Development of a water calorimeter for medium energy x-rays

Leon de Prez
Eduard van Dijk
Patricia Damen

Nederlands Meetinstituut

Introduction

- Introduction
- Design and construction
- Measurement assembly
- Correction factors
- Estimate of the uncertainties
- Preliminary results

Introduction - Aim

- *Why medium energy x-rays?*

  medium energy x-rays are still used in the Netherlands and for certain treatments an alternative to electron therapy

- *What is the aim?*

  determination of N_{Dw} for a reference chamber with an uncertainty smaller or equal to the current Dutch dosimetry protocol NCS-10

  i.e. ≤ 2 – 3 % (1 SD)

- *How is it achieved?*

  feasibility study for one NE 2571 chamber

  4 x-ray qualities (100 – 250 kV; HVL 0.16 – 2.5 mm Cu)

Introduction - Beam qualities

HVL and E_{mean} *behind insulation materials*
(no correction applied for attenuation of calorimeter walls)

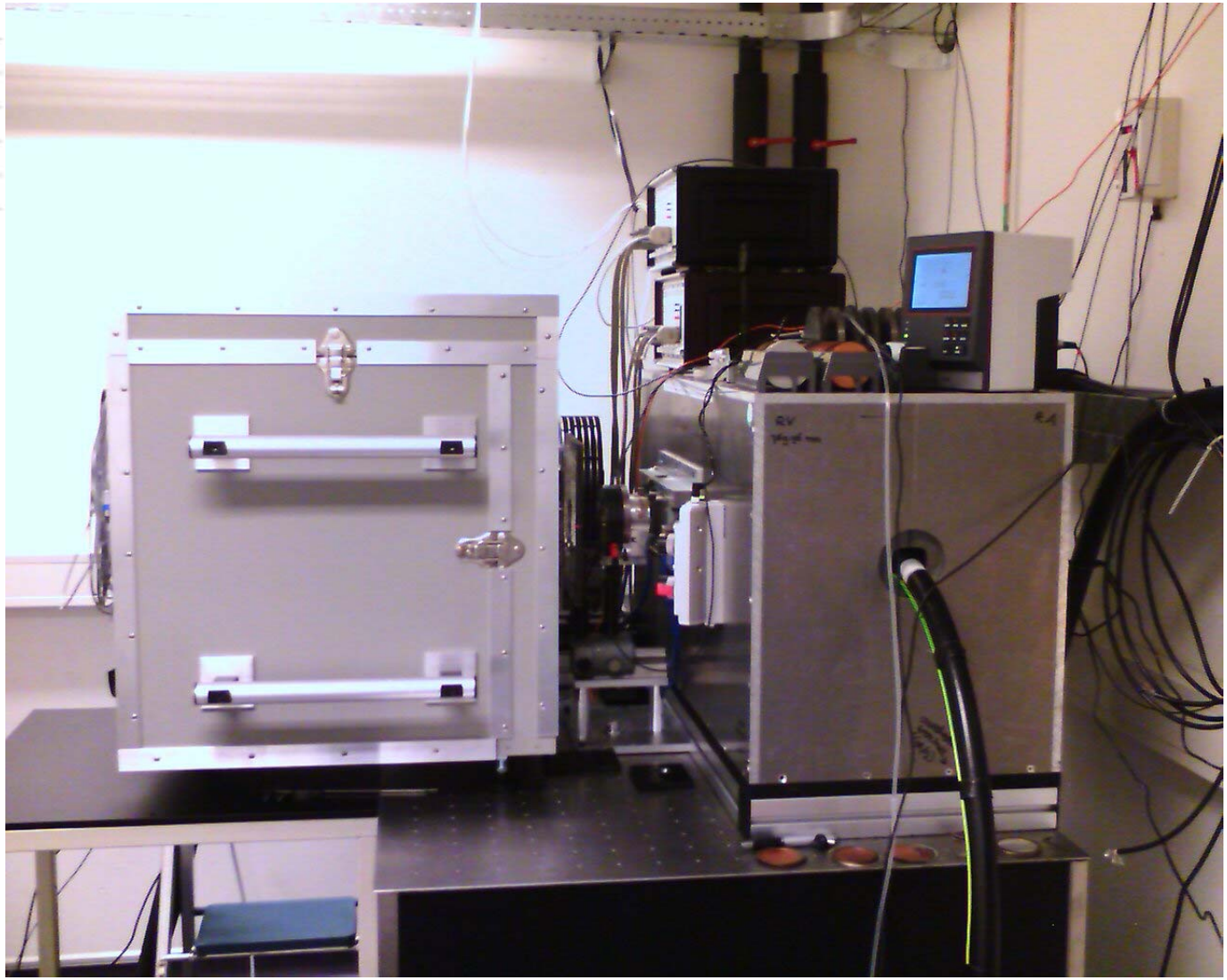
kVp	HVL / mm Cu	E_{mean} in air
250 kV	2.48	123.5
180 kV	0.987	85.1
135 kV	0.483	67.1
100 kV	0.159	51.4

Introduction - Principle

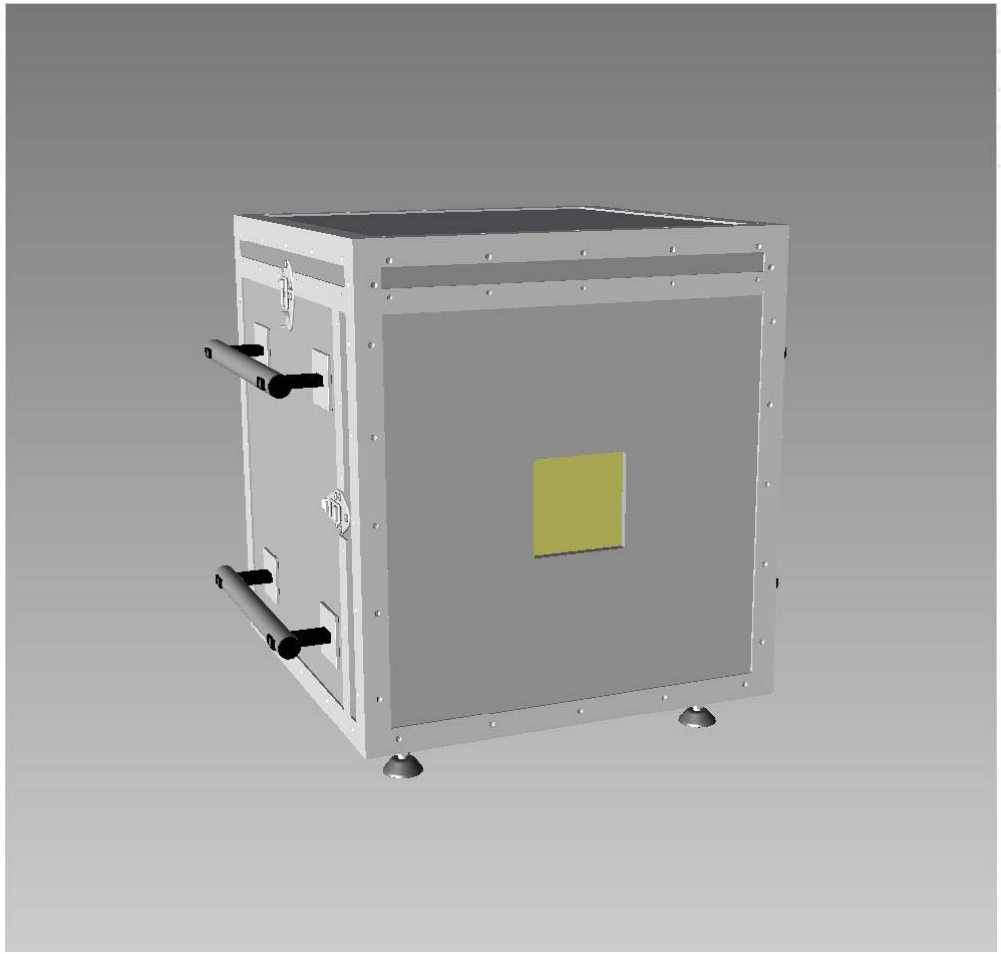
$$D_w = \Delta T \cdot C_w \cdot \prod k$$

- Sealed water calorimeter operated at 4 °C
- Horizontal beam (SDD 620 mm; depth 3.5 g·cm^{-2})
- ΔT with 2 thermistors in a Wheatstone bridge
- Correction factors:
  - attenuation and scatter: 1.004 – 1.075 (PENELOPE)
  - excess heat: 1.023 – 1.061 (Comsol Multiphysics)
  - heat defect: ~ 1.000 (published data)

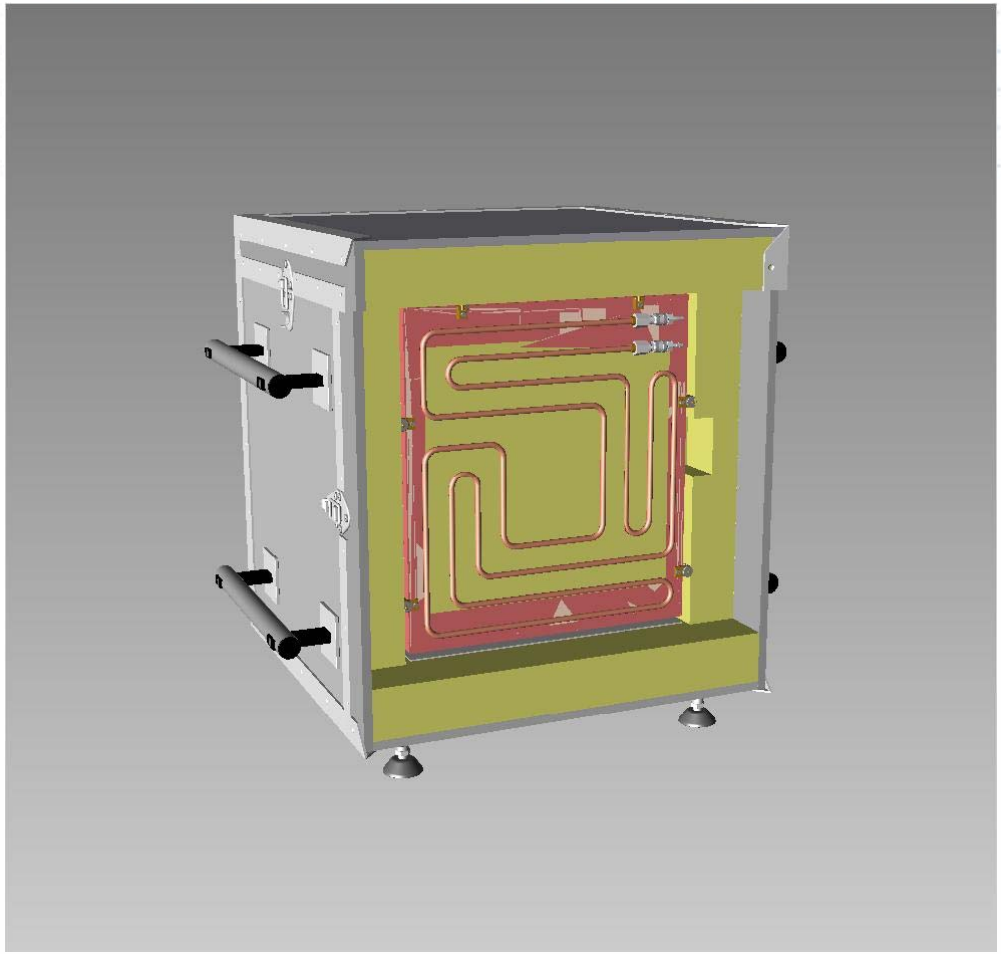
Design and construction



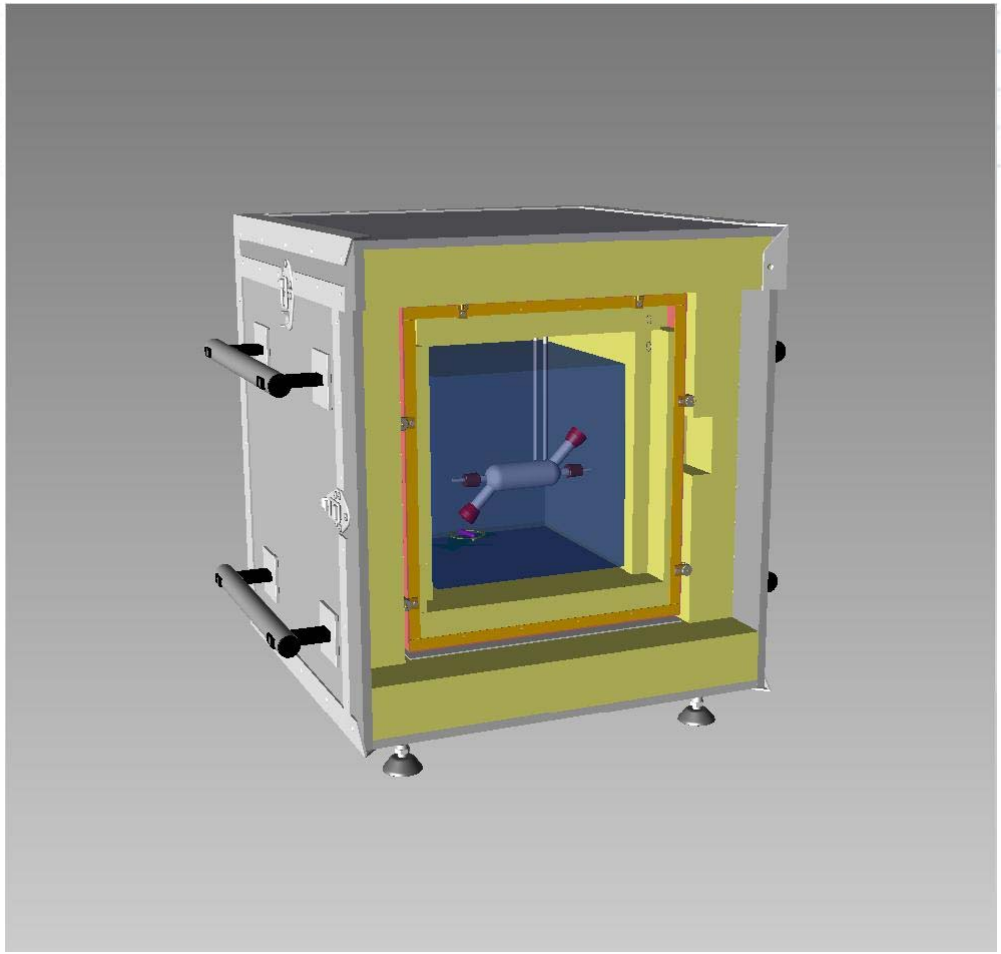
Design and construction



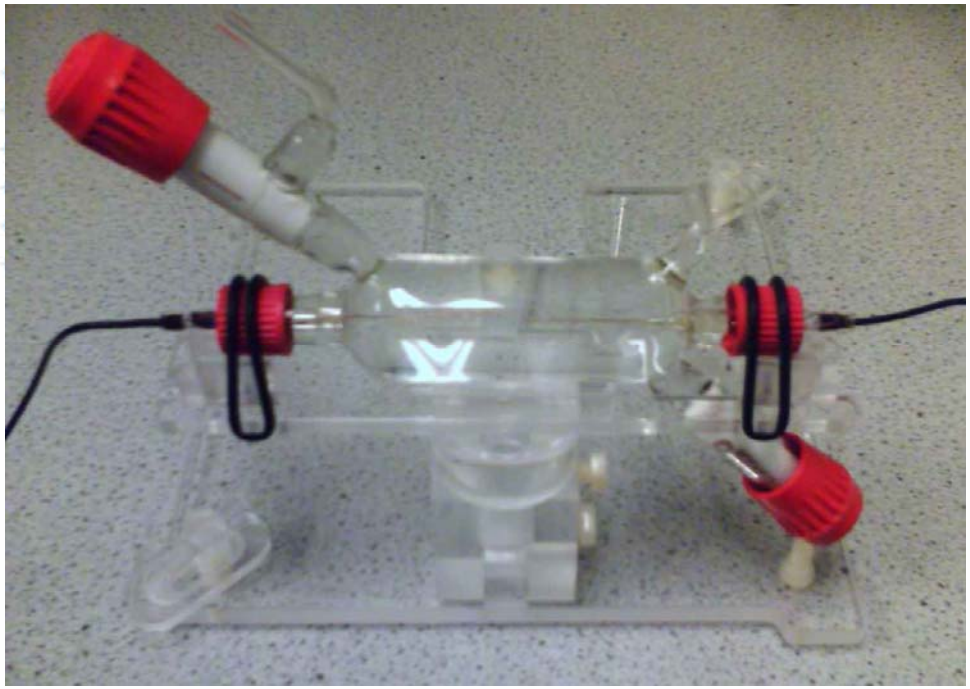
Design and construction



Design and construction



Design and construction



- Glass cell diameter 3.9 mm, glass thickness 0.8 mm
- Two 20 kΩ thermistors in glass probes (diameter 0.5 mm)
- Ultra pure water (Millipore: 3 ppb TOC; 18.2 MΩ·cm)
- Saturated with Argon

Measurement assembly

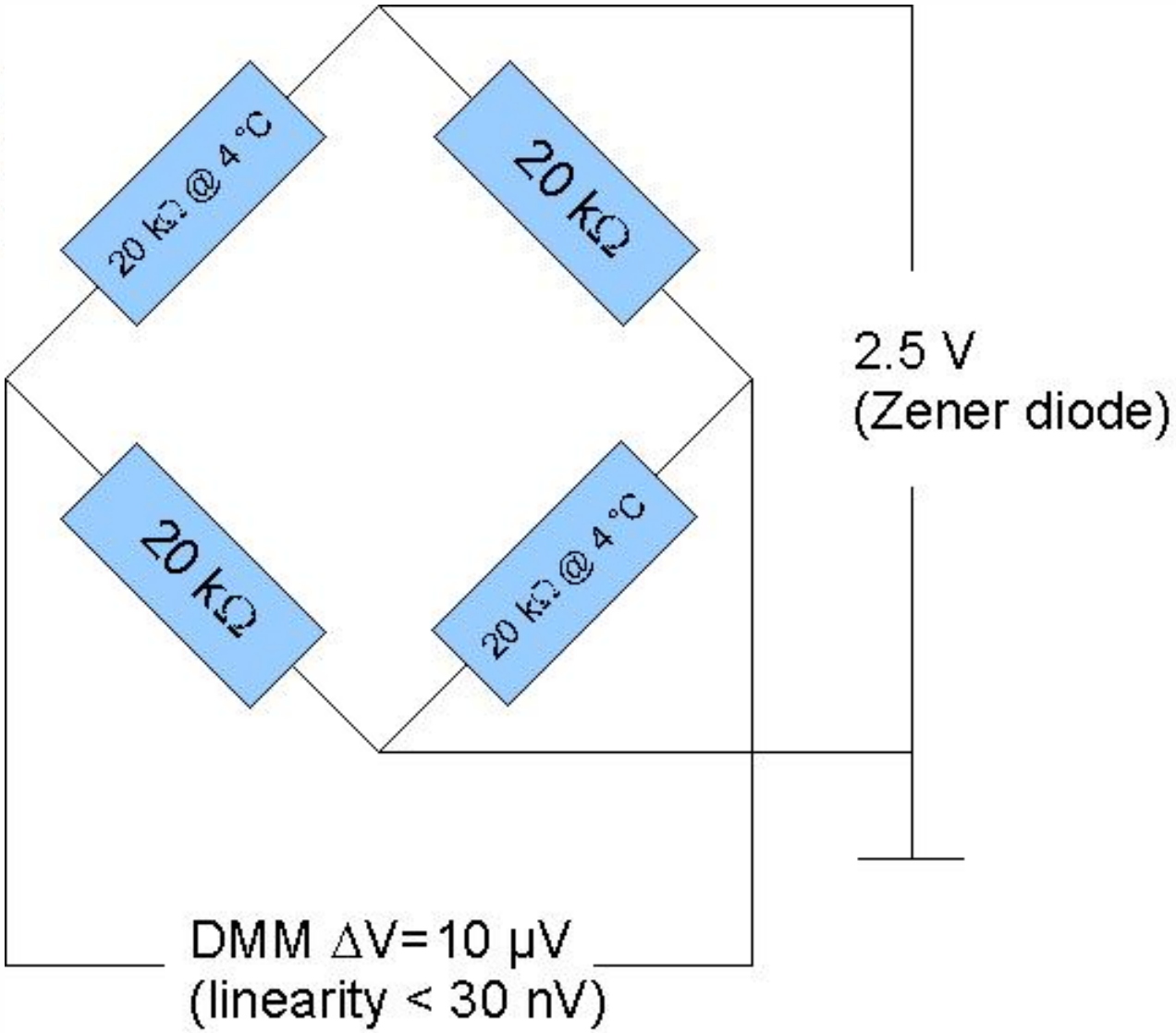
Optimization of signal

- SDD as small as practically possible (620 mm)

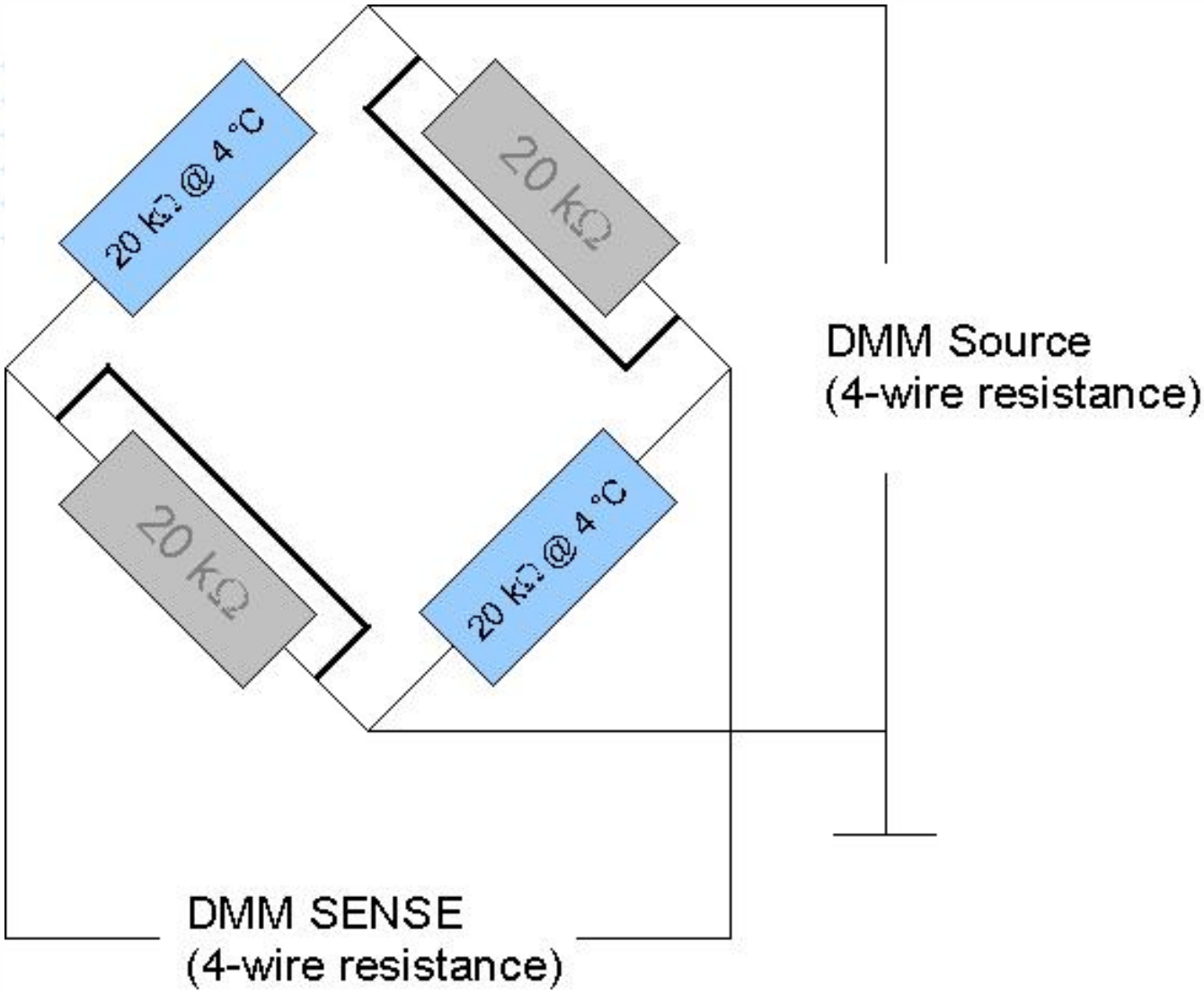
- Optimization of electrical circuit:
  - guarding in star shape
  - DC Wheatstone bridge in stead of direct resistance measurement
  - ability to compare 4-wire resistance with a Wheatstone configuration

Result: SD 1.7 % - 2.9 %

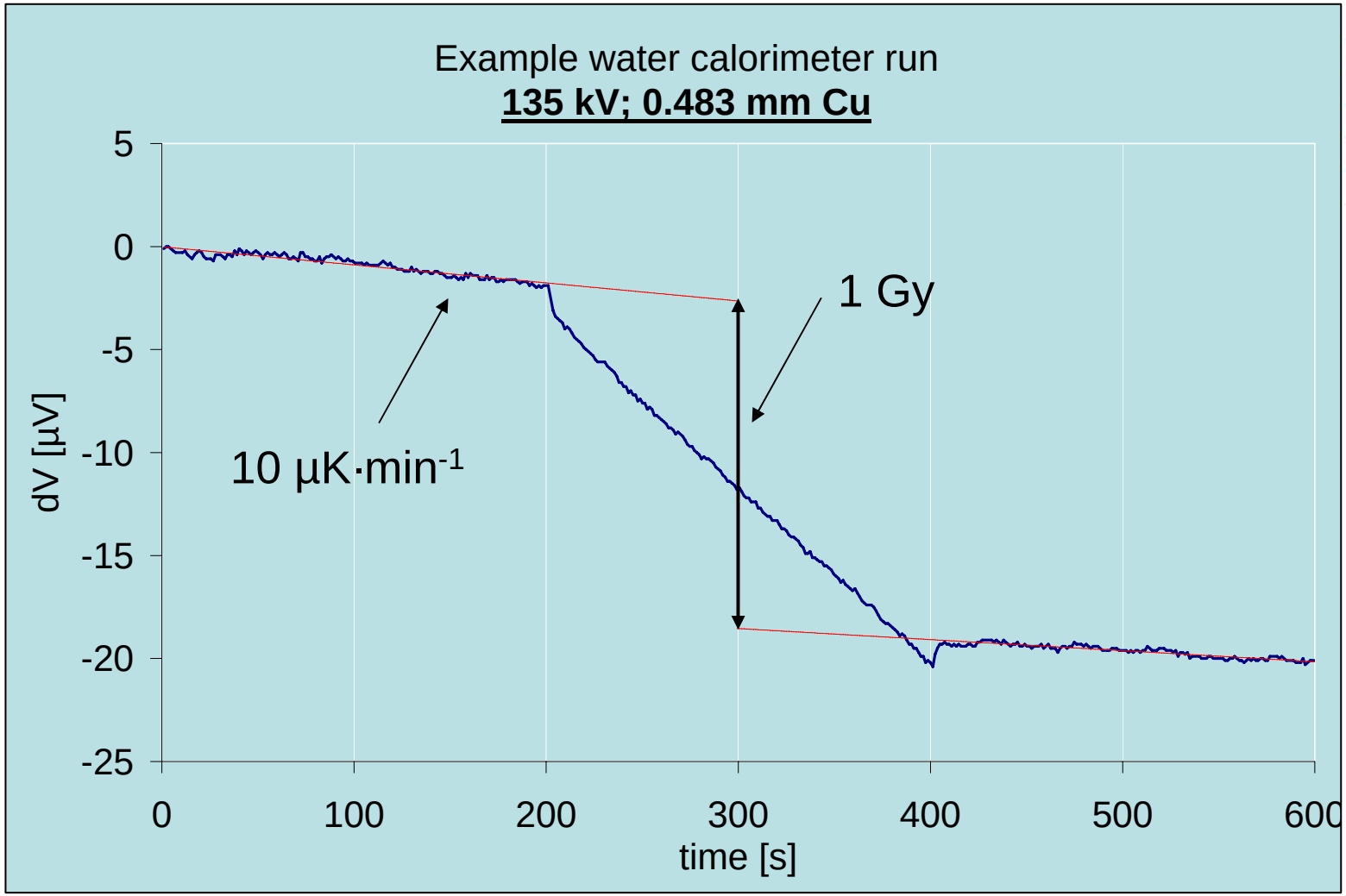
Measurement assembly



Measurement assembly



Measurements



Correction factors

k_{HD} Heat defect (~ 1.000)

k_{GLASS} Presence of non-water materials

k_{XS} Temperature gradients / heat transport

Glass correction

Calculated with the PENELOPE MC code

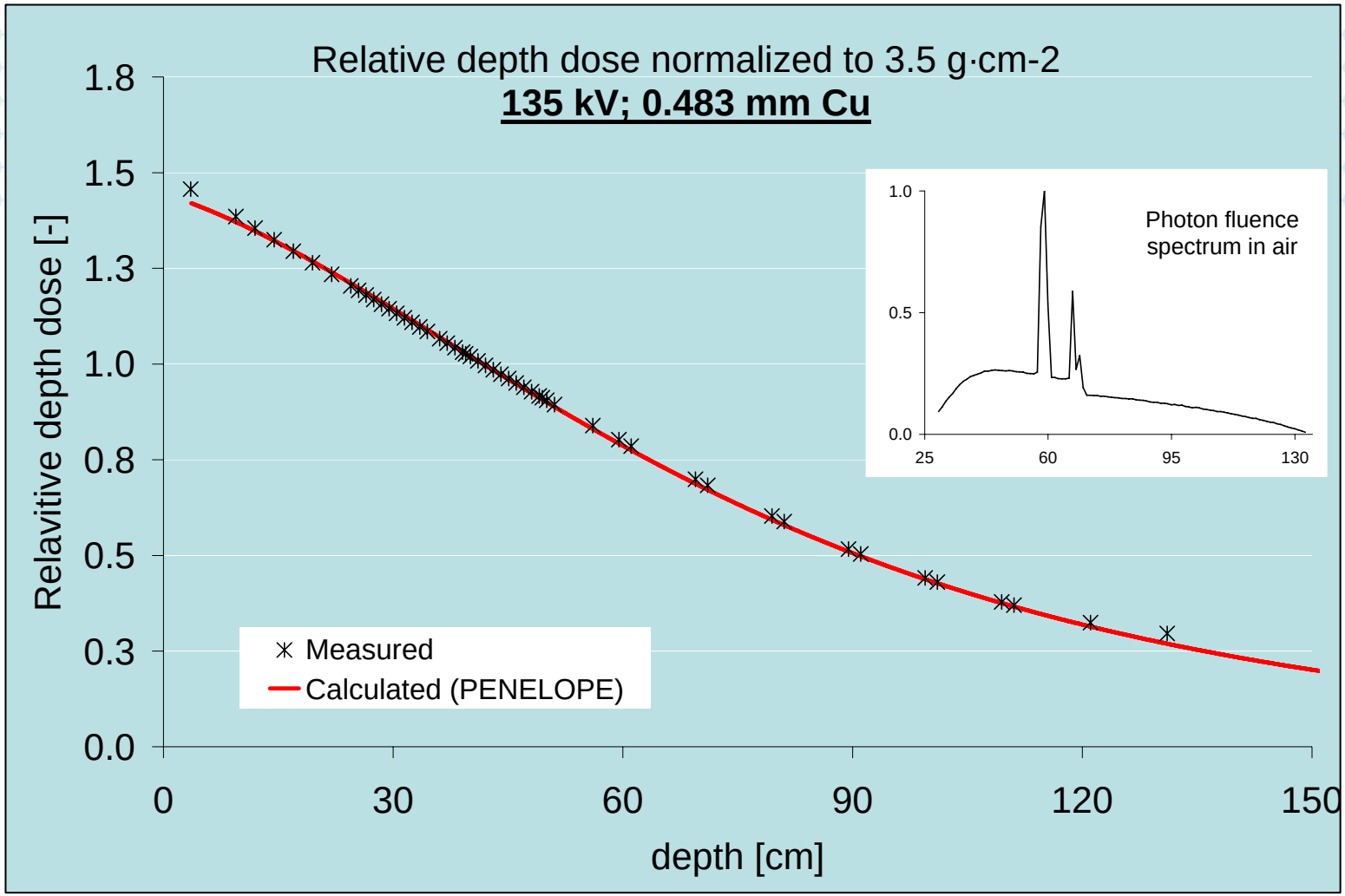
based on

photon fluence spectra measured with HP Ge-spectrometer

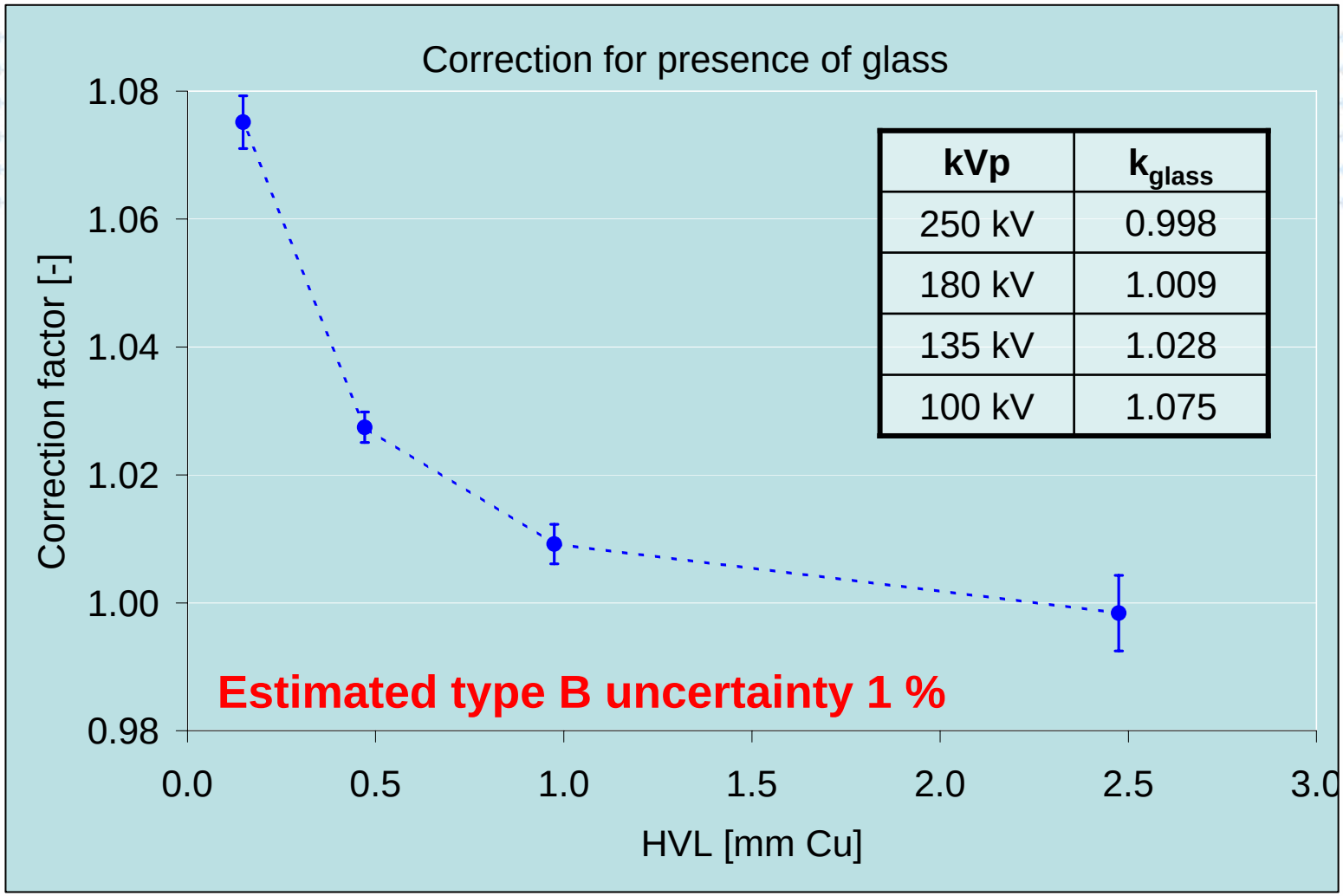
and verified with

measured depth dose distributions.

Glass correction - PDD



Glass correction - Results



kVp	k_{glass}
250 kV	0.998
180 kV	1.009
135 kV	1.028
100 kV	1.075

Excess heat correction

Calculated with Comsol Multiphysics 3.2

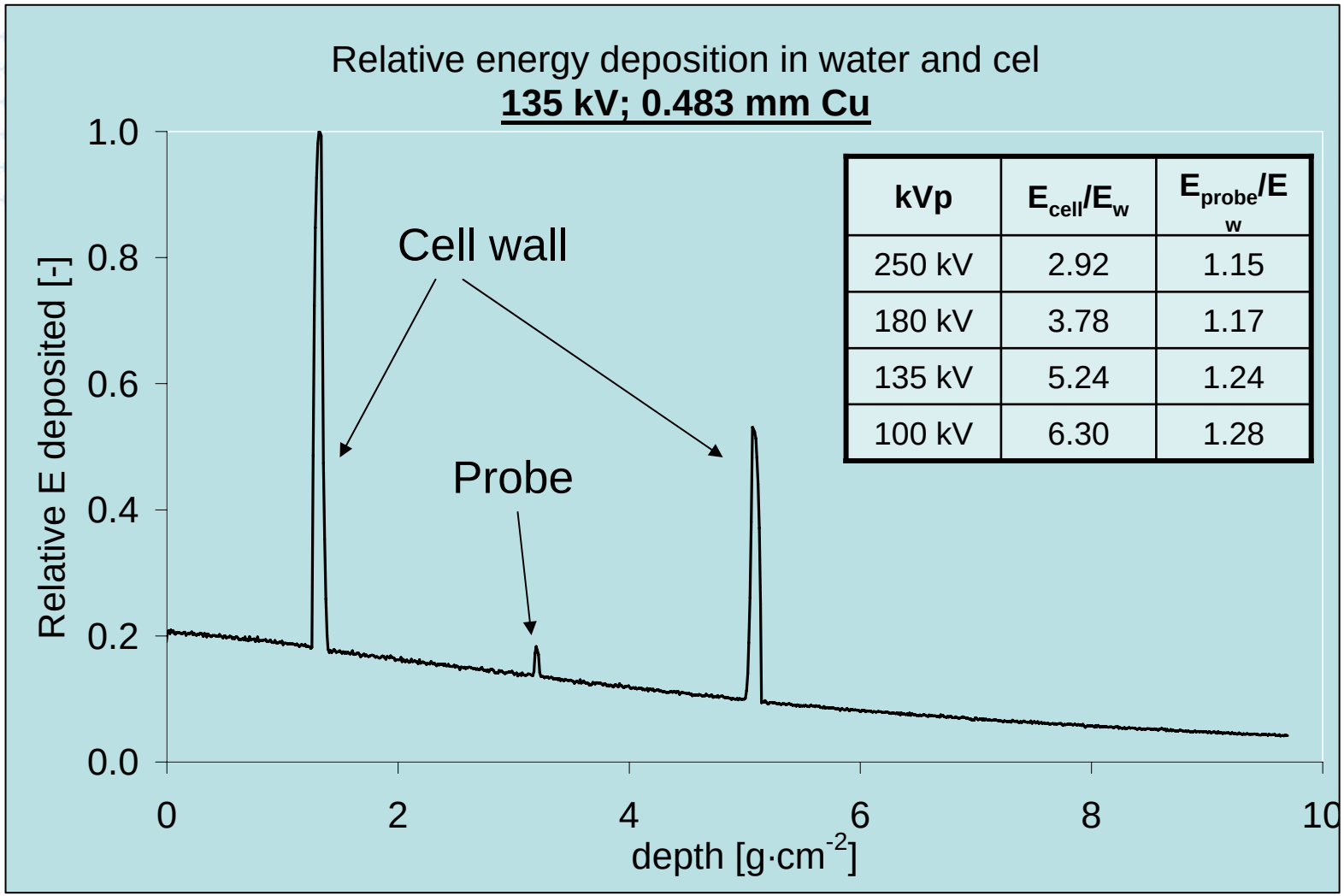
based on

MC calculations for the absorption of energy in the glass compared to water

model parameters

heat conduction (assuming no convection)

Excess heat correction



kVp	E_{cell}/E_w	E_{probe}/E_w
250 kV	2.92	1.15
180 kV	3.78	1.17
135 kV	5.24	1.24
100 kV	6.30	1.28

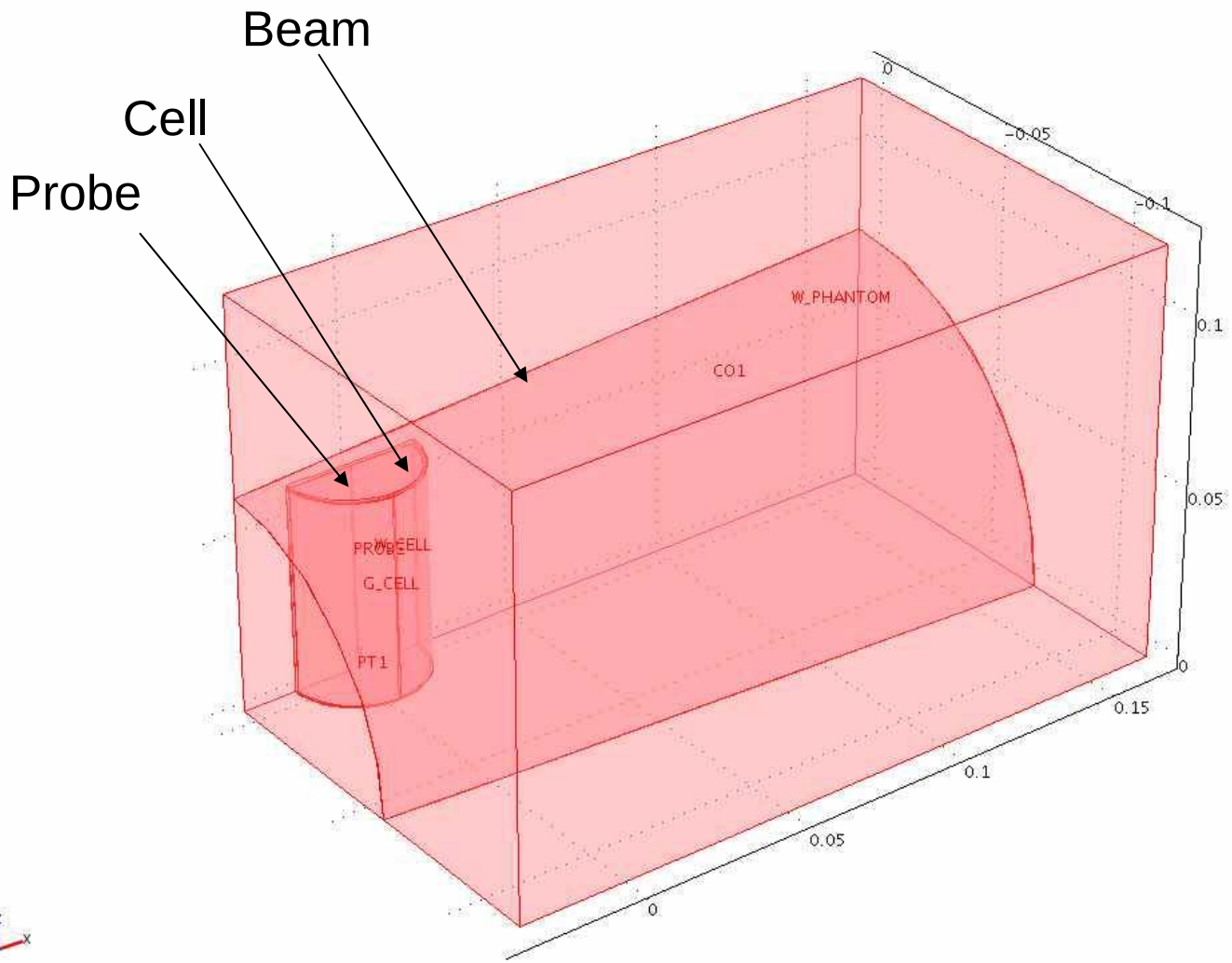
Used as input for the heat transport calculations

Excess heat correction

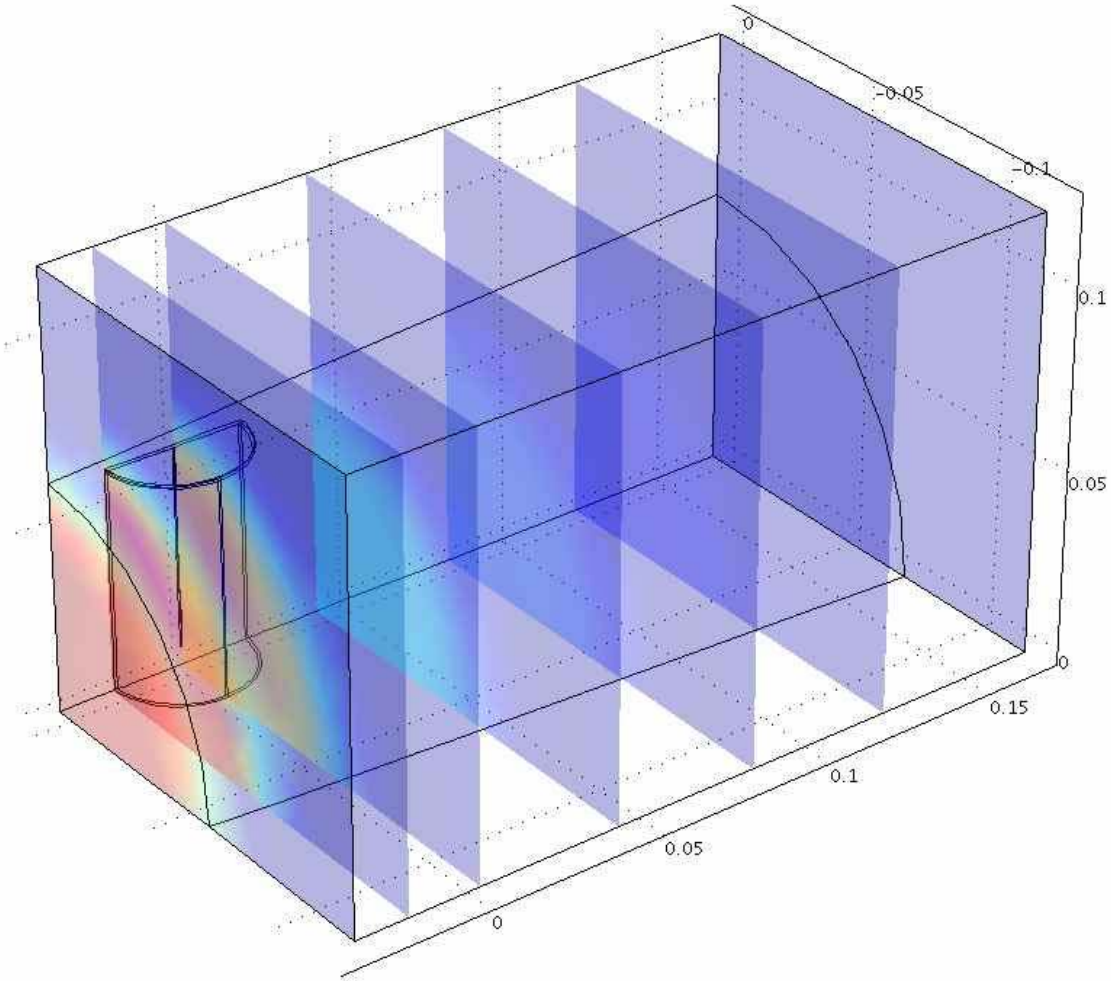
Heat transport model

- Comsol Multiphysics 3.2
- Heat transport by conduction
- PDD from MC calculations
- Relative energy absorption in glass compared to water from MC calculations

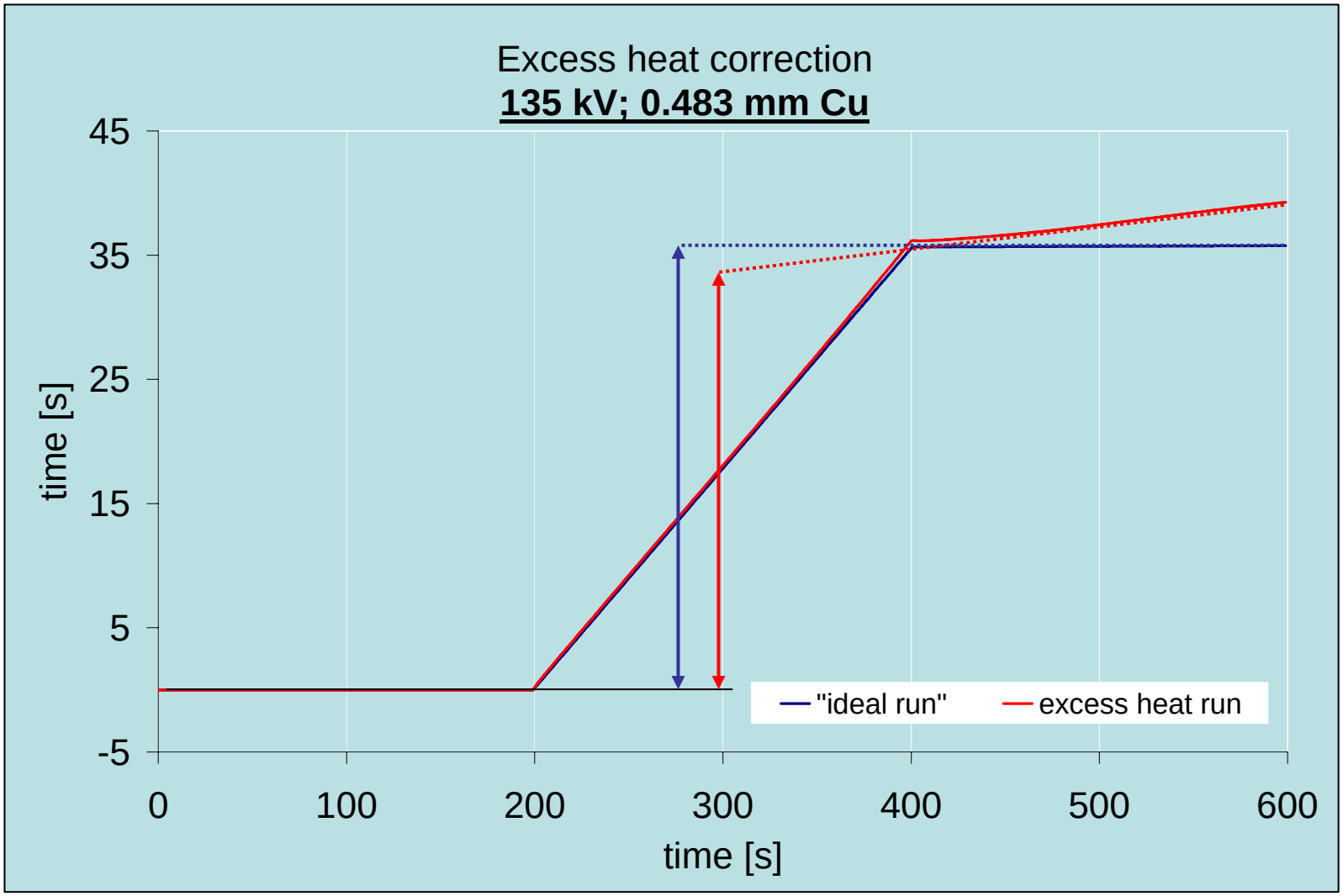
Excess heat correction



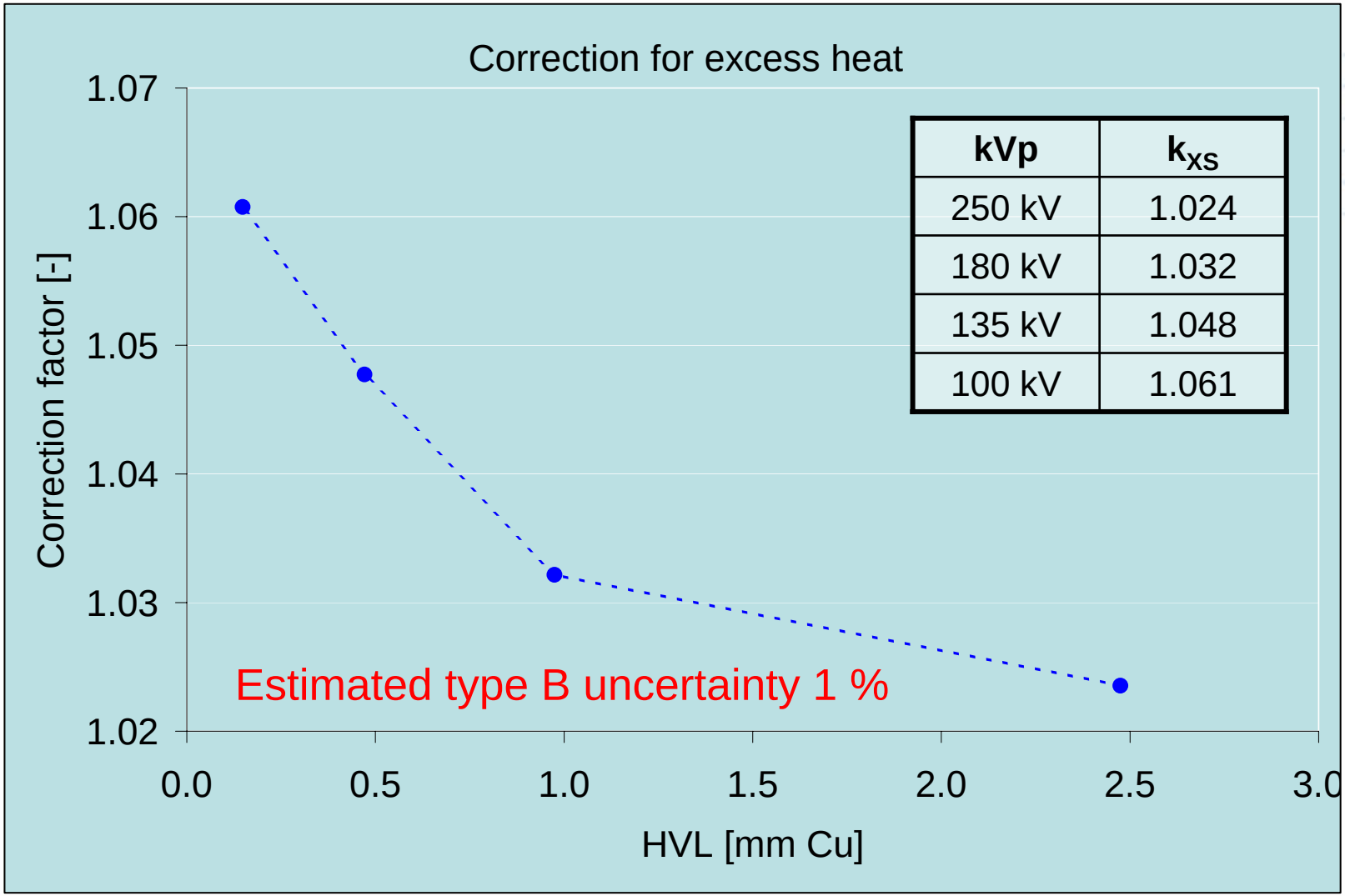
Excess heat correction



Excess heat correction



Excess heat correction



kVp	k_{xs}
250 kV	1.024
180 kV	1.032
135 kV	1.048
100 kV	1.061

Correction factors - Results

kVp	k_{glass}	k_{XS}	k_{tot}
250 kV	0.998	1.024	1.022
180 kV	1.009	1.032	1.041
135 kV	1.028	1.048	1.077
100 kV	1.075	1.061	1.141

Preliminary results

Comparison with Dutch dosimetry protocol: NCS-10

Water calorimeter

$$N_{D_w} = \frac{\left(\frac{D_w}{monitor}\right)}{\left(\frac{M_{stp}}{monitor}\right)}$$

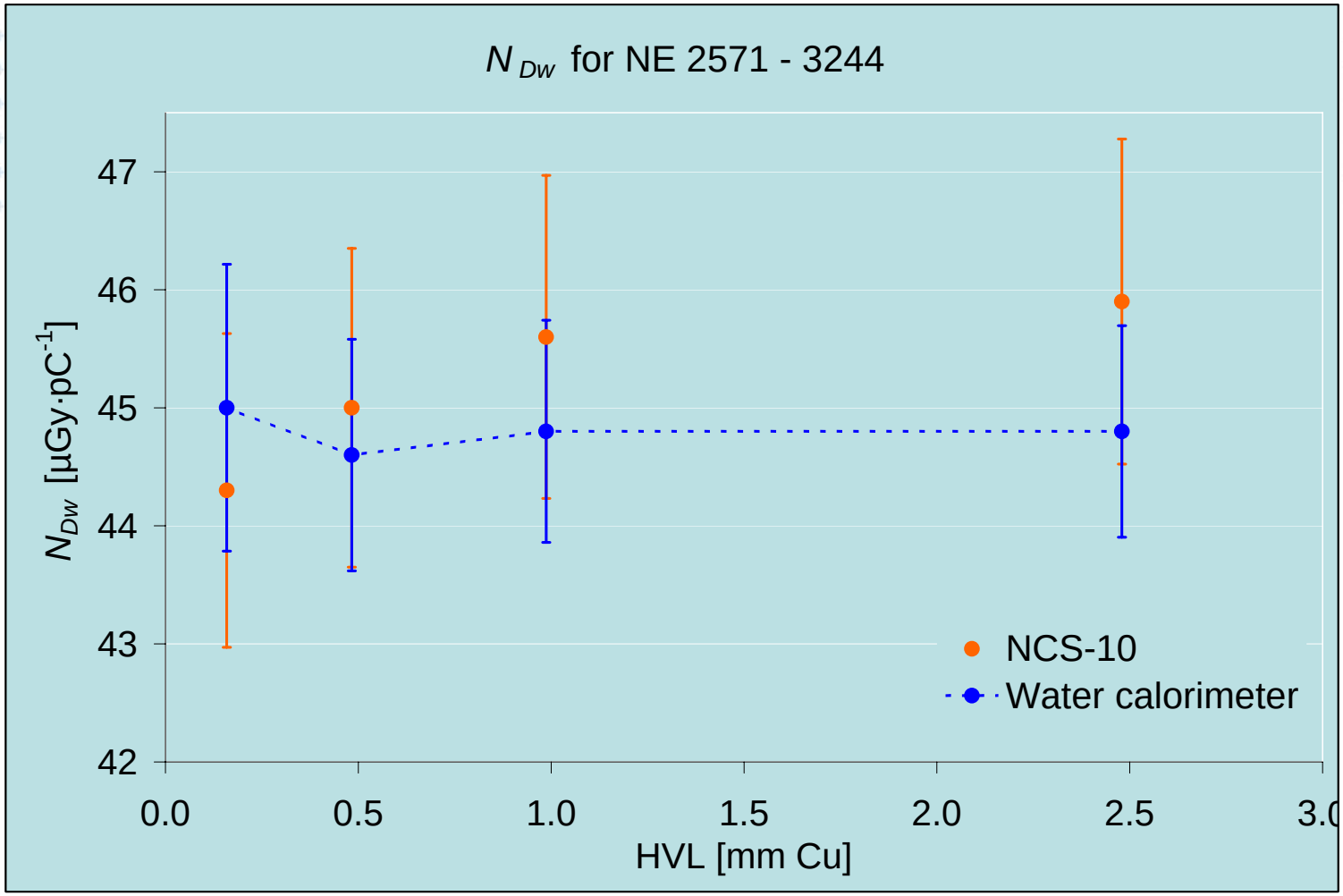
NCS-10 protocol

$$N_{D_w} = N_K \cdot \left(\frac{\bar{\mu}_{en}}{\rho}\right)^{d}_{w/air} \cdot k_{ch}$$

Preliminary results

	WCM		NCS-10		
kVp	N_{Dw}	***u* (*k* = 1)**	N_{Dw}	***u* (*k* = 1)**	
250 kV	44.8	**2.0 %**	45.9	**2.9 %**	**-2.4 %**
180 kV	44.8	**2.1 %**	45.6	**2.7 %**	**-1.8 %**
135 kV	44.6	**2.2 %**	45.0	**2.7 %**	**-0.9 %**
100 kV	45.0	**2.7 %**	44.3	**2.7 %**	**+ 1.7 %**

Preliminary results



Conclusion and future work

Conclusion:

- Water calorimetry for medium energy x-rays is possible within 2 – 3 % uncertainty

Future work:

- Further verifying calculations with measurements
- Improving the uncertainty budget

Thank you for your attention.