\text{displaced, Z=0.25mm}}} = 1.0002$$



NPL

Displacement correction factor, R-axis



$$D(r) \propto \frac{1}{r^2}$$

$$D(r+\varepsilon)$$

$$\varepsilon = d\cos\theta$$

$$\iint d\theta dr D(r + d\cos\theta)$$

Taylor expansion

$$\frac{D_{\text{displaced}}}{D_{\text{symmetric}}} \approx 1 + \underbrace{\frac{3}{2}\frac{d^2}{r^2}}_{0.1\%}$$

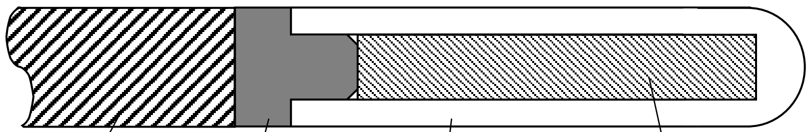
0.1%

With *r* = 25 mm

→ ***d* = 0.64 mm**

NPL

Self-heating of Nucletron microSelectron ^{192}Ir source

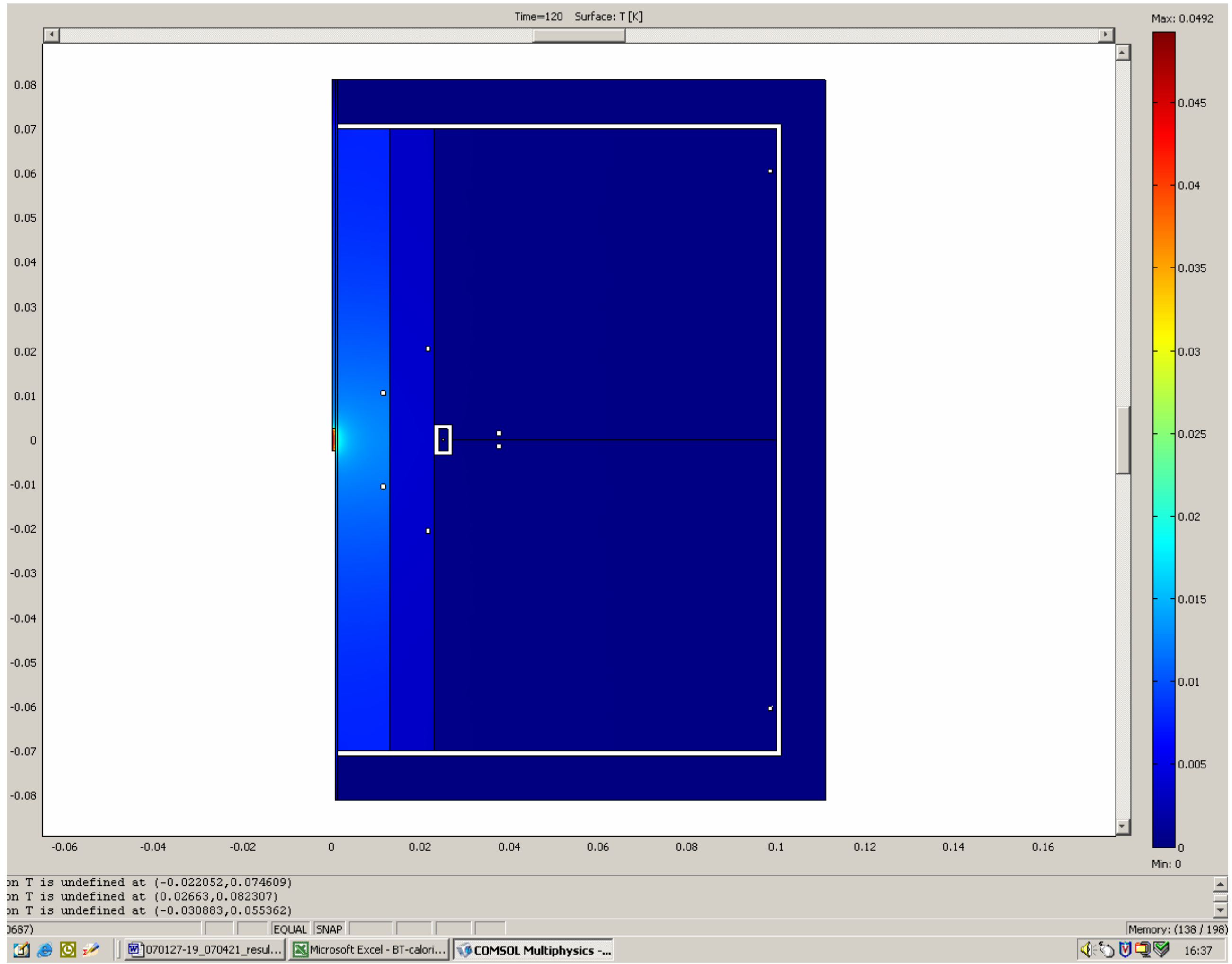


- Maximum source activity = 550 GBq
- Self-heating due to gamma radiation = 1.04E-2 W
- Self-heating due to electrons = 1.59E-2 W
- Total self-heating power = 2.63E-2 W

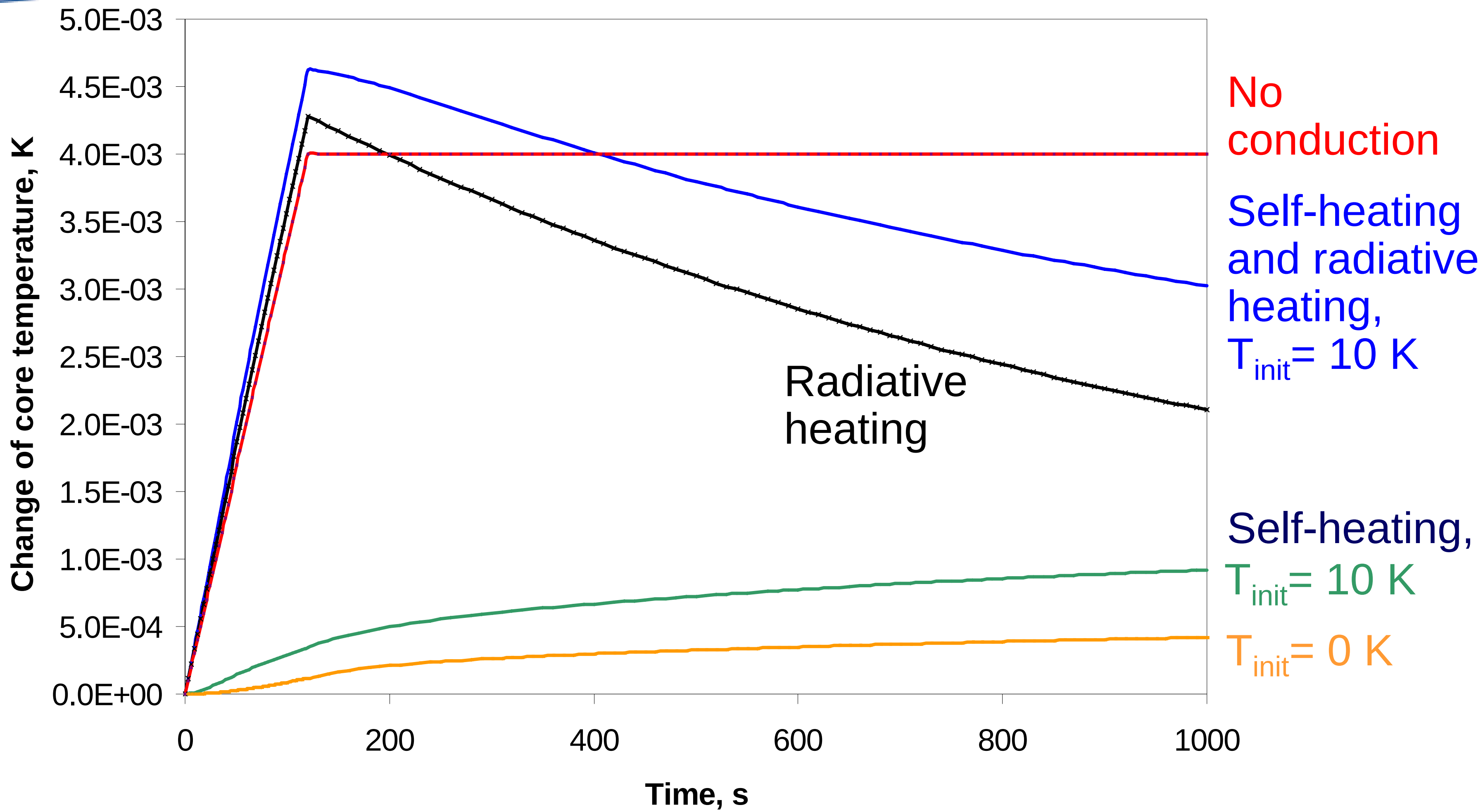
NPL

Heat transfer simulations

- Main modes of heat transfer:
  - Conduction
  - Thermal radiation
- Heat equation: solved by finite element modelling
- Stationary and transient solutions



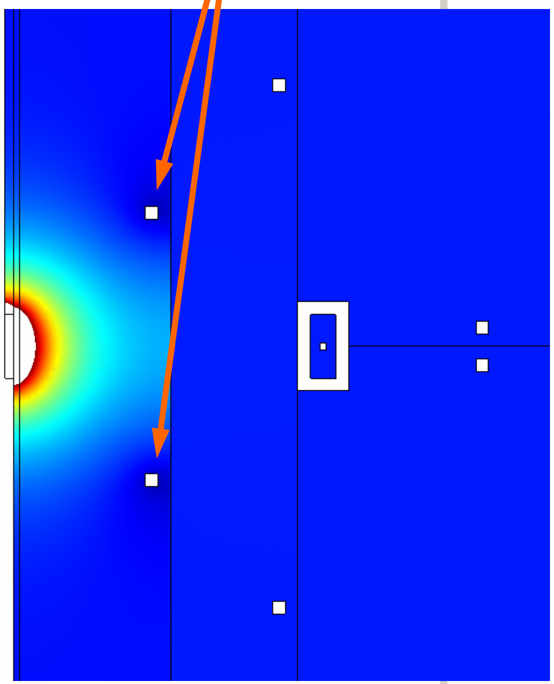
Example: heat conduction from self-heating and radiative heating

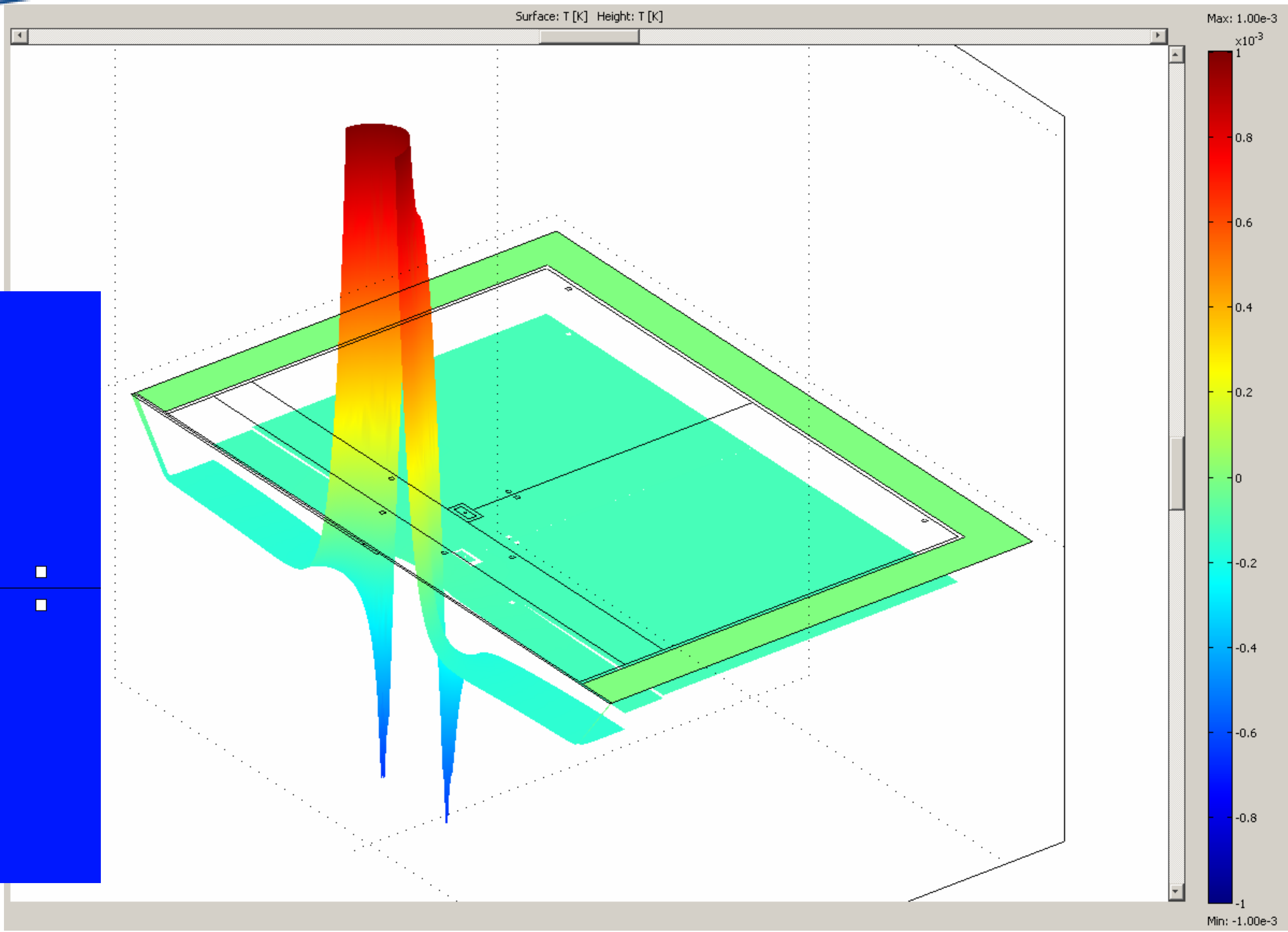


NPL

Control of self-heating effect, stationary solution, thermostatic mode

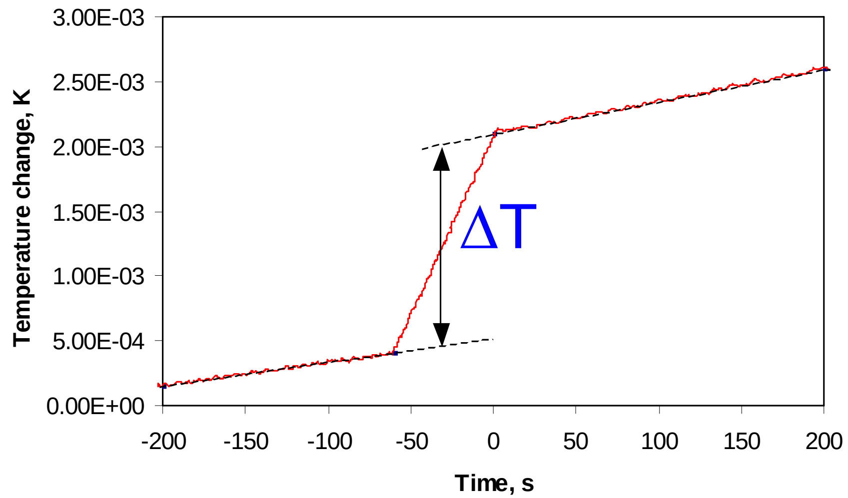
Thermistor 1+2:
-45.55 W m^{-2}



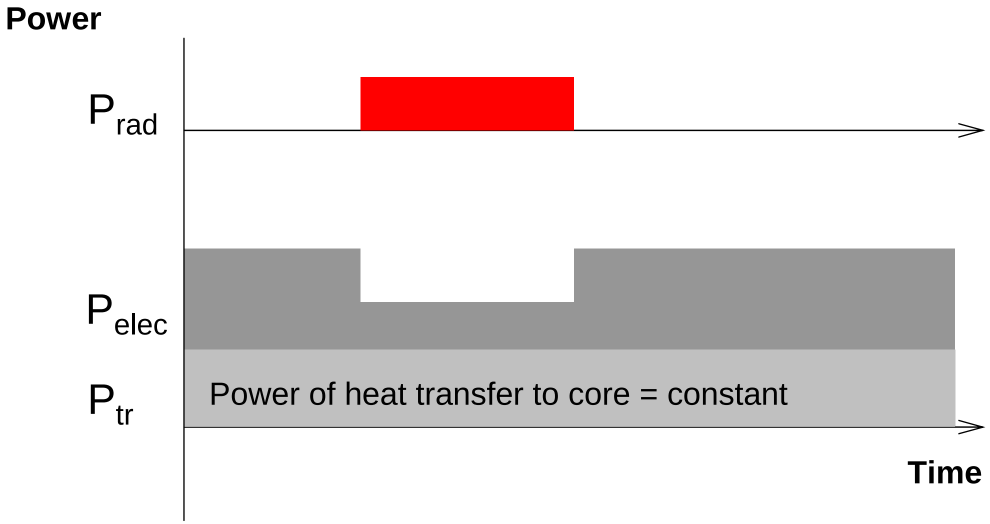


Modes of operation

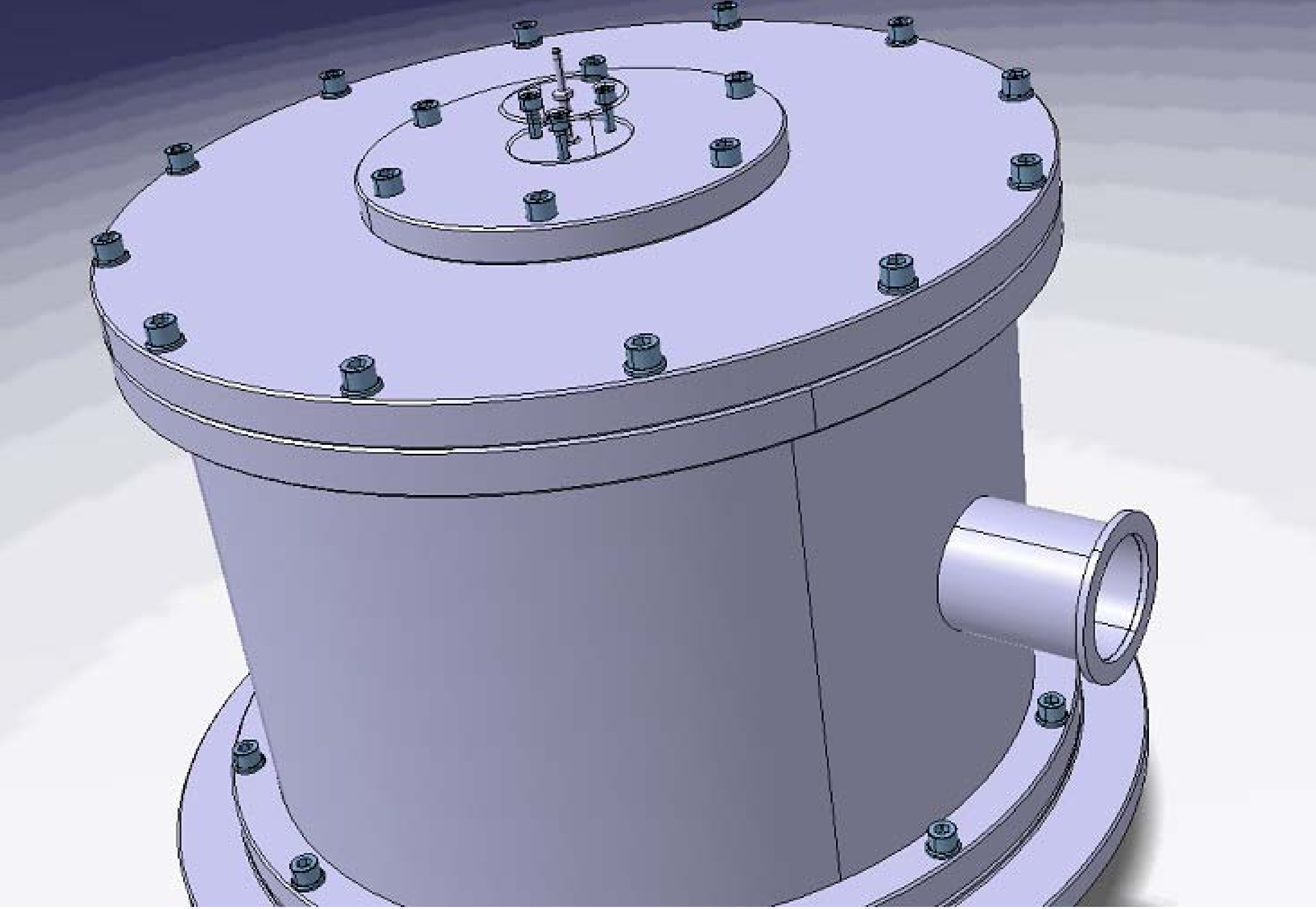
- Adiabatic mode
- Measurement of temperature difference

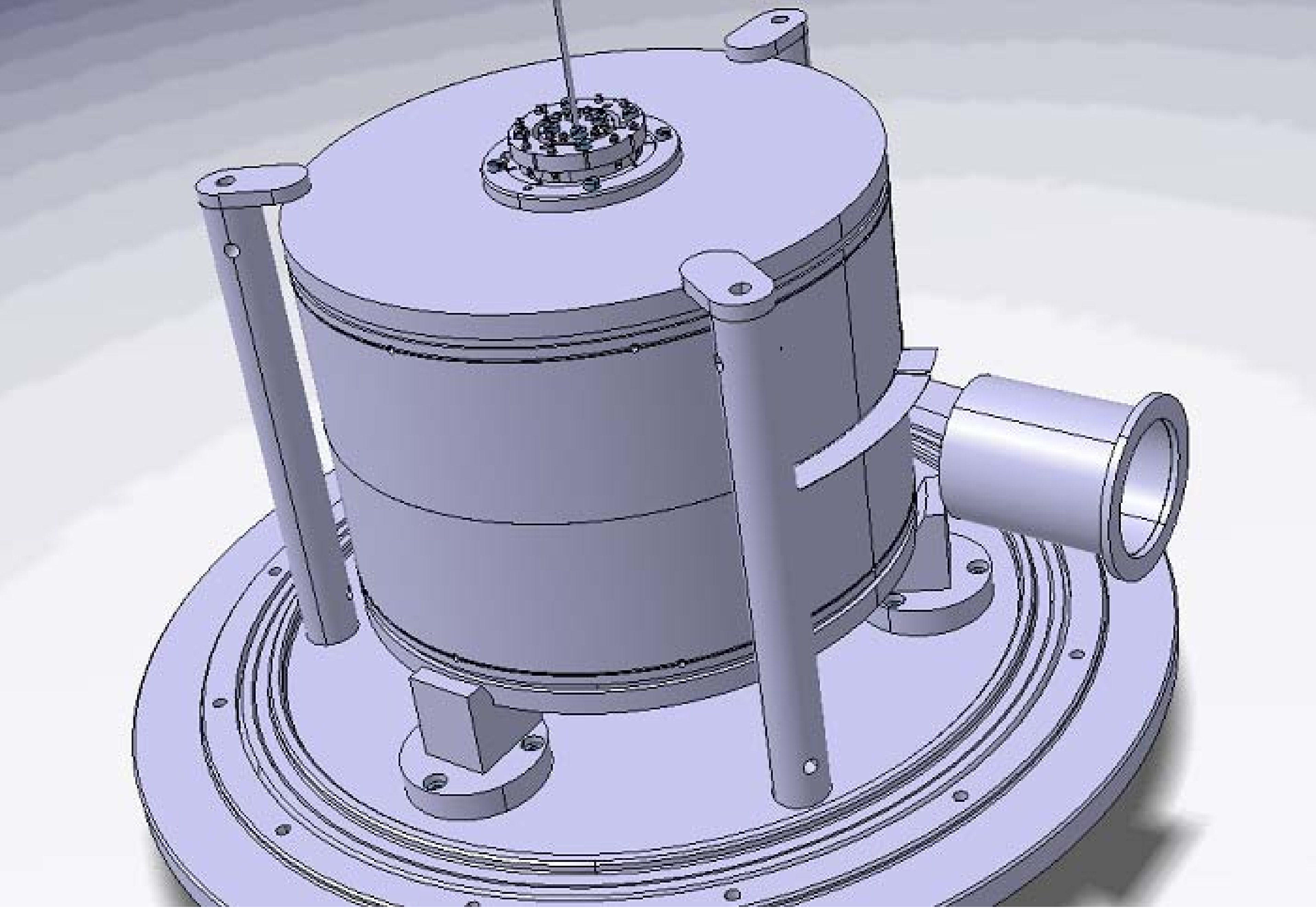


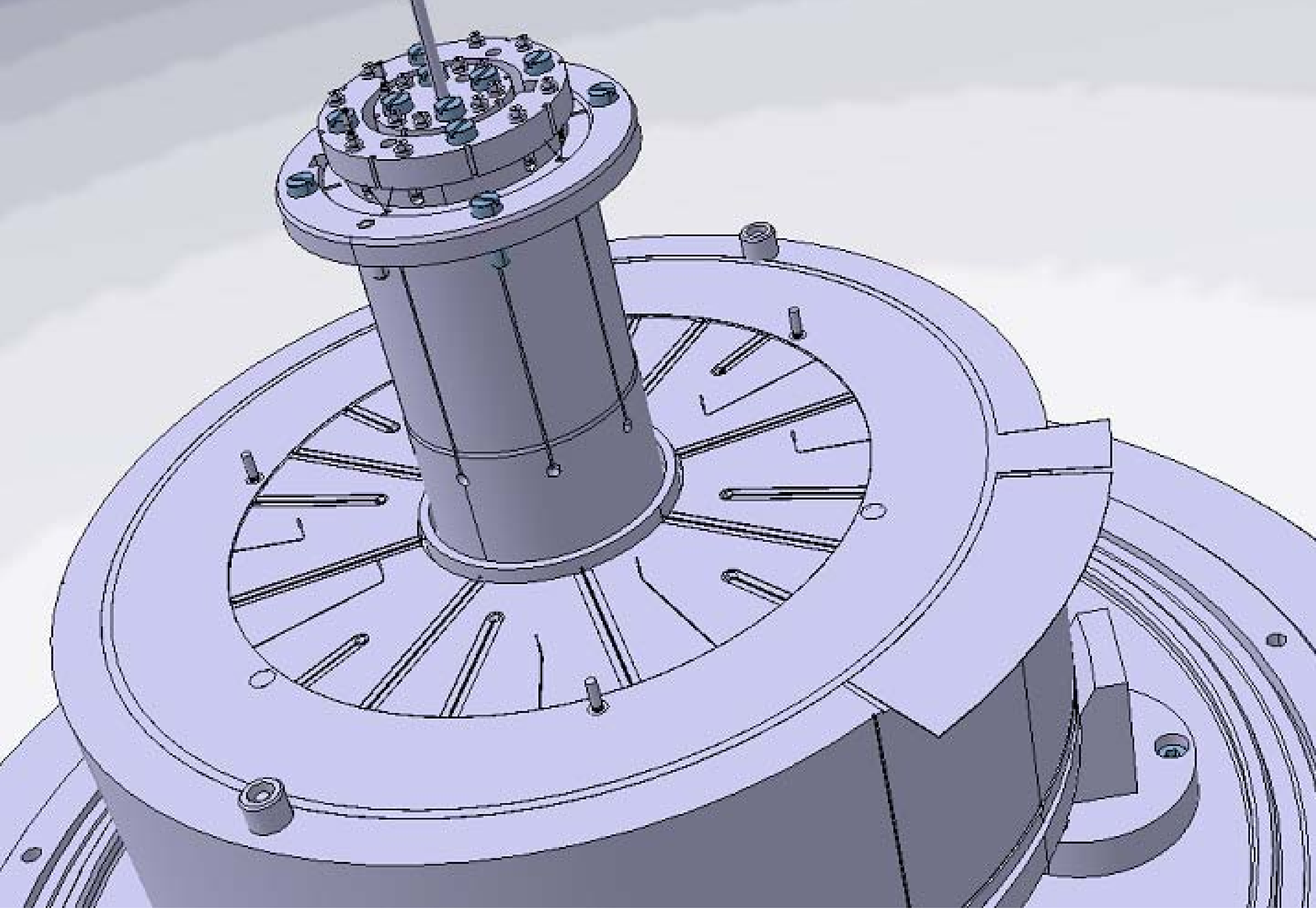
- Thermostatic mode
- Electrical substitution method
- Advantage: rapid repetition of calorimeter runs is possible

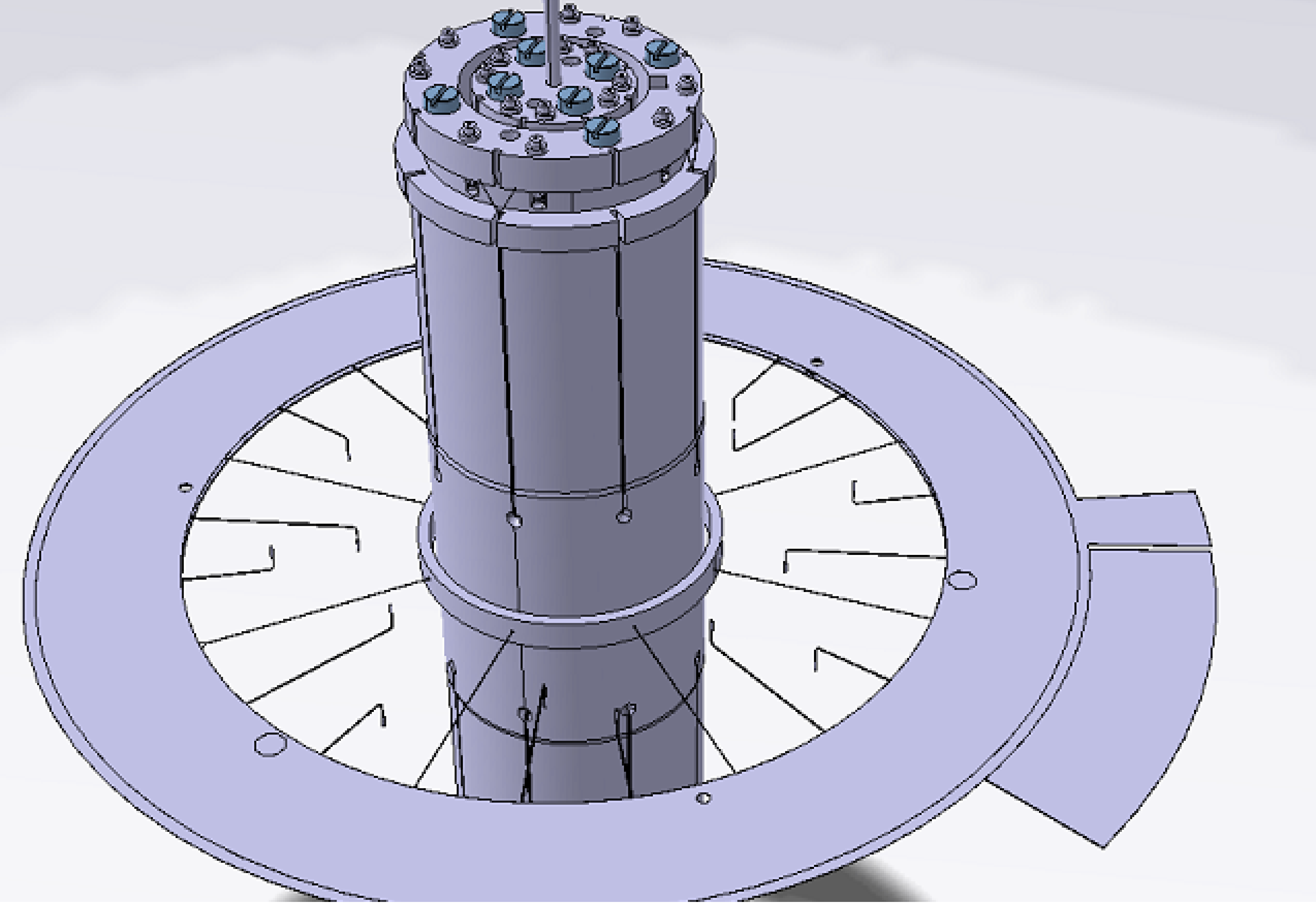


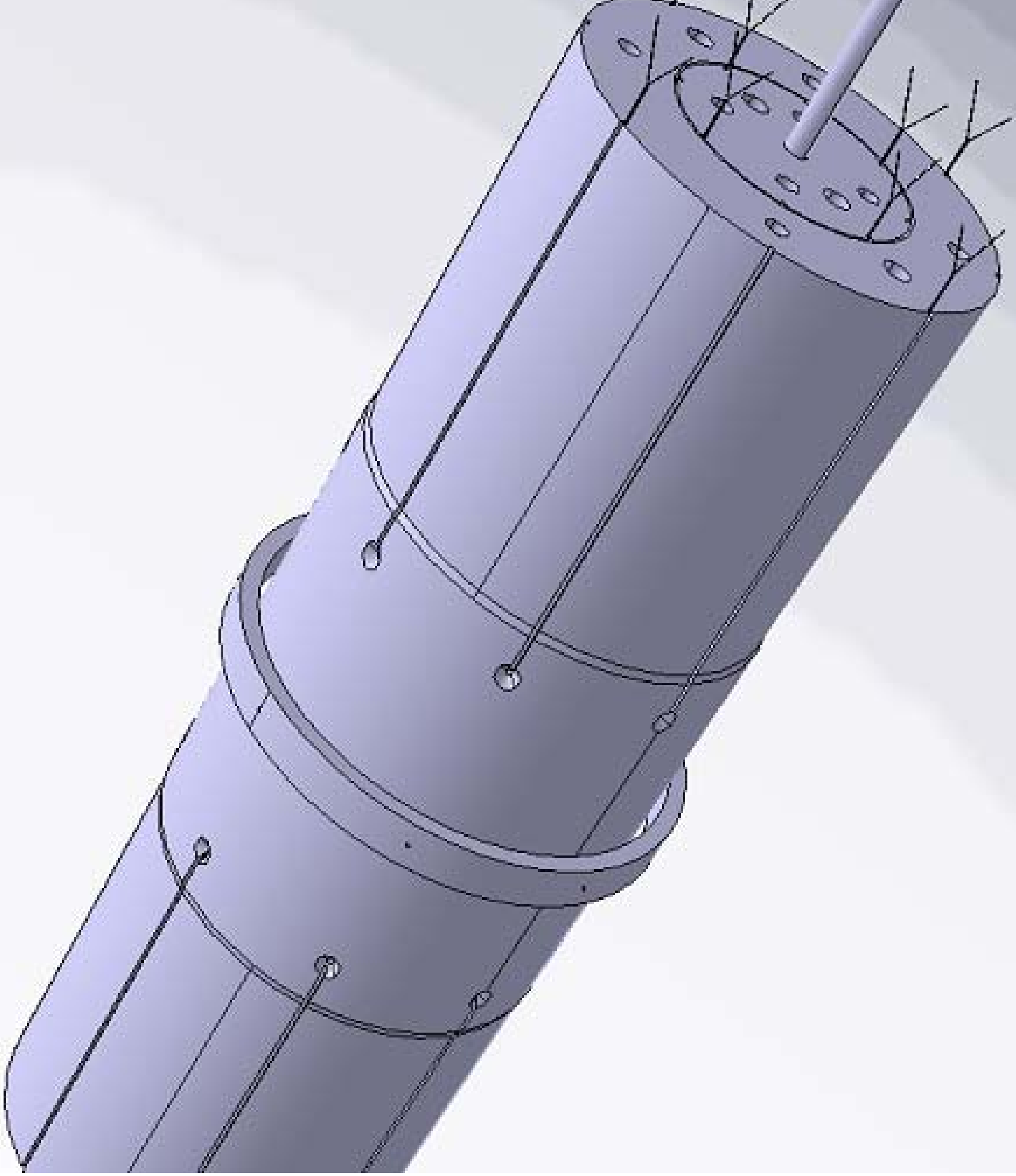
NPL



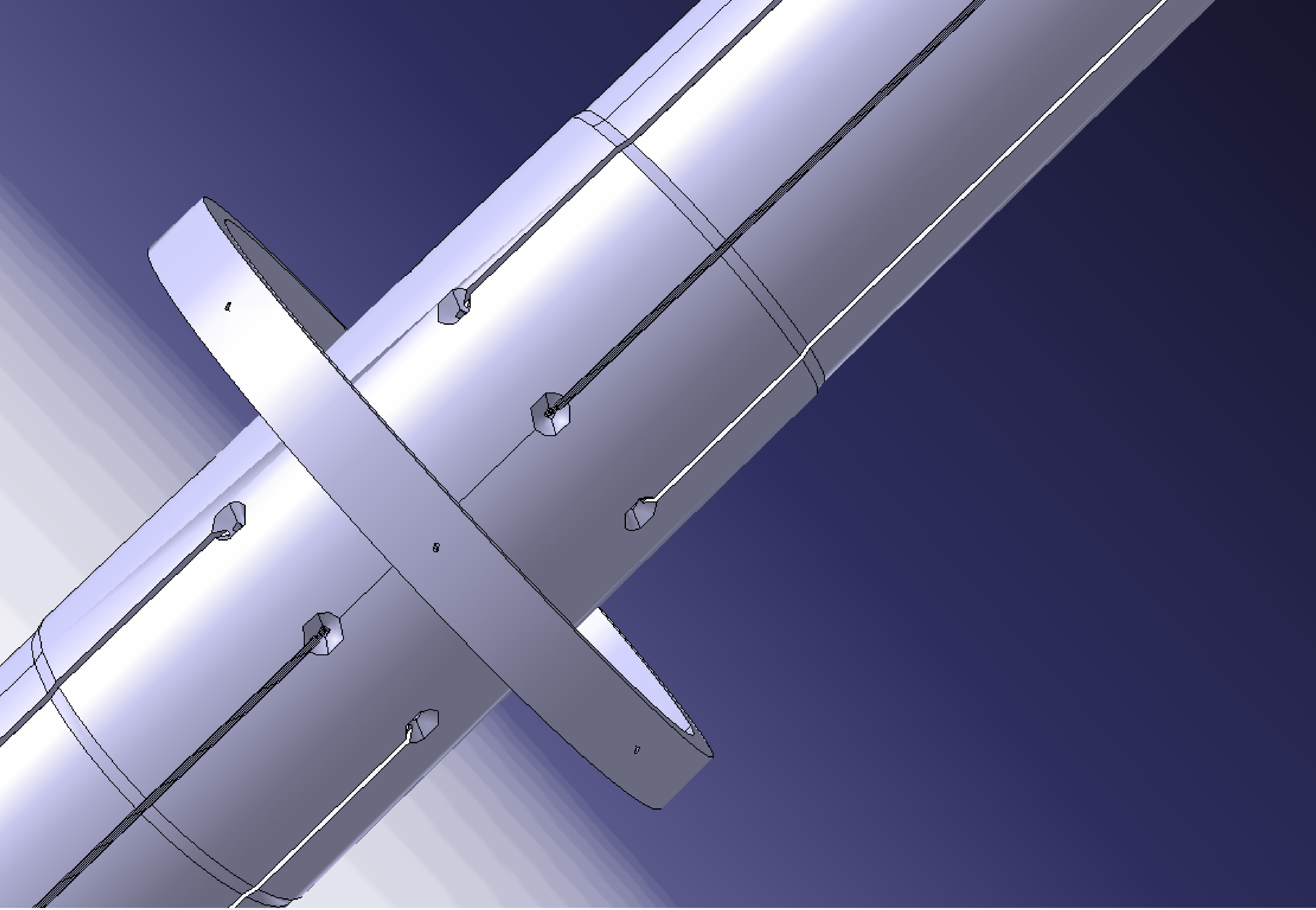








NPL



Conclusions + future work

- **Prototype calorimeter for HDR brachytherapy sources:**
  - Suitable dimensions and materials derived from MC simulations
  - Vacuum gap around core to control self-heating effect of radioactive source
  - Heat transfer simulations used to find optimum position for thermistors and maximum heating power required per component
- **Future work:**
  - Build, test and characterise calorimeter + refine correction factors for final design
  - Work out conversion from absorbed dose to graphite → water
  - Measure absorbed dose and compare with RAKR approach and TG43

NPL

Acknowledgements

- University supervisors: Ivan Rosenberg and Robert Speller
- UCLH: Derek D'Souza
- NPL staff: Hugo Palmans, Simon Duane, Mark Bailey, David Shipley, Nigel Lee, Chris Thomas, Gary Mapp, Edmund Kirby, Peter Bird, Keith Burgon, Geoff Stammers, Pravin Patel