

Water calorimeter-based electron beam reference dosimetry and determination of beam quality conversion factors for clinical electron beams

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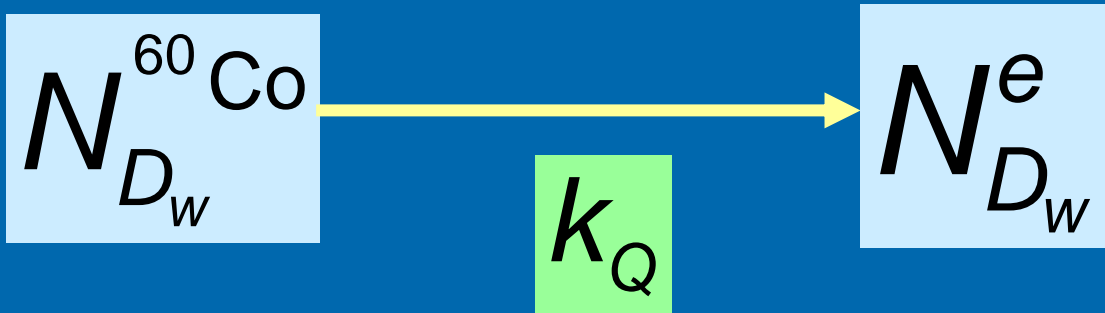
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The advantage of using water calorimetry for electron beams



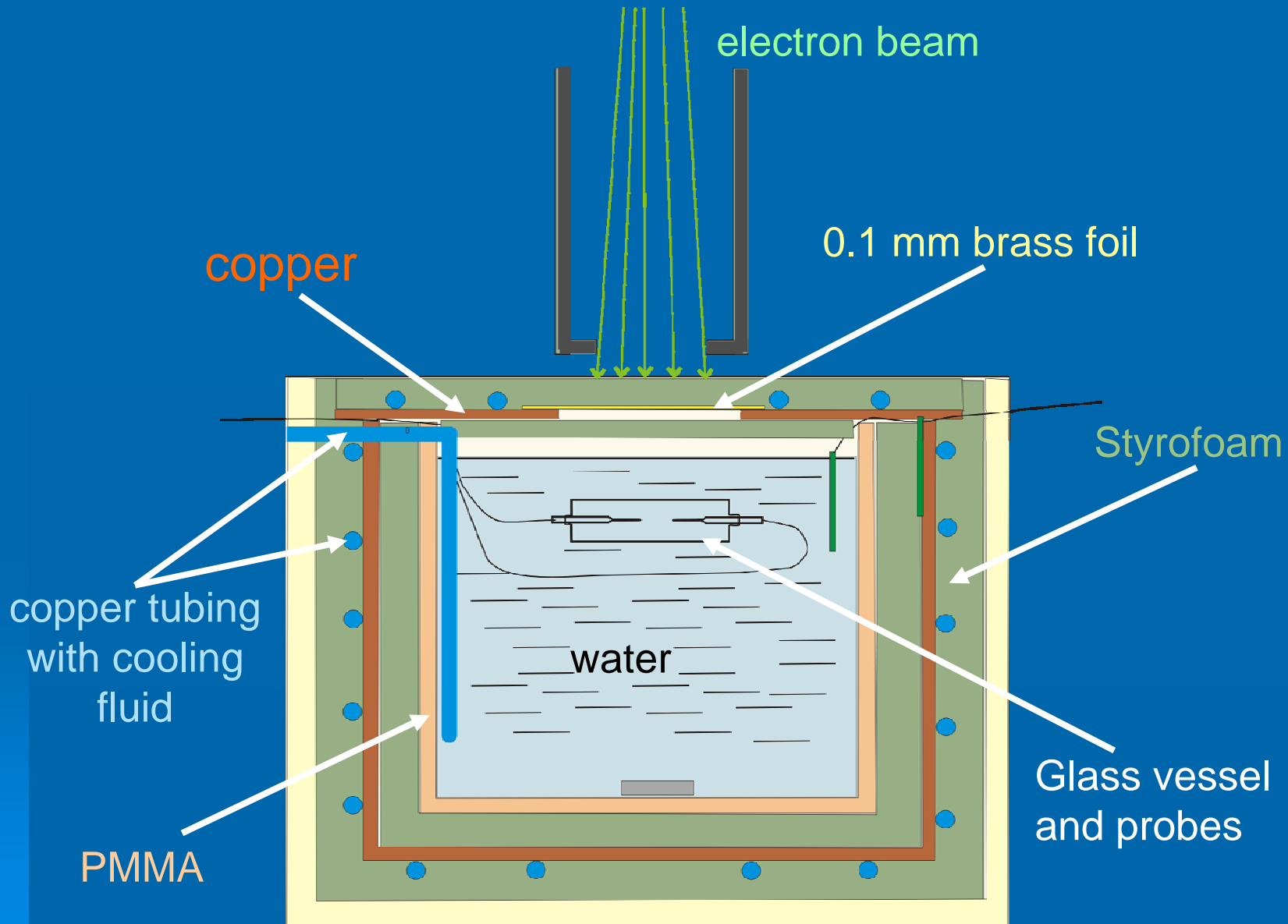
$$D_w = M k_Q N_{D_w}^{60\text{Co}}$$

$$D_w^e = M N_{D_w}^e$$

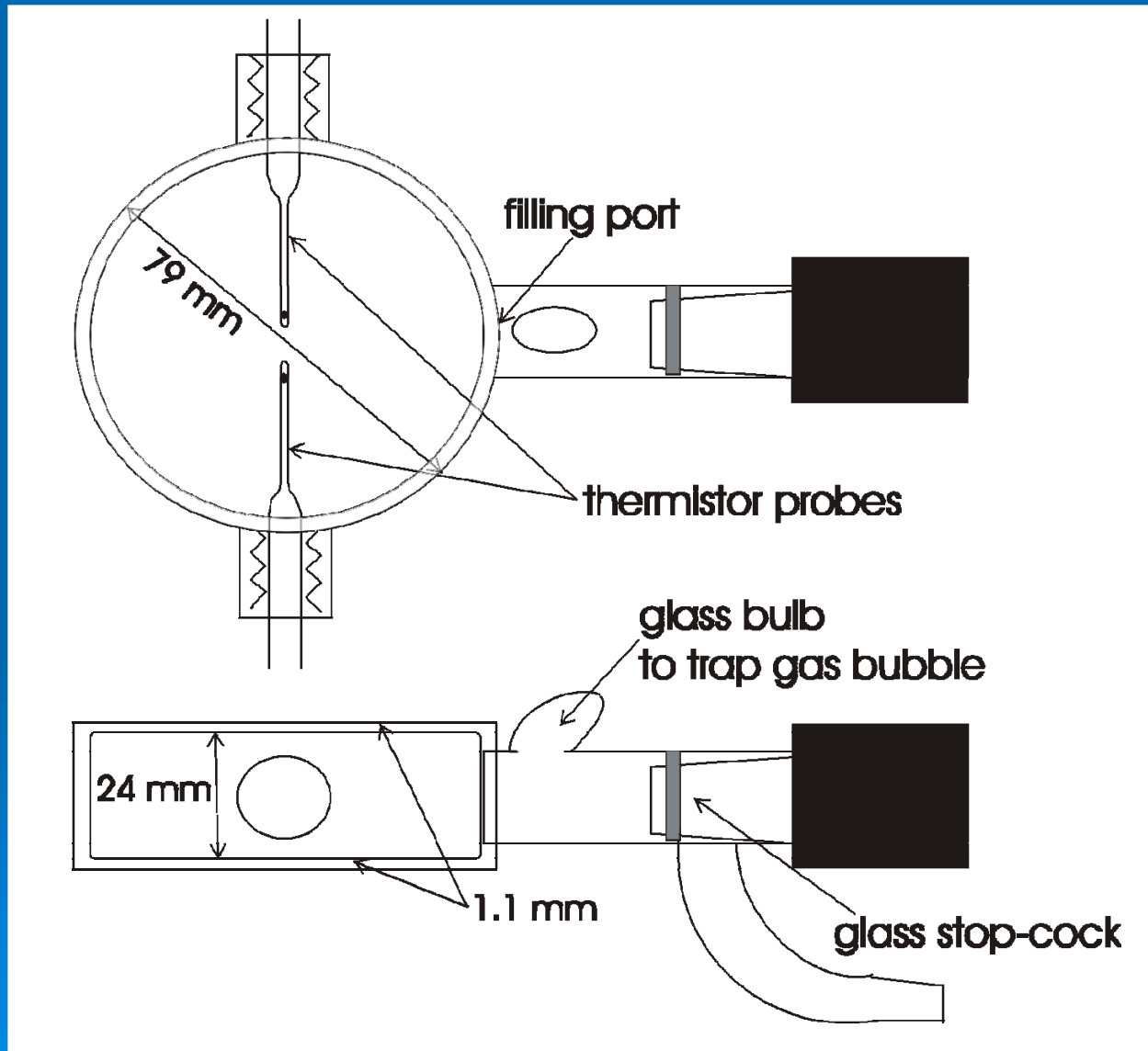
The ESW calorimeter

- specifically designed for measurements in clinical electron beams
 - small vessel to allow for measurements at depths as shallow as 12 mm (reference depth for 6 MeV electron beams)
 - phantom designed for irradiation from above
 - height set to allow space for electron applicators
 - transportable design that can be moved into any treatment room for measurements over a weekend
- operated at 4°C to eliminate effects of convective heat transfer

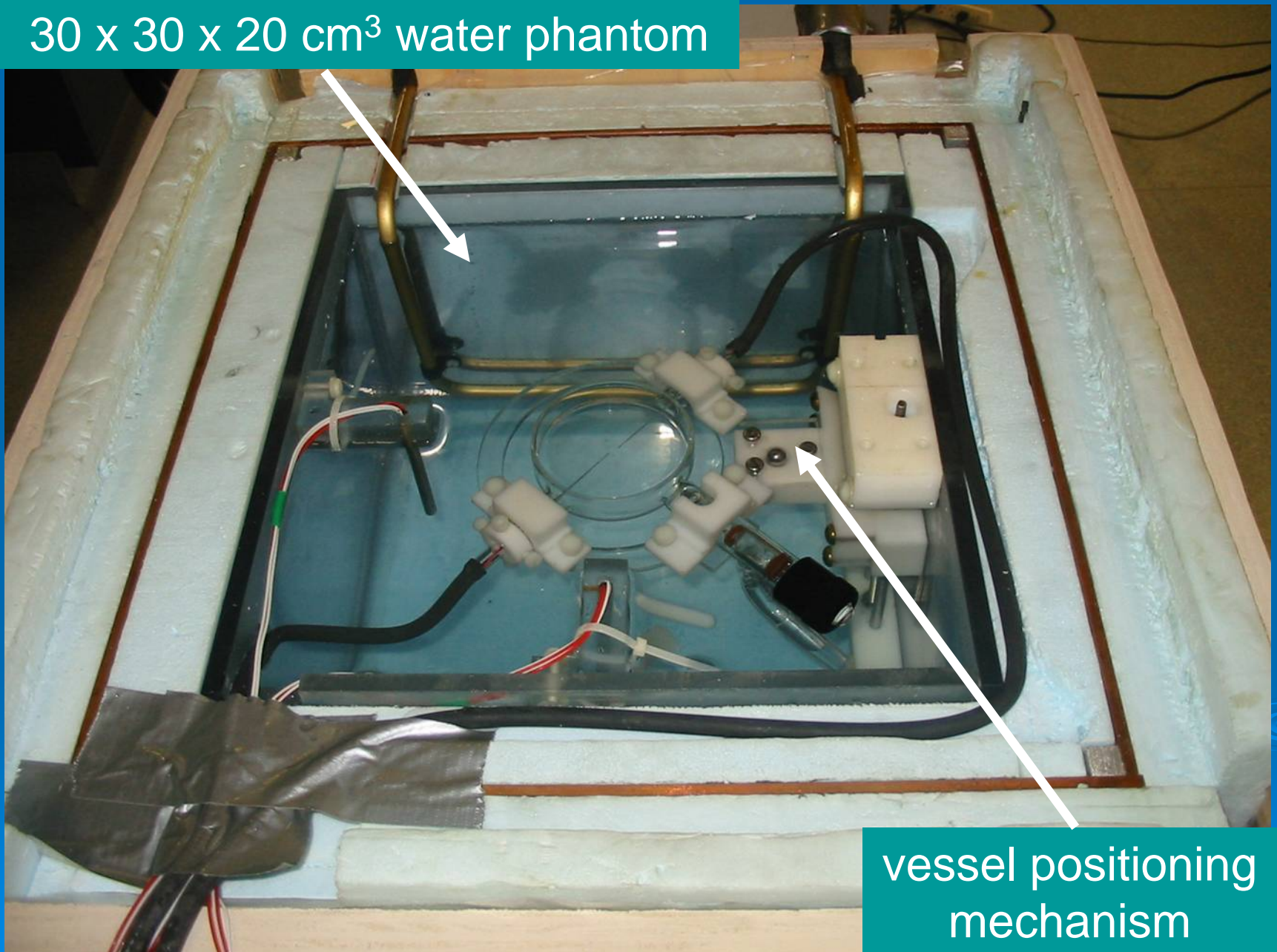
The ESW Calorimeter



Glass vessel and probes



30 x 30 x 20 cm³ water phantom



vessel positioning
mechanism

$$D_w = c_w \Delta T k_{HT} k_{HD} k_P$$

- D_w = dose to water
- c_w = specific heat of water
- ΔT = change in water temperature
- k_{HT} = conductive heat transfer correction
- k_P = vessel perturbation correction
- k_{HD} = heat defect

Measurements – electron beams

- Varian Clinac 21EX
6, 9, 12, 16 and
20 MeV
- dose ~ 6 Gy in 40 s
at d_{ref}
- ion chambers
 - PTW Roos
(plane-parallel)
 - Exradin A12
(cylindrical)



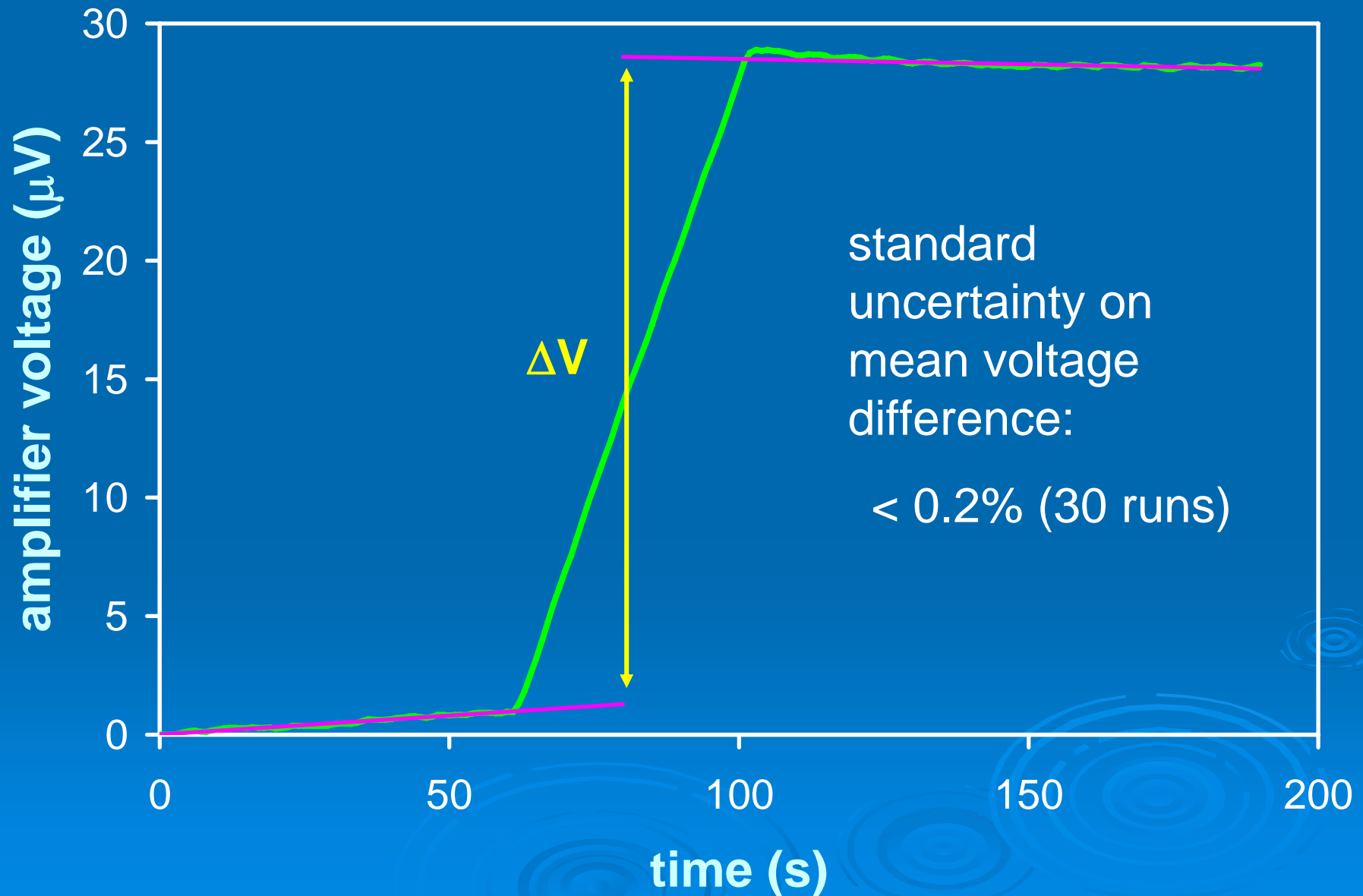
Measurements – photon beams

- Varian Clinac 21EX (MGH)
 - 6 and 18 MV
- T-780 (JGH)
 - ^{60}Co
- Elekta Precise (NRC)
 - 6 MV

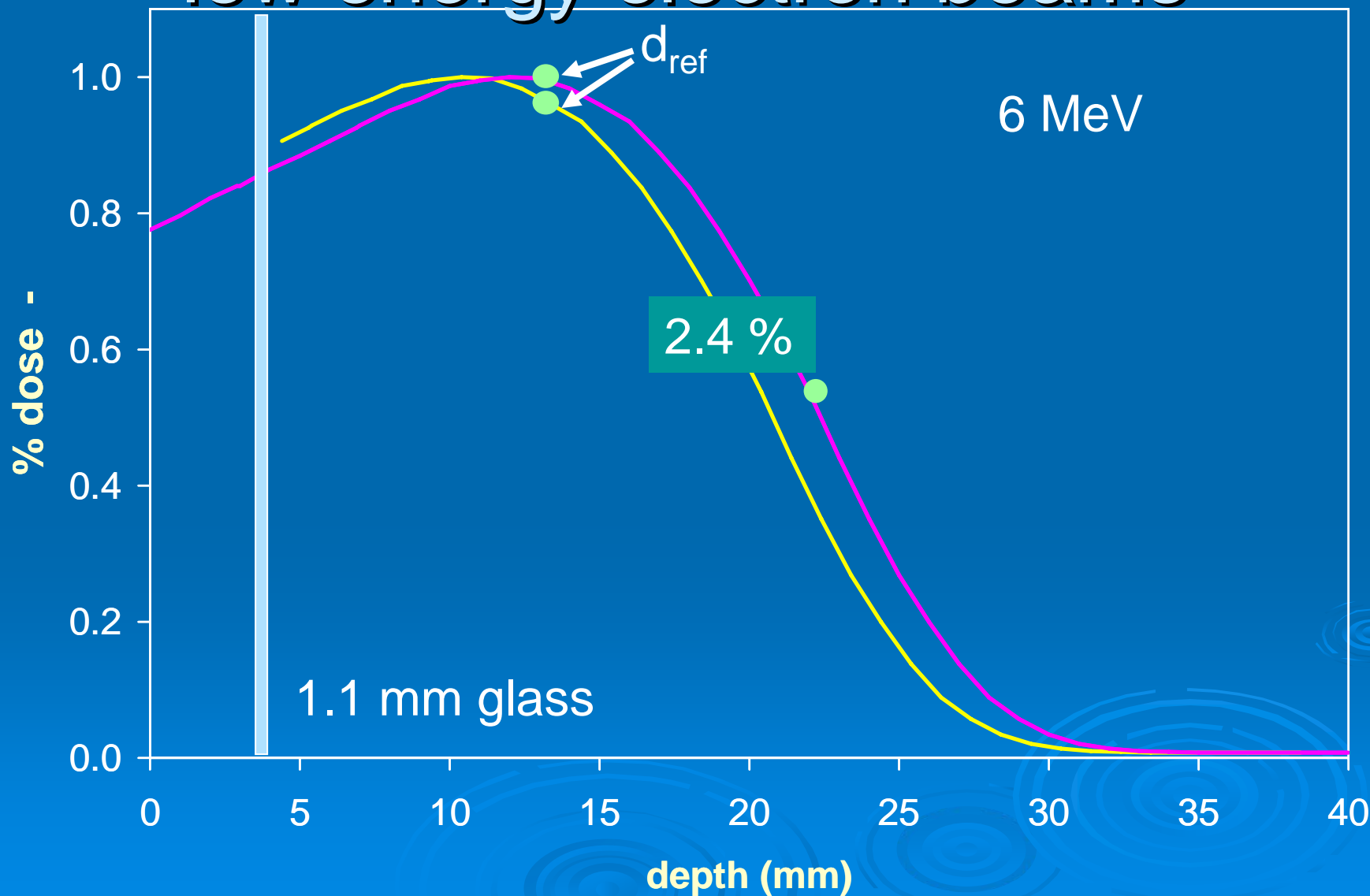
- Exradin A12 cylindrical chamber



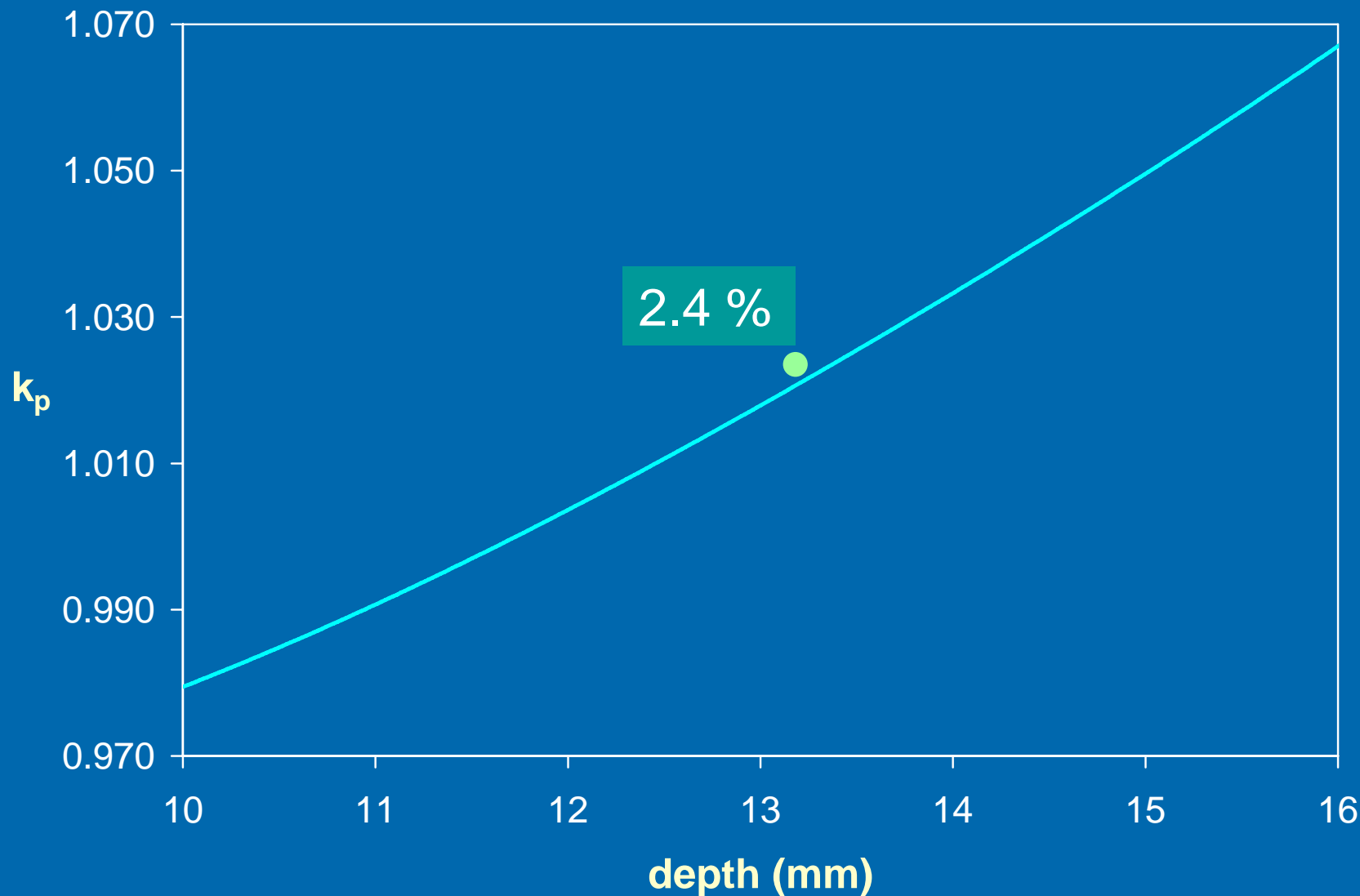
Electron beam measurements



Challenges of water calorimetry in low energy electron beams



Challenges of water calorimetry in low energy electron beams

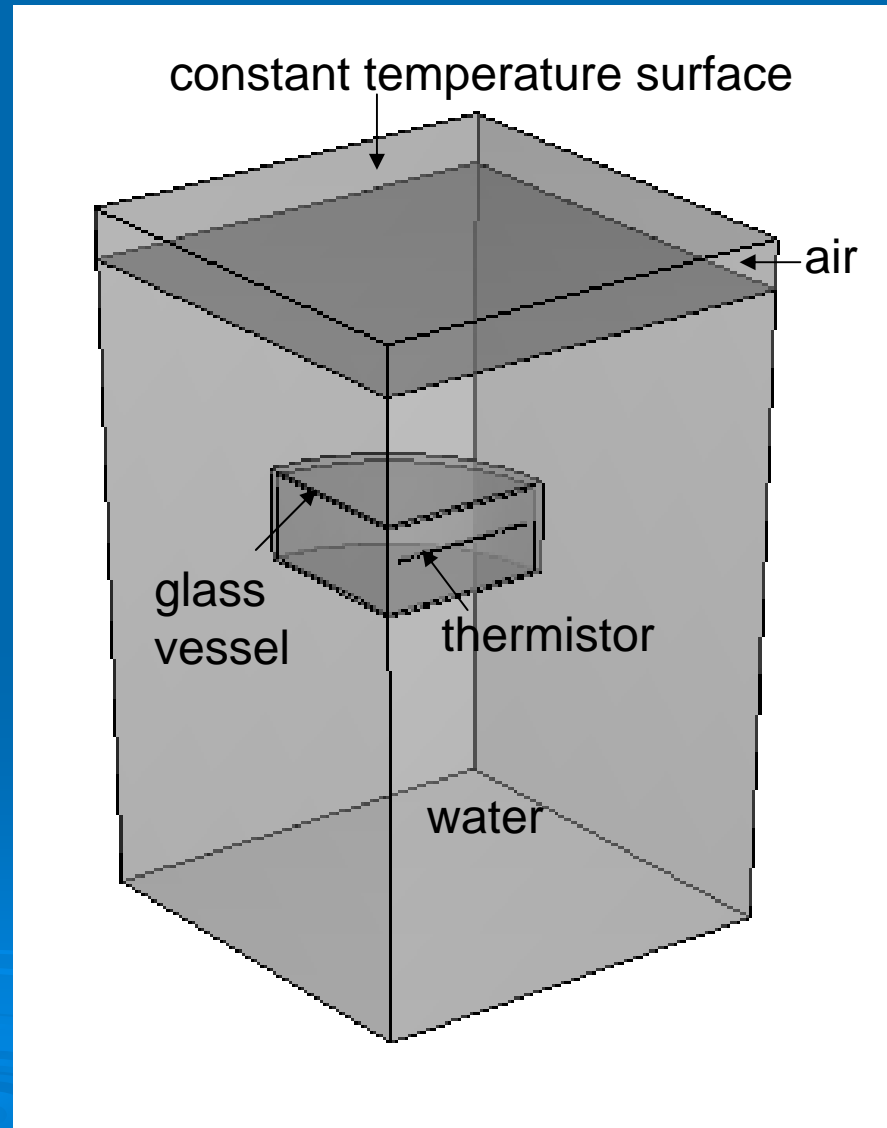


Vessel perturbation corrections

- EGSnrc / dosrznrc Monte Carlo simulation
- dose scoring region
 - 1mm thickness
 - 1 cm radius
- $k_p = (\text{dose with no glass}) / (\text{dose with glass})$
- 0.1% statistical uncertainty
- additional uncertainty related to position uncertainty of ± 0.5 mm

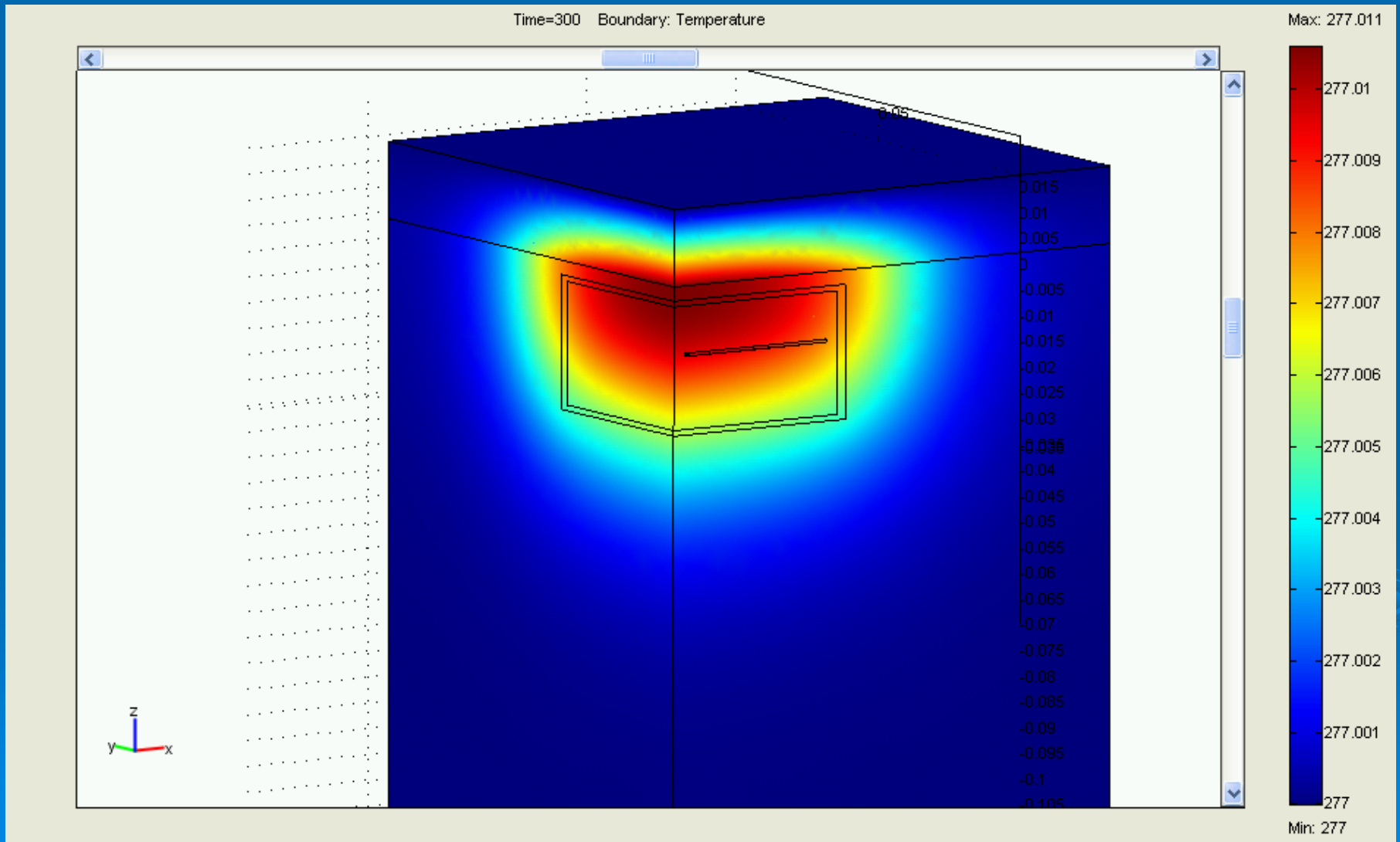
Heat loss corrections

- Evaluated using COMSOL MULTIPHYSICS software (Finite Element Modeling)
- 3D time-dependent solution of heat transfer by conduction

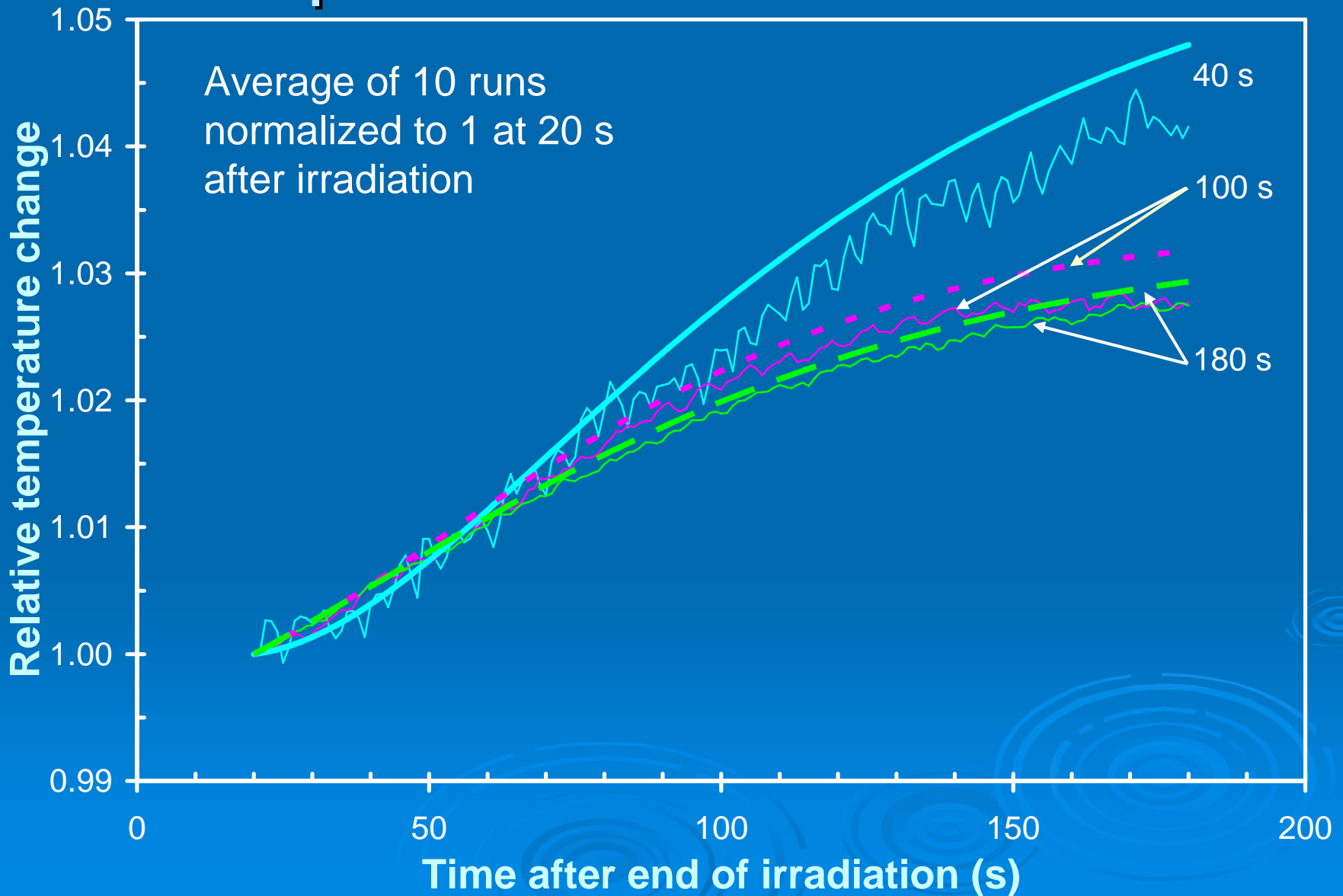


Simulated heating

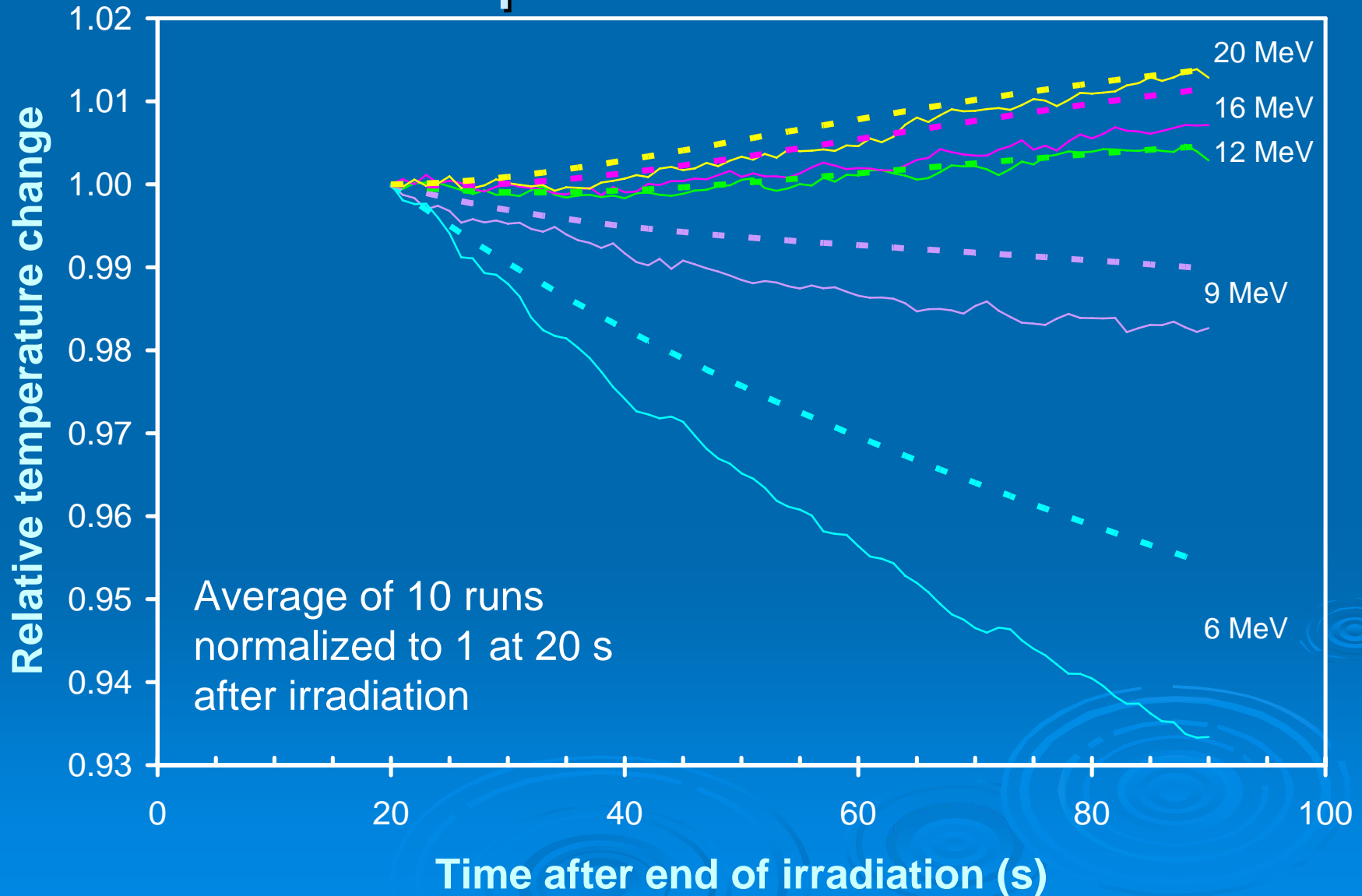
6 MeV, 40 s irradiation, 260 s drift, 12 runs



6 MV - simulated and measured post-irradiation drifts



Electrons – simulated and measured post-irradiation drifts

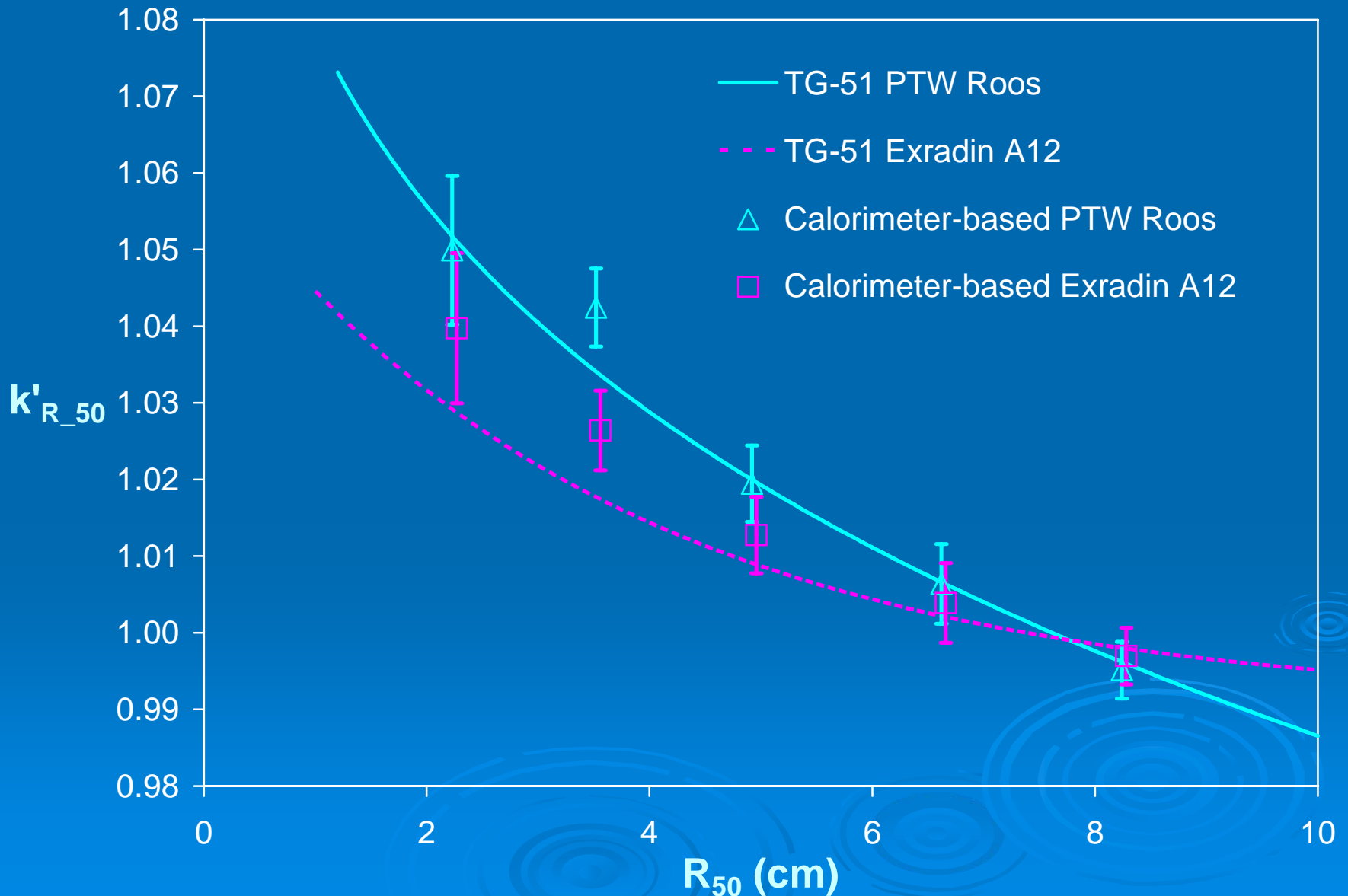


Correction Factors –

40 s irradiation, 60 s pre-drift, 90 s post-drift

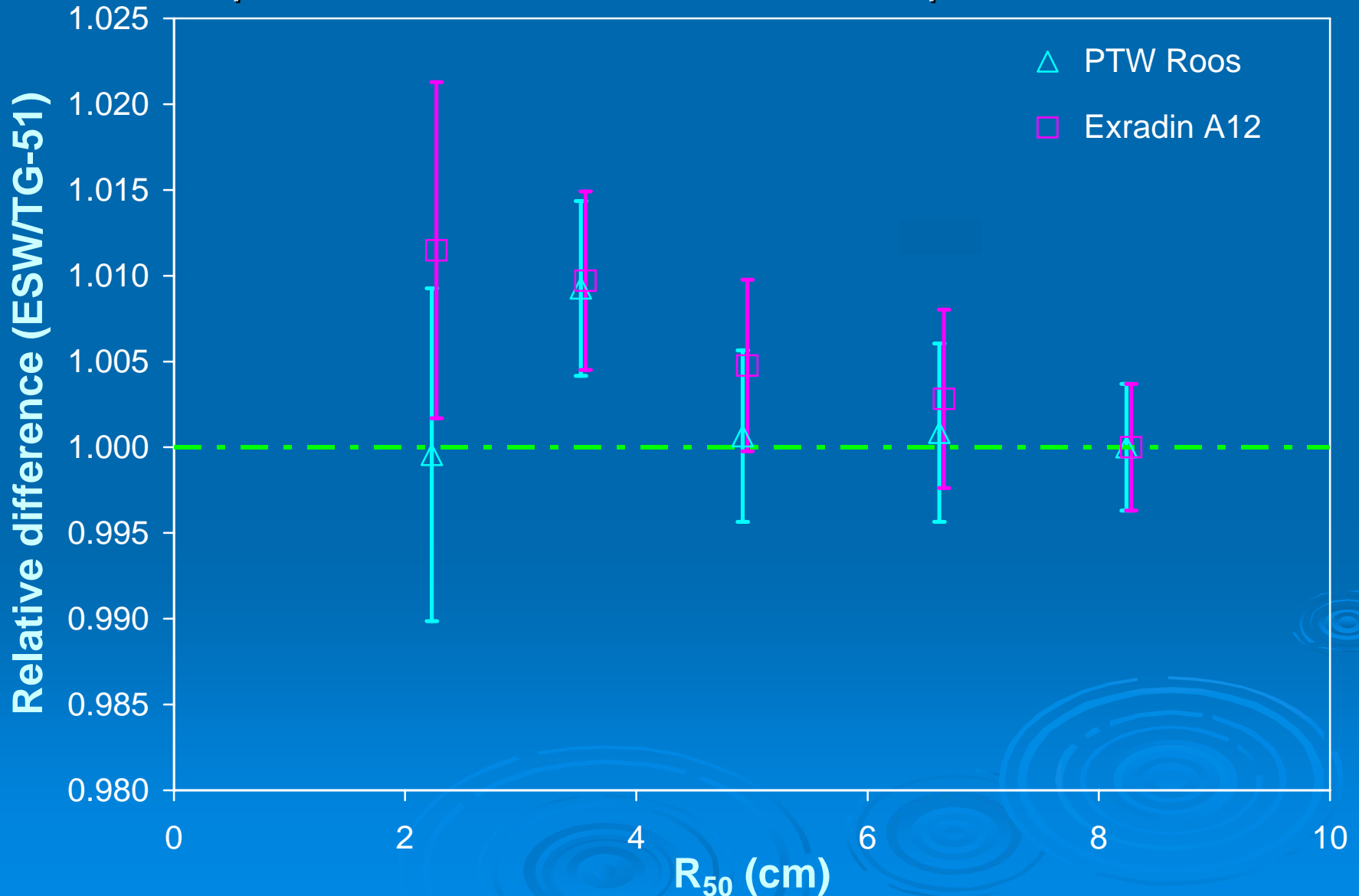
	R_{50} (cm)	k_P	k_{HT}
20 MeV	8.26	1.001	1.004
		0.003	0.001
16 MeV	6.64	1.000	1.006
		0.003	0.001
12 MeV	4.94	0.999	1.007
		0.003	0.001
9 MeV	3.54	0.999	1.010
		0.003	0.002
6 MeV	2.25	1.024	1.013
		0.006	0.006

Electron beam results

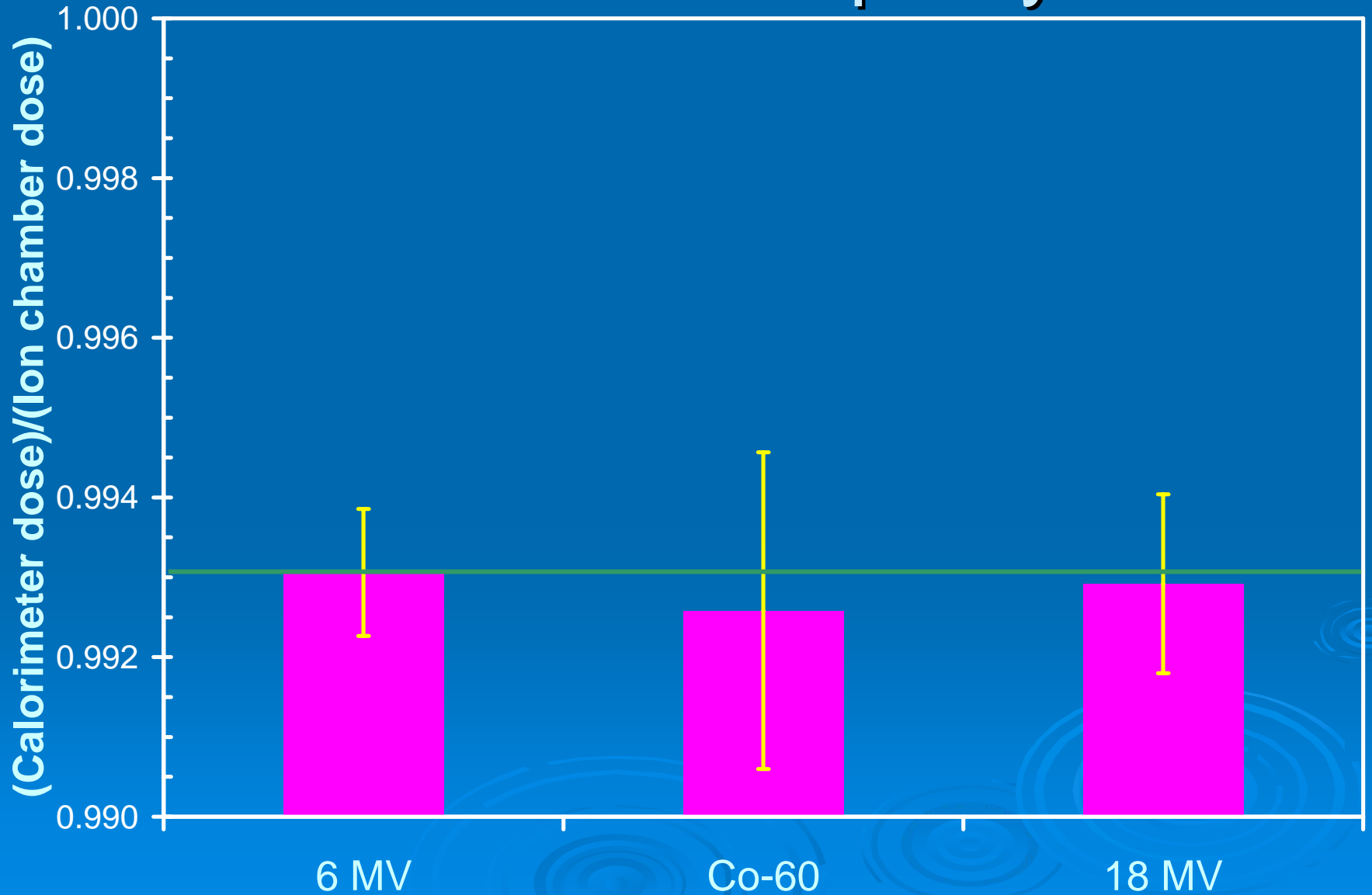


Electron beam results

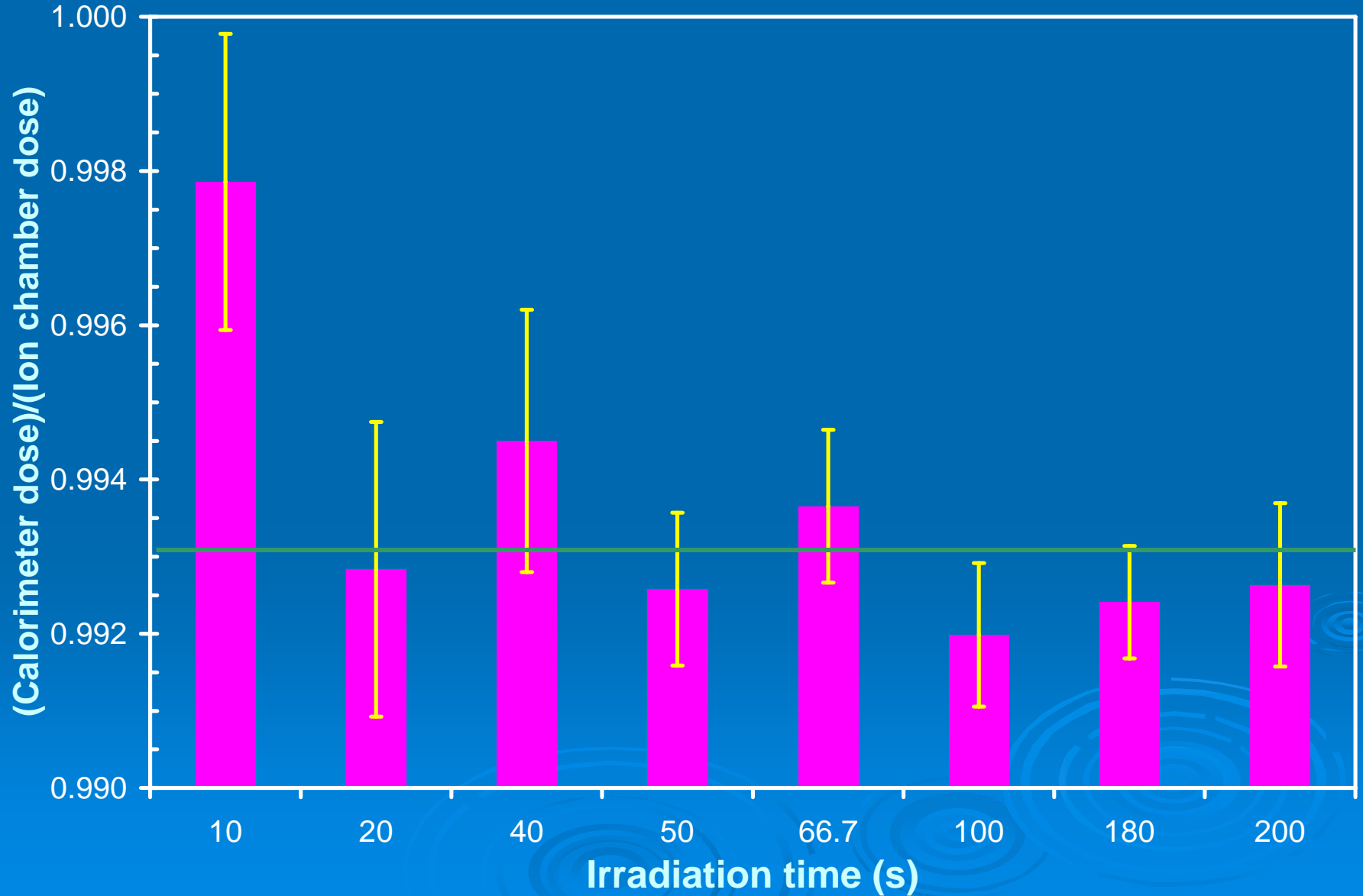
Ratio plot: calorimeter-based values / protocol values



Photon beam results versus beam quality



Photon beam results versus irradiation time



Photon beam validation

- The ESW calorimeter dose is $0.7 \pm 0.1\%$ lower than the dose measured with a calibrated Exradin A12 chamber for all photon beams
 - chamber calibration based on NRC calorimeter measurements in ^{60}Co
- This difference was confirmed by 6 MV measurements at NRC with the ESW vessel and thermistors in the NRC calorimeter phantom

Photon beam validation

- Possible reasons for this discrepancy
 - thermistor calibration
 - re-calibrated thermistors at NRC (0.1%)
 - heat defect (water/gas purity)
 - leak-tested seals
 - tested H₂ and N₂ systems at NRC (<0.1%)
 - perturbation corrections
 - MC correction verified with ion chamber (<0.1%)

Photon beam validation

➤ heat transfer corrections

- currently comparing corrections evaluated using different finite element analysis software
 - Flex PDE
 - in-house software
- some discrepancies have been observed and are still under investigation
- correction is very sensitive to thermistor position relative to glass

Conclusions & Future Work

- Reproducible calorimeter measurements were performed in clinical electron beams with energies as low as 6 MeV
- Correction factors are 1% or less for 9 to 20 MeV beams
- Preliminary evaluation indicates differences from TG-51 values of $k_{R_{50}}$ of up to 1.1%

Conclusions & Future Work

- More investigation must be done to find the reasons for the discrepancy between the ESW and NRC calorimeters in photon beams
- Heat transfer corrections are being investigated as the most likely source of this discrepancy

Acknowledgements

- Robin Van Gils
- David Marchington
- Malcolm McEwen
- Arman Sarfehnia
- Genevieve Jarry
- Leo Heistek
- Vlad Bobes
- Joe Larkin
- Pierre Leger
- Bhavan Siva

Funding has been provided by

- Canadian Institutes of Health Research
- Natural Sciences and Engineering Research Council
- J Seuntjens is a research scientist with funds provided by the National Cancer Institute of Canada

