Simulation of radiation dose response in phantom for CT

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Radiation dosimetry

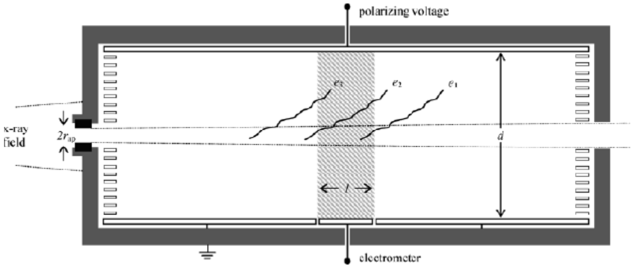
- Photon interactions
  - Photoelectric absorption, coherent and incoherent scattering
  - secondary electron equilibrium

- Dose (energy Gy = J/kg)
  - Air kerma: “kinetic energy of all charged particles liberated per unit mass”
  - absorbed dose: “energy absorbed per unit mass”
  - Absorbed dose to water: tissue equivalent, homogeneous

- Two primary methods to provide dosimetry standard:
  - Measuring charge: Ionization chamber
    - ✓ simulation: Monte Carlo photon and electron transport
  - Measuring heat, temperature rise in medium: Water calorimetry
    - ✓ Simulation: Comsol

ENERGY RANGES & QUANTITIES

10-50 keV – low energy x-rays	Air Kerma
50-300 keV – medium energy x-rays	Air Kerma
Cs-137 & Co-60	Air Kerma
Co-60	Absorbed Dose
Linac photon (x-ray) beams	Absorbed Dose
Linac electron beams	Absorbed Dose

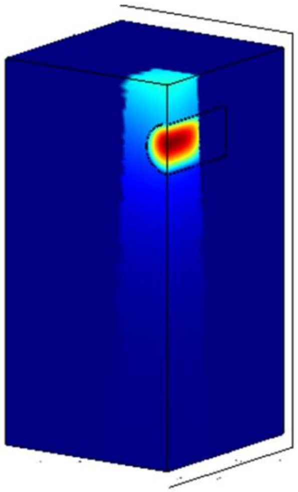


Collect charge in ionization chamber

$$K_{air} = \frac{Q_{air}}{\rho_{air} \cdot V} \cdot \left(\frac{W}{e}\right)_{air} \cdot \frac{1}{1 - g} \cdot K_{att} \cdot K_{sc} \cdot K_{e} \cdot K_{hum} \cdot P_{pol} \cdot P_{ion}$$

http://www.aapm.org/meetings/09SS/documents/15McEwen-PrimaryStandardsfinalforVL.pdf

Static 10 cm x 10 cm beam

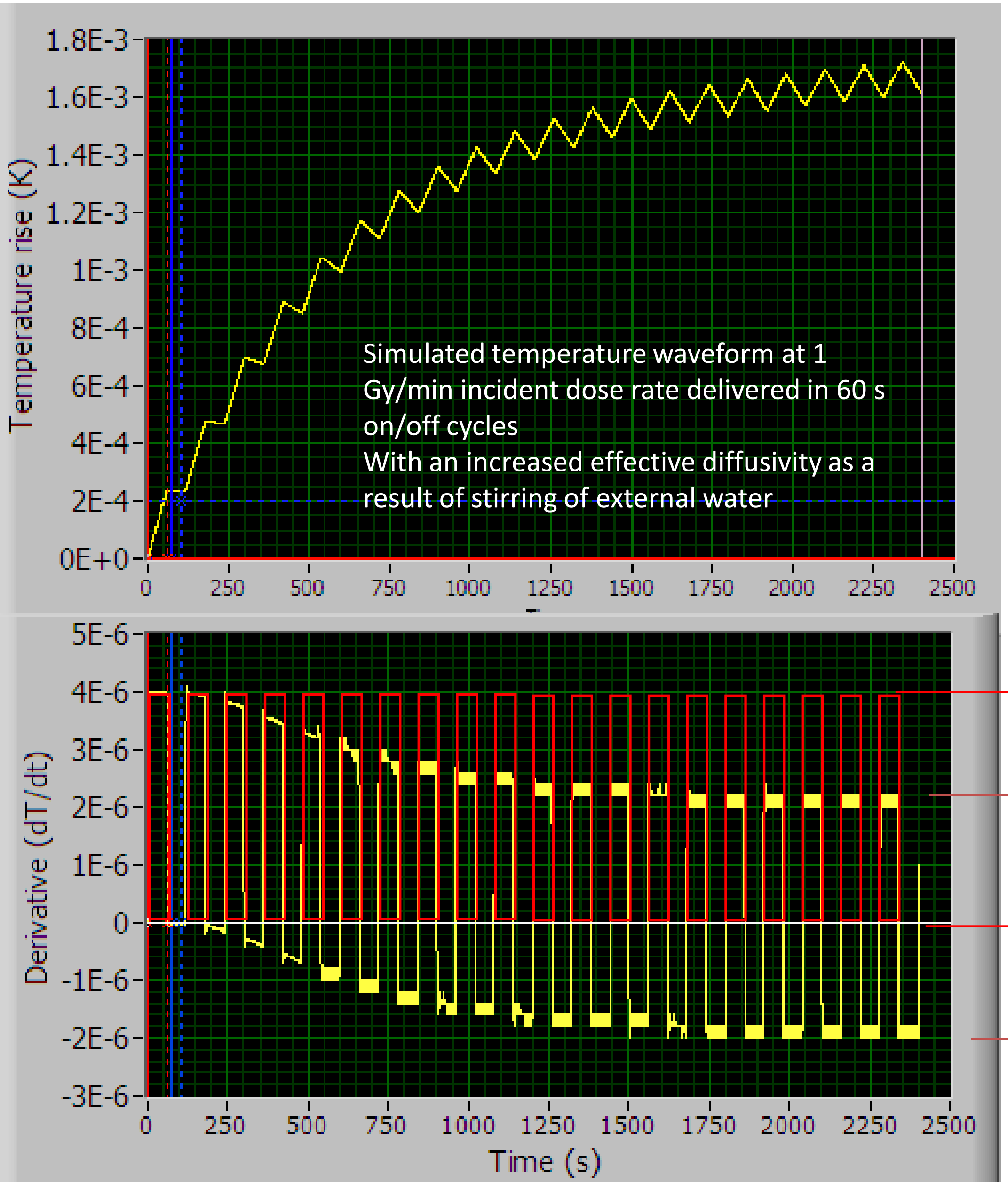


Measure temperature rise to determine dose

$$D = c_p \Delta T$$

1 Gy of radiation -> temperature rise in water 0.24 mK

Comsol simulation of a water calorimeter



Simulated temperature waveform at 1 Gy/min incident dose rate delivered in 60 s on/off cycles
With an increased effective diffusivity as a result of stirring of external water

Incident radiation at D= 1 Gy/min, corresponding to a temperature rise of 3.99e-6 K/s

Correction due to heat conduction

$$\partial T/\partial t = D/c_p + \kappa\, \partial^2 T/\partial x^2$$

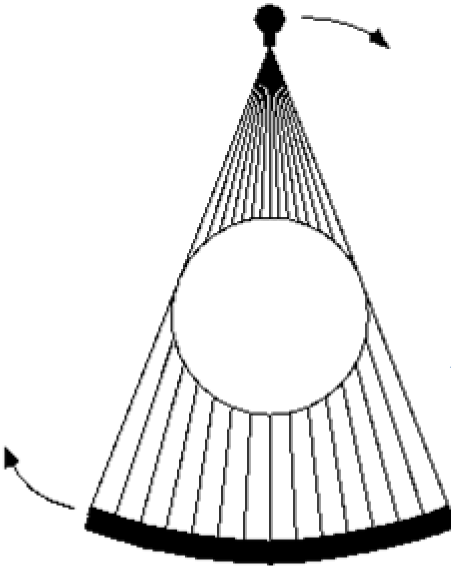
1D heat equation

T – temperature
D – dose rate (Gy/s)
κ – thermal diffusivity

CT dose

- On the order of mGy, therapy level Gy
- Non-static beam, a few s rotation time

X-ray CT scanner



X-ray source

Detector array

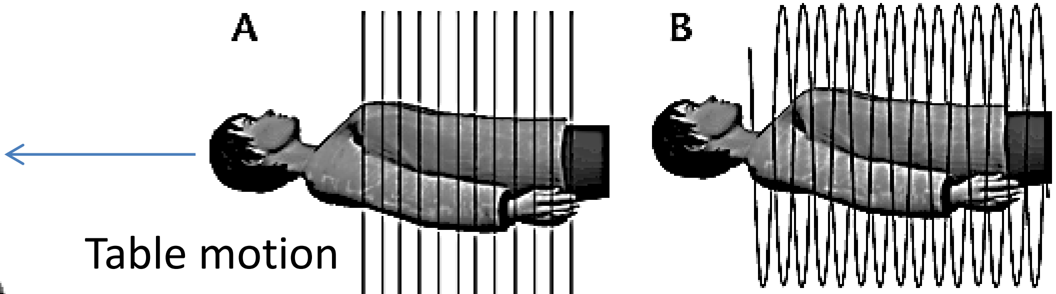


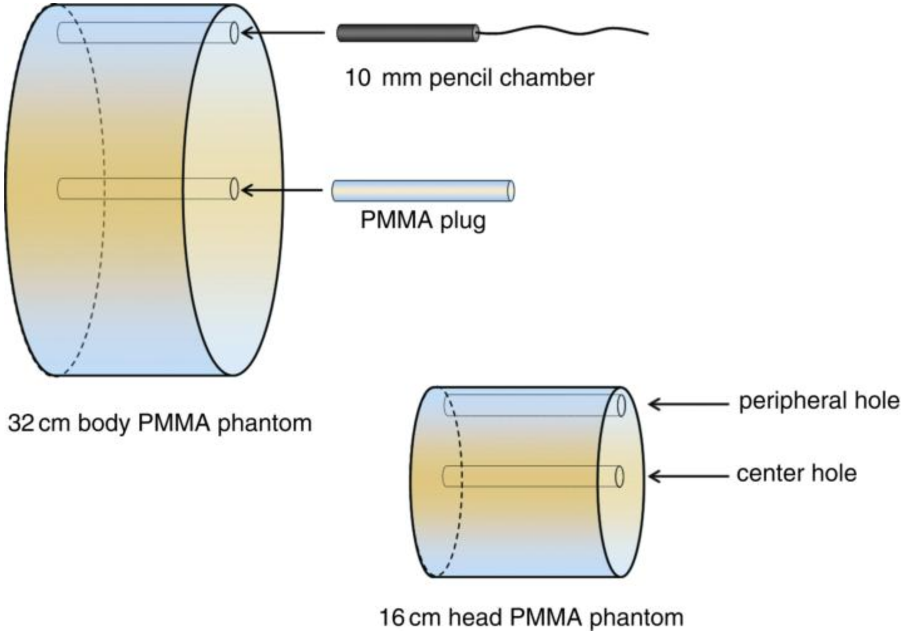
Table motion

Artwork from: http://drugline.org/img/term/helical-cat-scan-6894_1.gif

Axial scan (step and shoot)

Helical scan

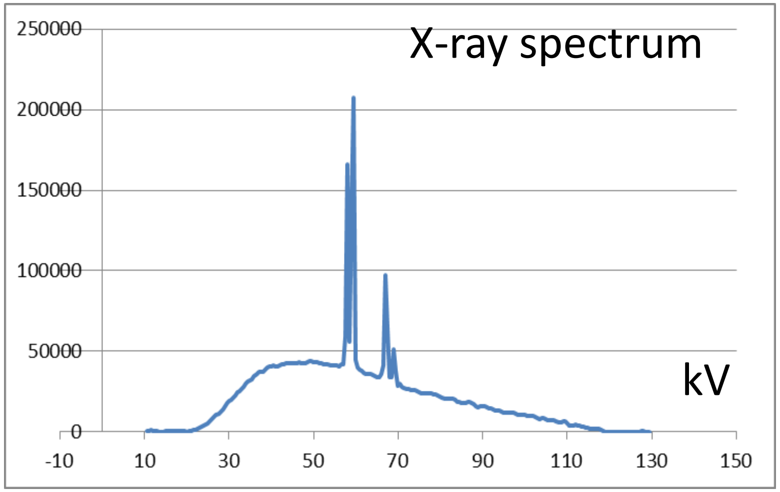
Current CT dose standard – $CTDI_{100}$



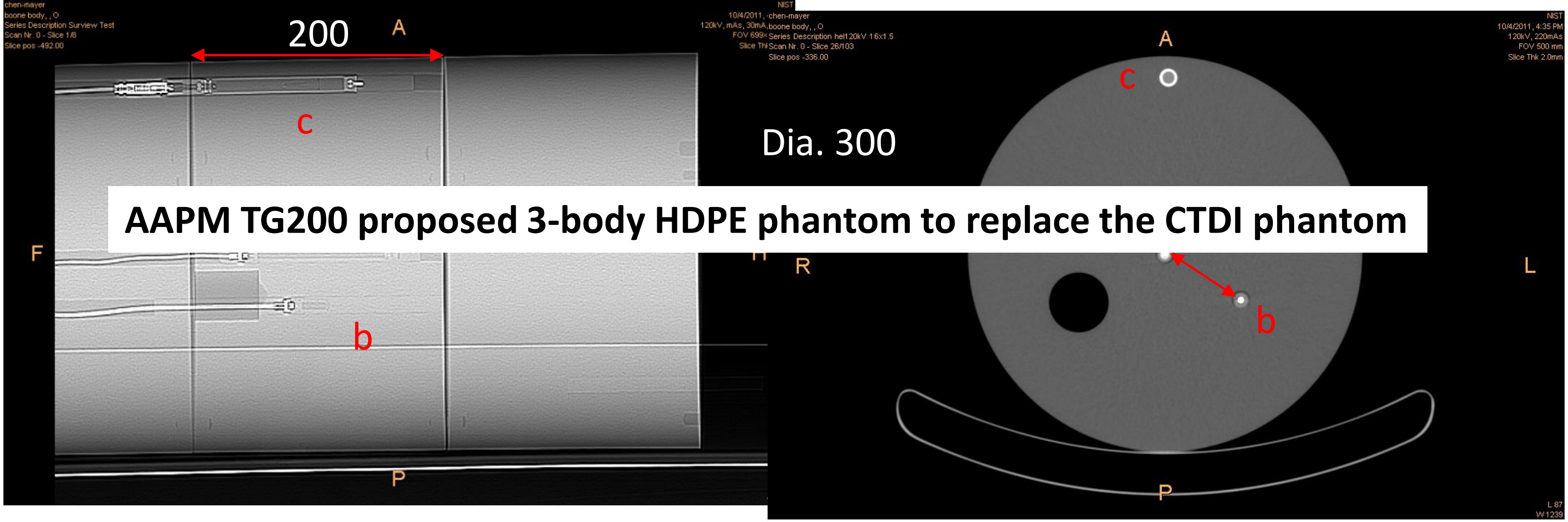
Various conversion steps:

$$CTDI_{100} = \frac{1}{nT}\int_{-50mm}^{50mm} D_a(z)dz$$

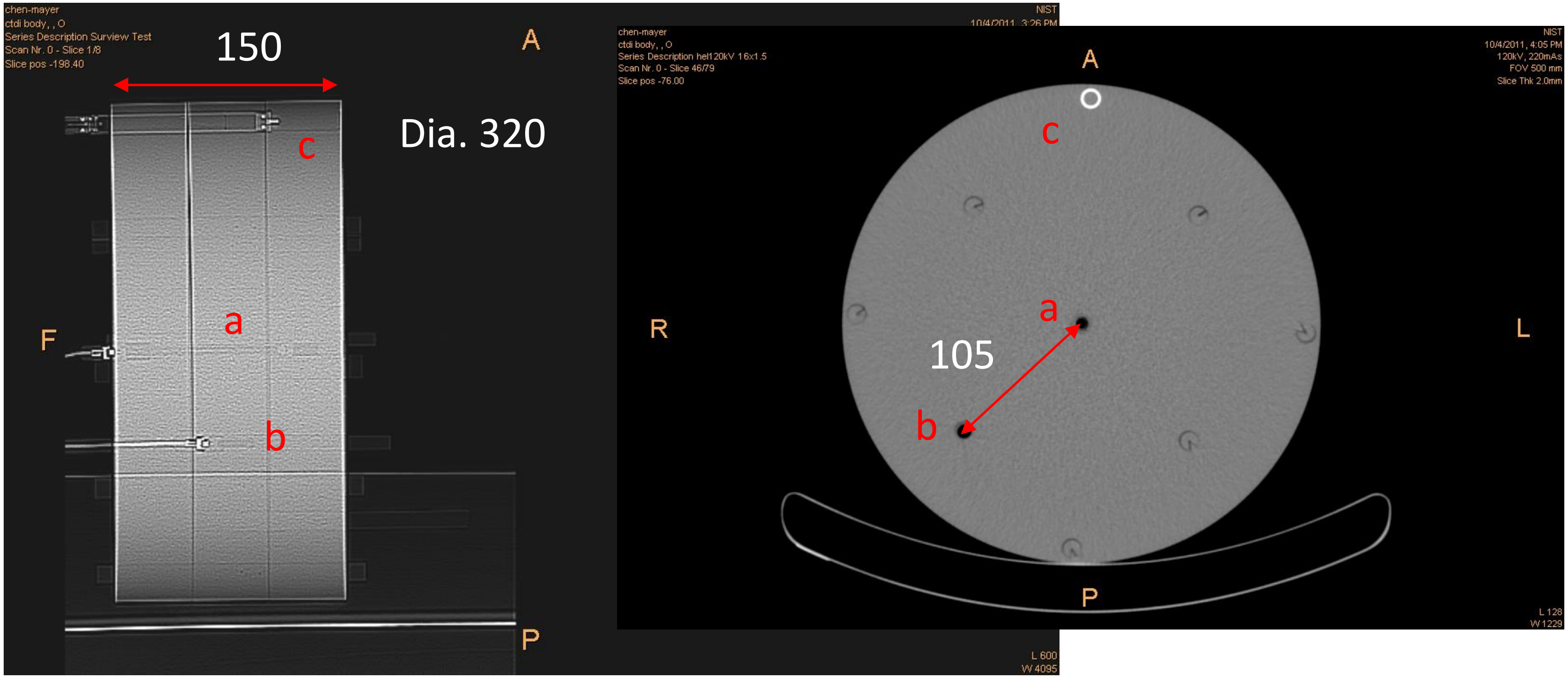
$$D_{material} \approx K_a\left(\bar{\mu}_{en}/\rho\right)^{material}_{air} \approx qN_k\left(\bar{\mu}_{en}/\rho\right)^{material}_{air}$$

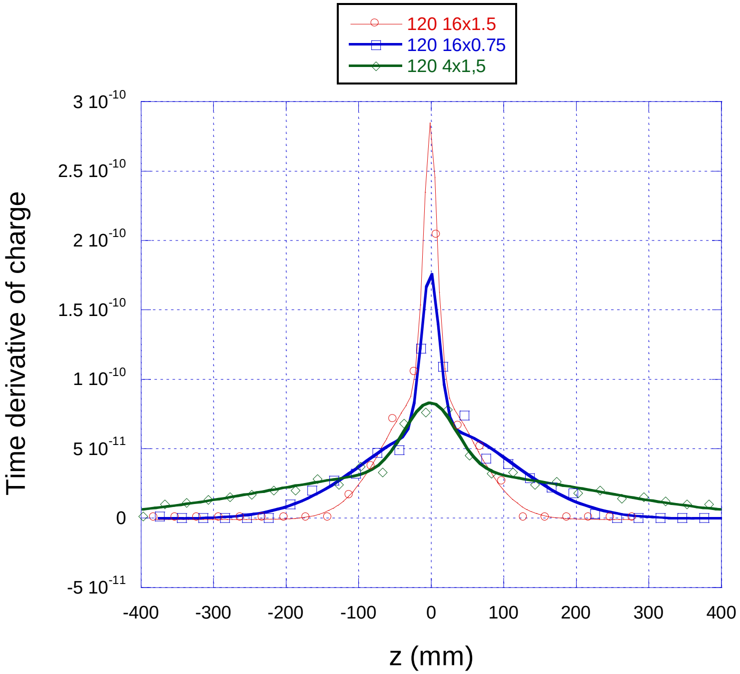


AAPM TG200 proposed 3-body HDPE phantom to replace the CTDI phantom

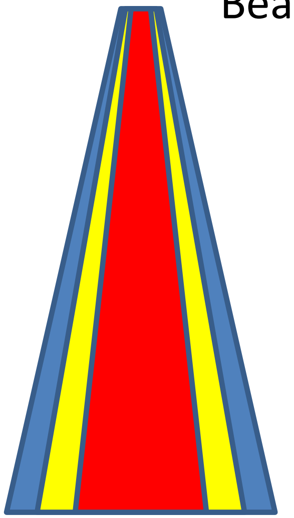


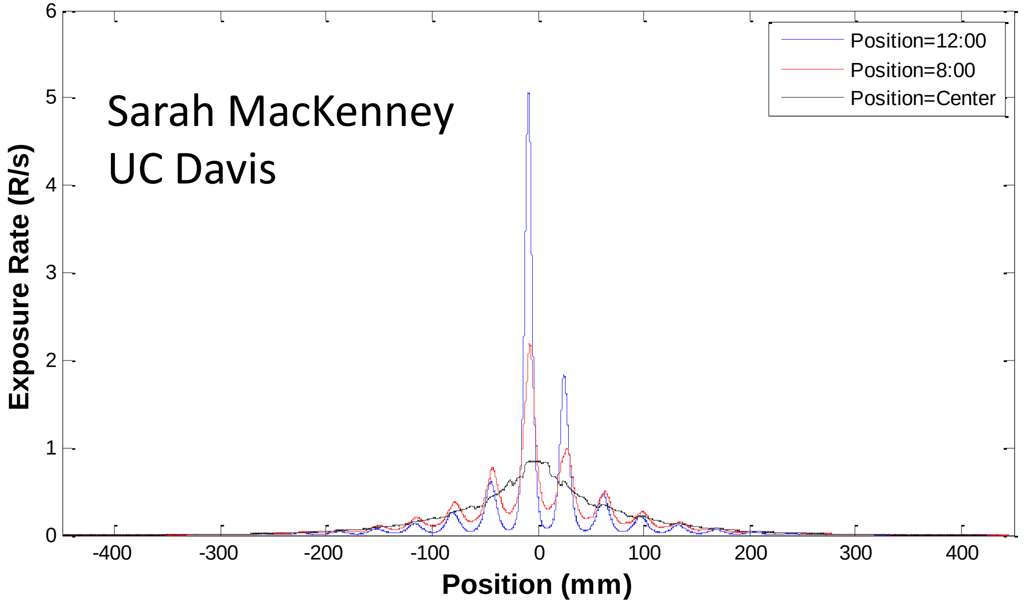
a) 10 cm chamber, b) 0.6 cc chamber, c) RTI dose profiler



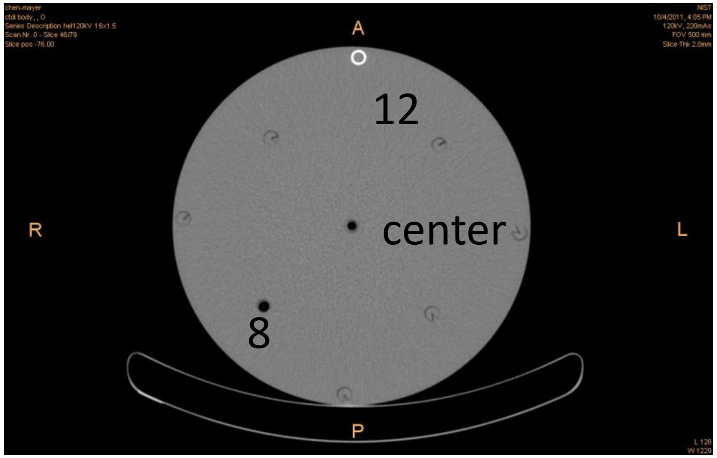


Beam collimation





Sarah MacKenney
UC Davis



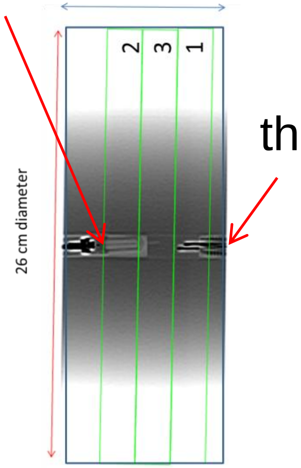
Detector position

Measurement in CT

Calorimetry – direct realization of the dose

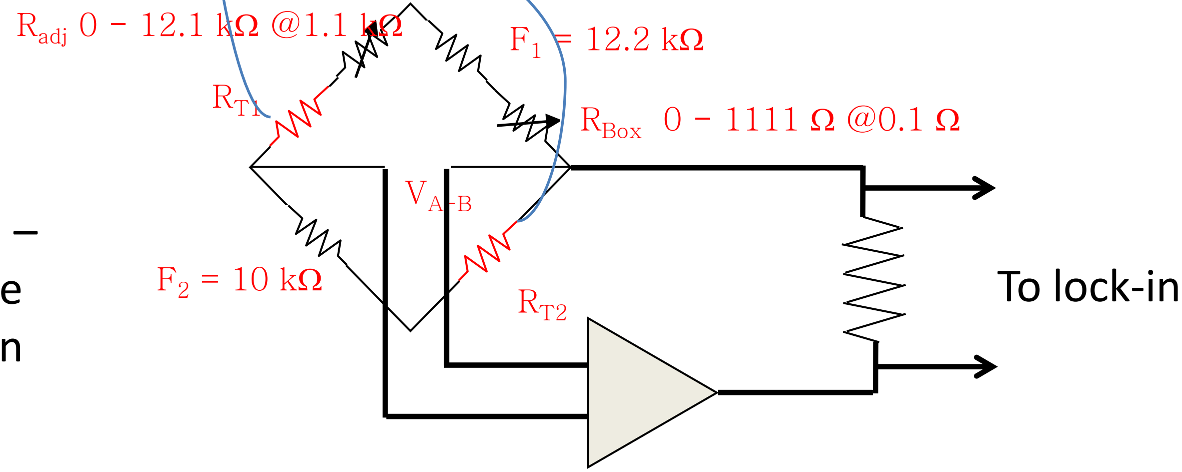
Photo of PE phantom with electrical wiring for thermistors

Ionization chamber



thermistors

CT projection image showing on axis arrangement of an ionization chamber and the pair of thermistors.



microKelvin temperature rise – need Wheatstone bridge and lock-in detection

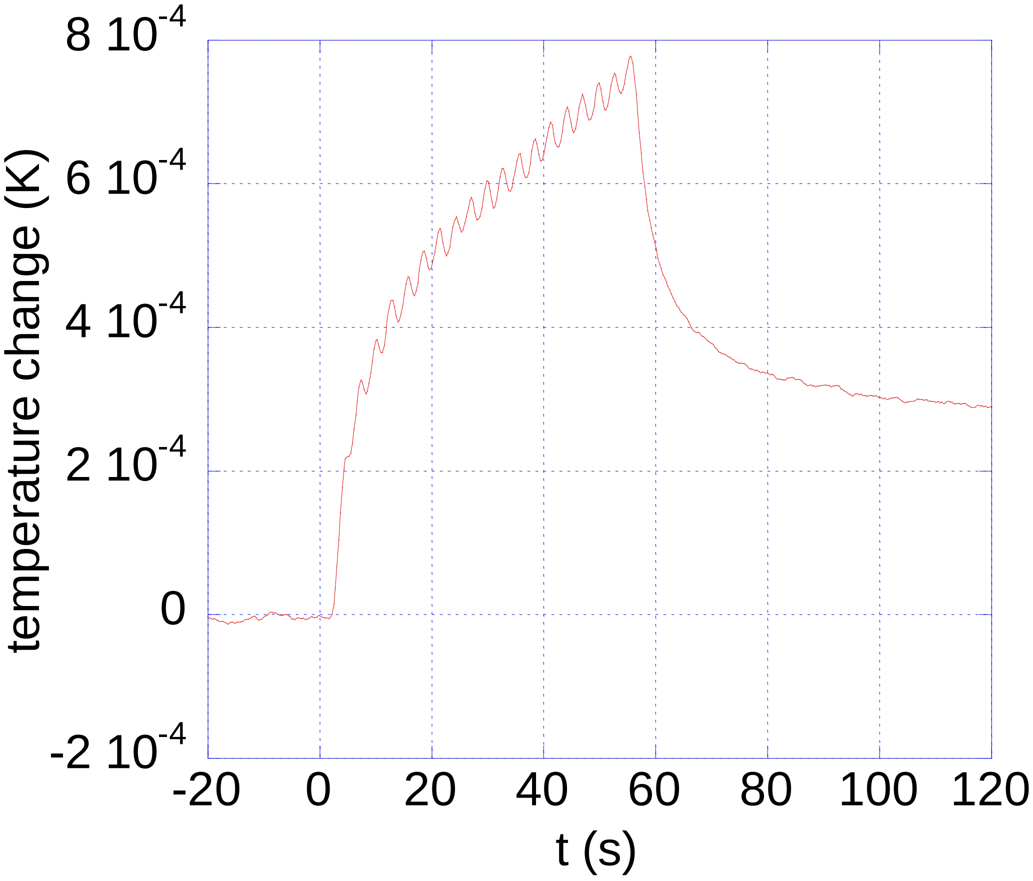
HDPE vs water

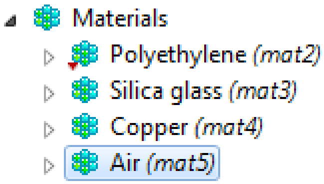
$$D = c_p \, \Delta T \qquad\qquad \partial T/\partial t = D/\boxed{c_p} + \boxed{\kappa}\, \partial^2 T/\partial x^2$$

- High density polyethylene has a heat capacity about 2.5 times lower and thermal conductivity of 30% lower than water.

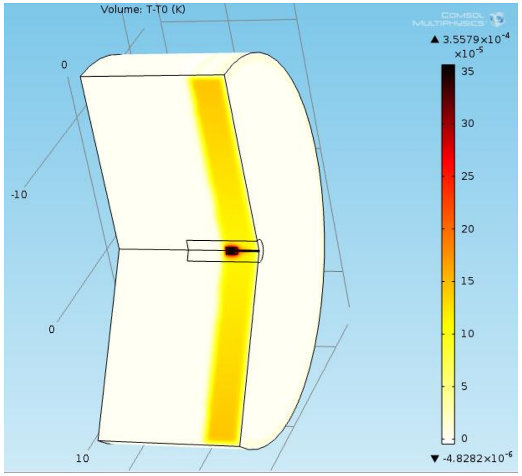
- The temperature sensitivity of Wheatstone/lock-in device is about 3 μK
- 1 Gy of radiation
  - temperature rise in water 0.24 mK
  - temperature rise in PE is about 0.6 mK
- A typical CT scan delivers a dose of 10s of mGy
  - 2.4 μK in water
  - 6 μK in PE.

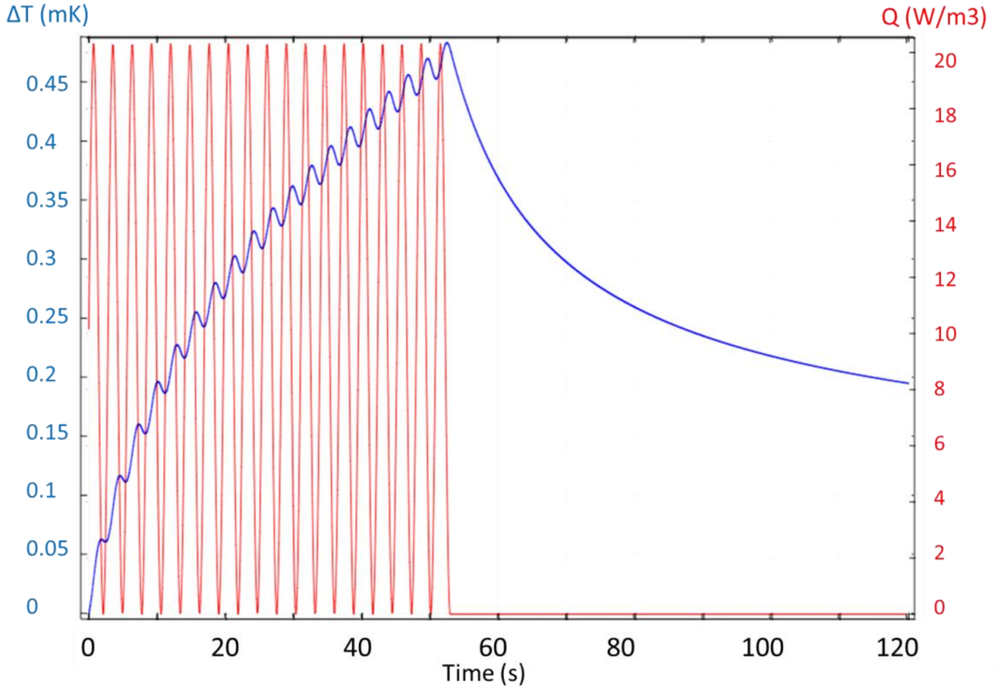
Measurements were performed in a 16-slice medical CT scanner at 120 kVp. For the purpose of this study, an elevated dose is delivered by using twenty consecutive axial scans at 250 mA, which delivers a nominal total dose of 705 mGy in 50 s.

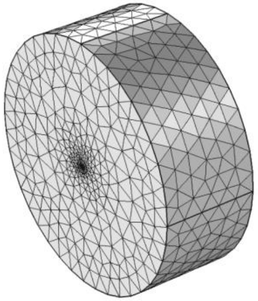




- Materials
  - Polyethylene *(mat2)*
  - Silica glass *(mat3)*
  - Copper *(mat4)*
  - Air *(mat5)*







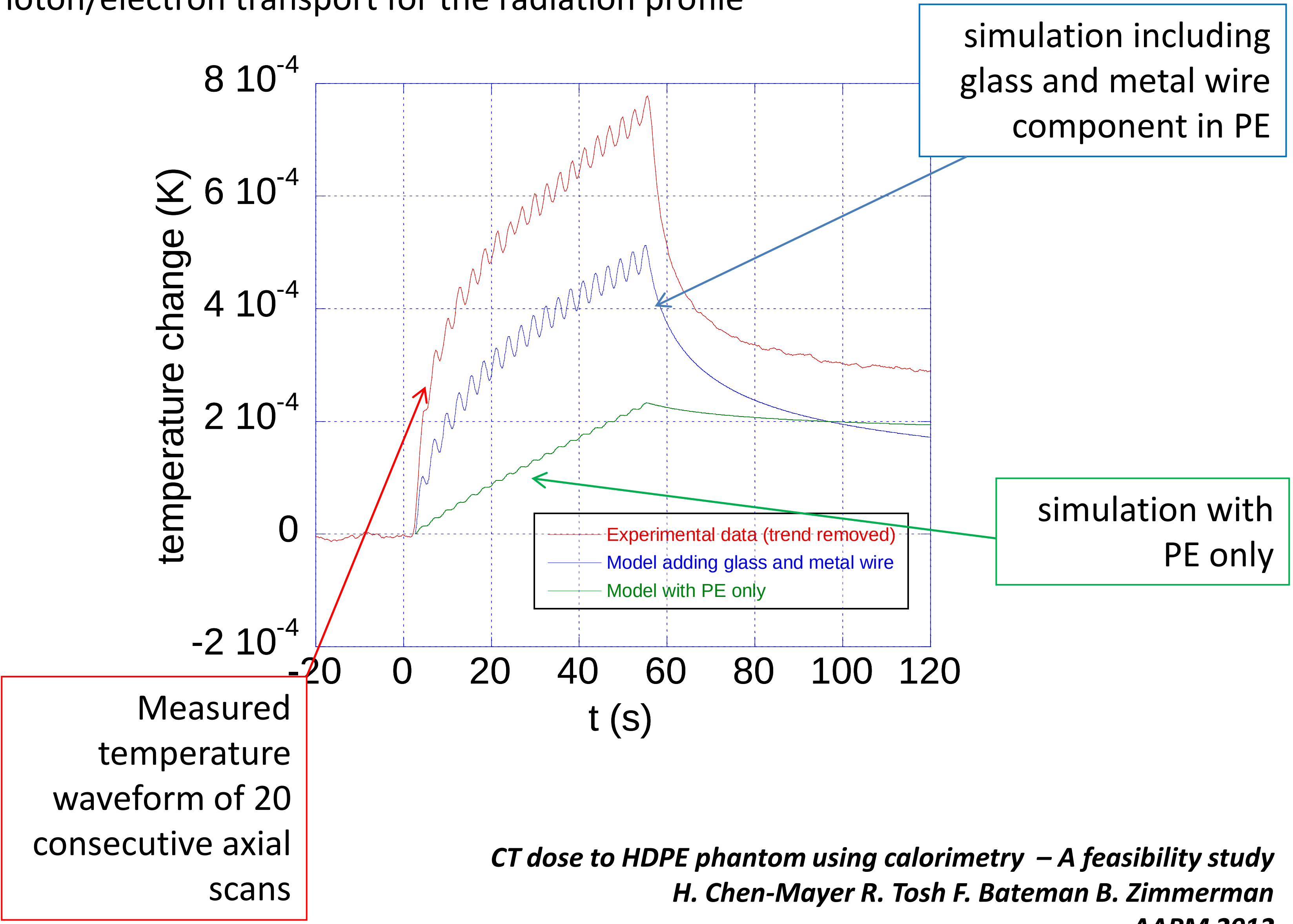
$$\rho C_p \frac{\partial T}{\partial t} - \nabla \cdot (k \nabla T) = Q$$

$$Q = Q_0 e^{-ar+b}\,(1 + \sin 2\pi t/\tau)\ \ (z_{min} < z < z_{max})$$

Need to do:

Heat defect not yet accounted for, could be as high as 10%

Photon/electron transport for the radiation profile



simulation including glass and metal wire component in PE

simulation with PE only

Measured temperature waveform of 20 consecutive axial scans

CT dose to HDPE phantom using calorimetry – A feasibility study
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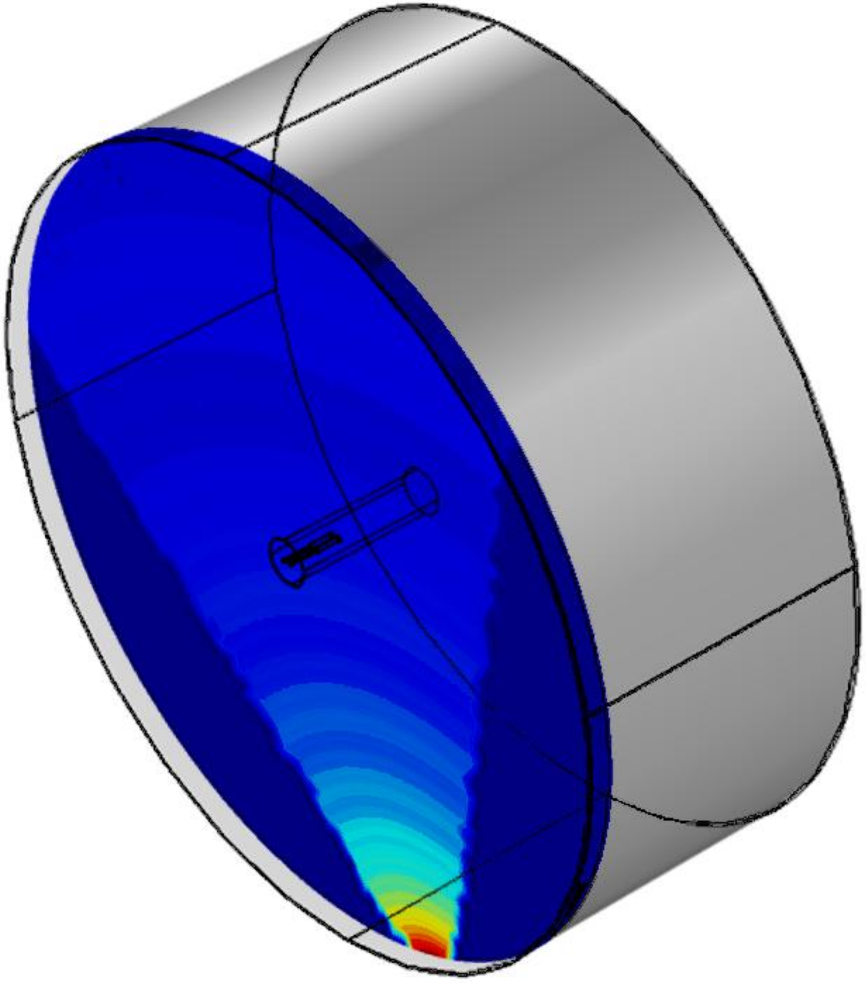

Work in progress