

# Effect of CT number – stopping power conversion uncertainties on dose distributions

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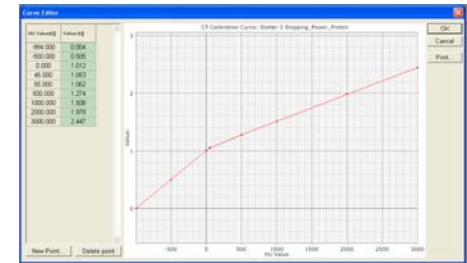




- Treatment planning system dose calculations are based on CT images of the patients



- CT numbers are converted to relative proton stopping power via a calibration curve



- Proton range in patient is calculated by integration of tissue relative stopping power along the beam path

- Uncertainties on the calibration curves translate into uncertainties on the calculated proton range and dose distributions



- Determined according to the Schneider *et al* (1996) recipe
- Based on a electron density phantom
- Hounsfield numbers measured for a range of phantom arrangements and CT parameters
- The stoichiometric method applied for the calculation of Hounsfield numbers
- Relative stopping power (RSP) measured and calculated for all tissue substitutes
- Tissue-wise linear fits provided the calibration curve

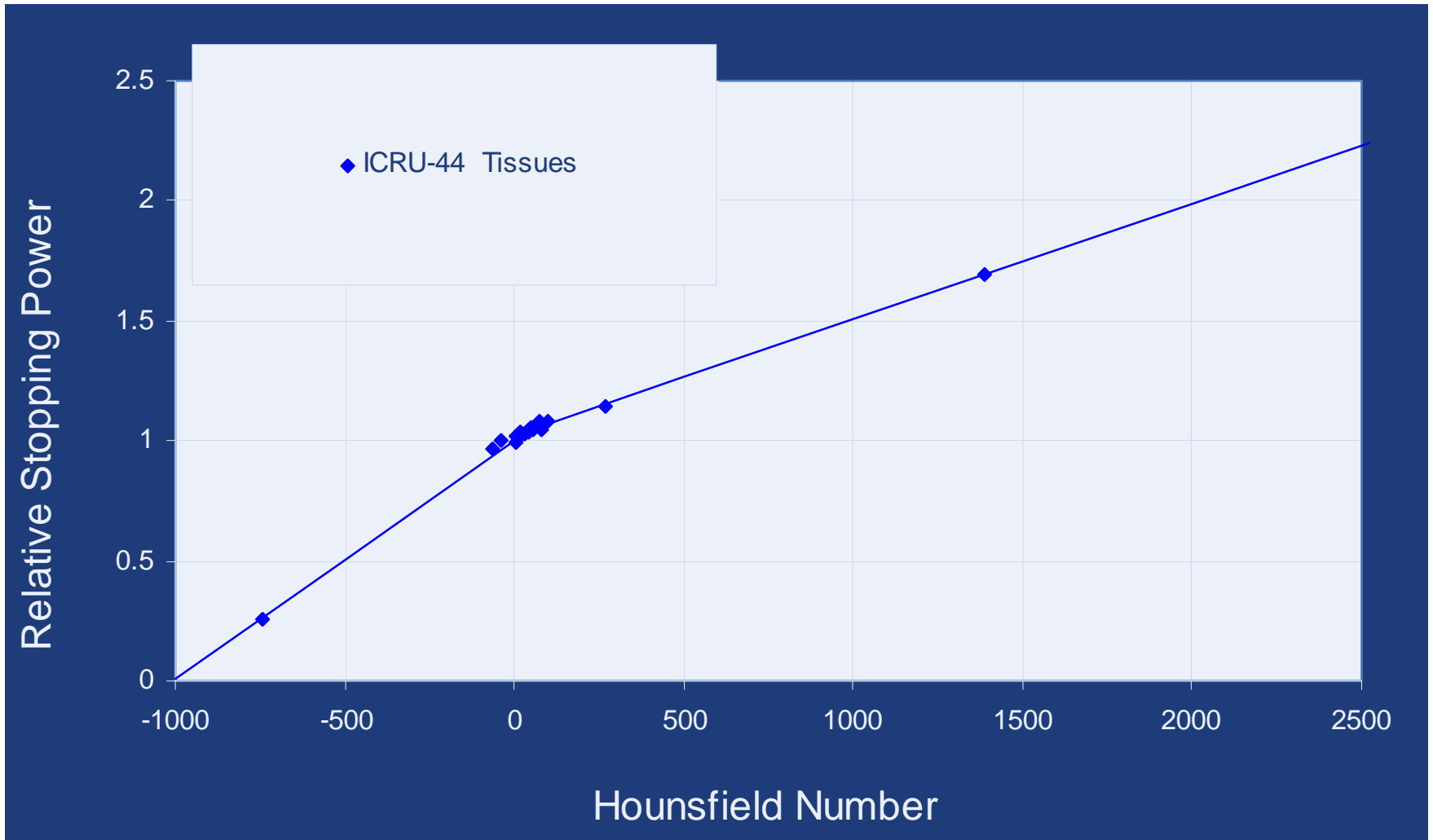


- CIRS Electron density phantom (M062)
- Modular phantom made of solid water
  - ❖ Head (~18 cm WE diameter)
  - ❖ Body (~30.5 cm WE diameter)
  - ❖ Large body (~39 cm WE diameter)
- 20 Tissue equivalent plugs (d= ~3 cm, h= ~8 cm)
- CIRS provided density and composition for the specific inserts
- Insert density was also measured



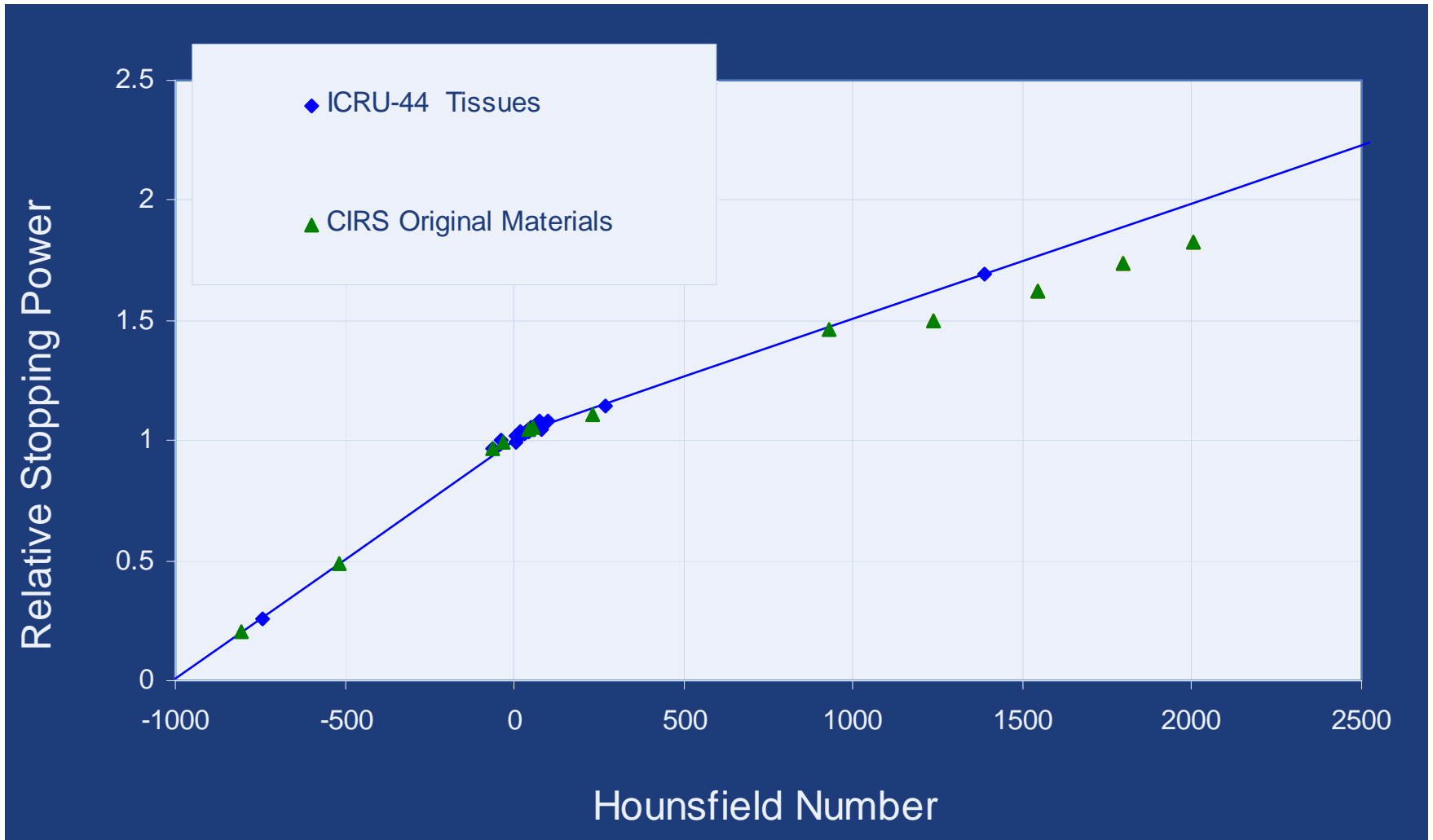


# Tissue equivalent materials



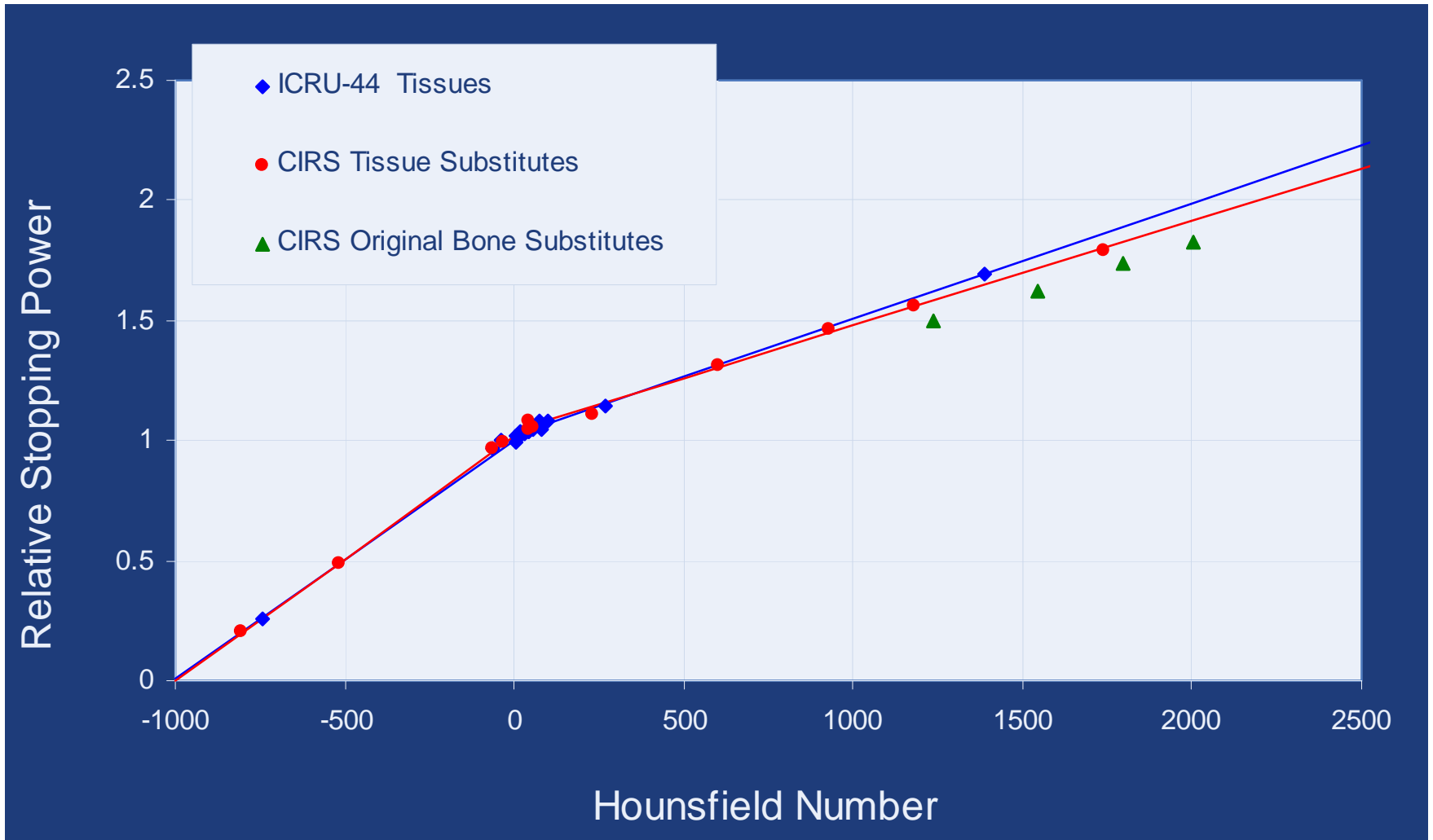


# Tissue equivalent materials



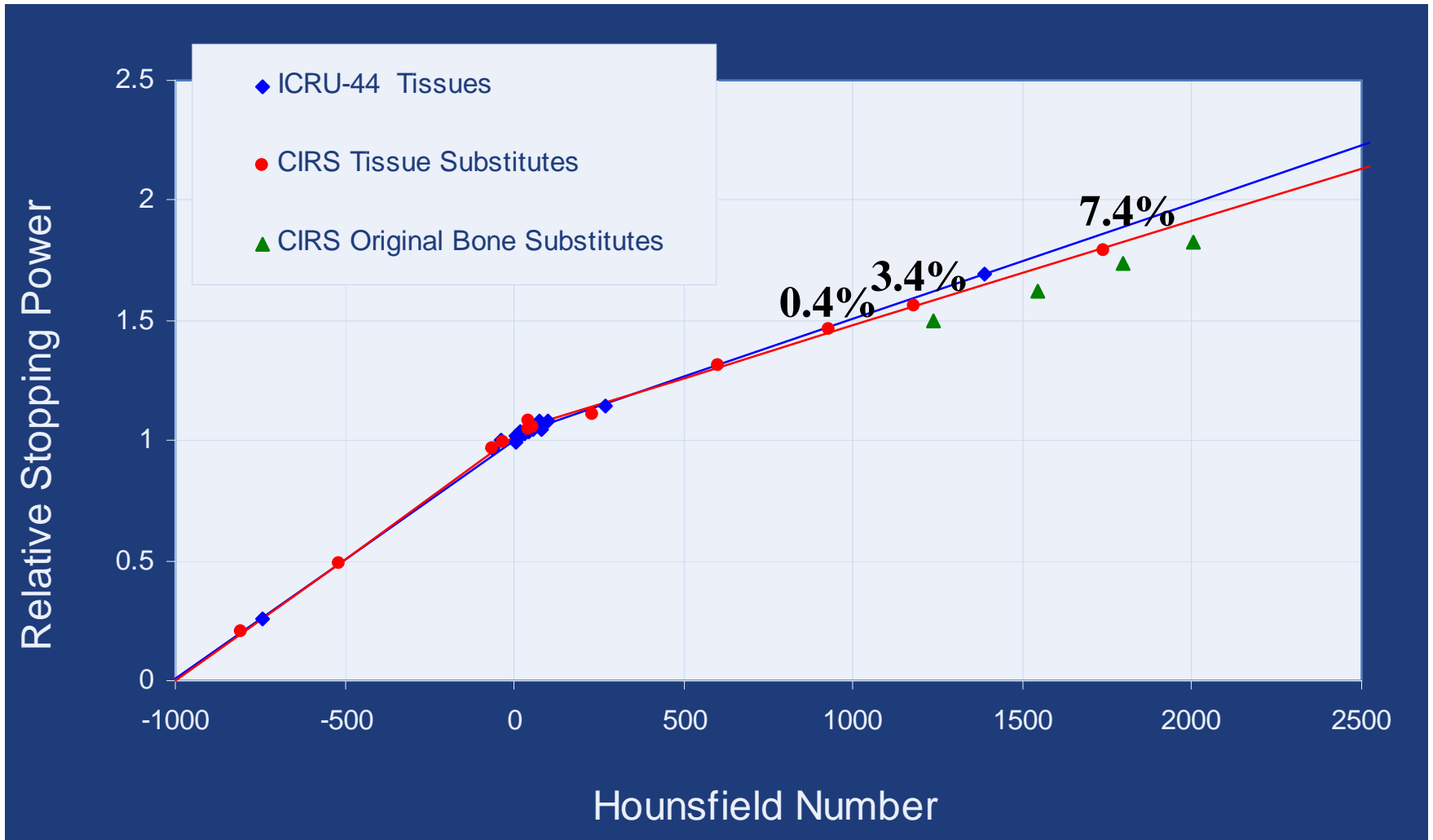


# Tissue equivalent materials





# Tissue equivalent materials







# Relative stopping power calculations

- RSP depends on physical density, elementary composition and mean excitation energy

$$RSP = \frac{\rho_m \sum_i^m \frac{\omega_i Z_i}{A_i} \ln\left(\frac{k(E)}{I_m}\right) - \beta^2}{\rho_w \sum_j^w \frac{\omega_j Z_j}{A_j} \ln\left(\frac{k(E)}{I_w}\right) - \beta^2}$$

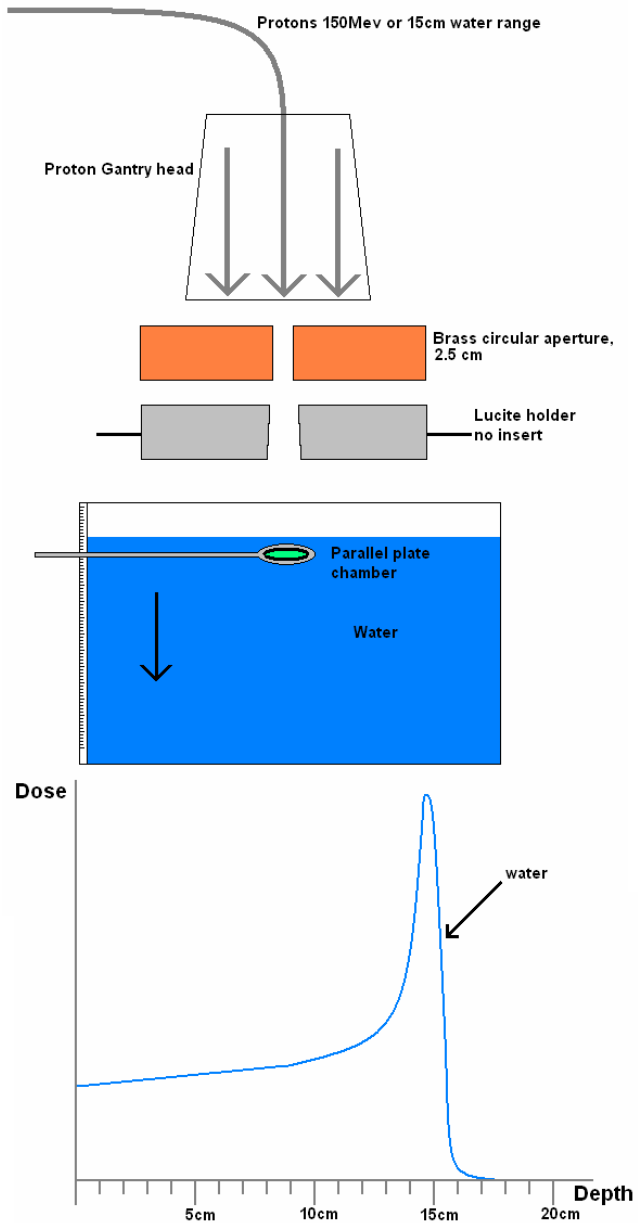
- Density and composition are difficult to find
- Mean excitation energy has small effect
- Example: Lucite

1% Density change  $\Rightarrow$  1% RSP

$I_{\text{meas}} = 74 \text{ eV}$ ,  $I_{\text{calc}} = 70.9 \text{ eV} \Rightarrow 4\% I \Rightarrow 0.7\% \text{ RSP}$

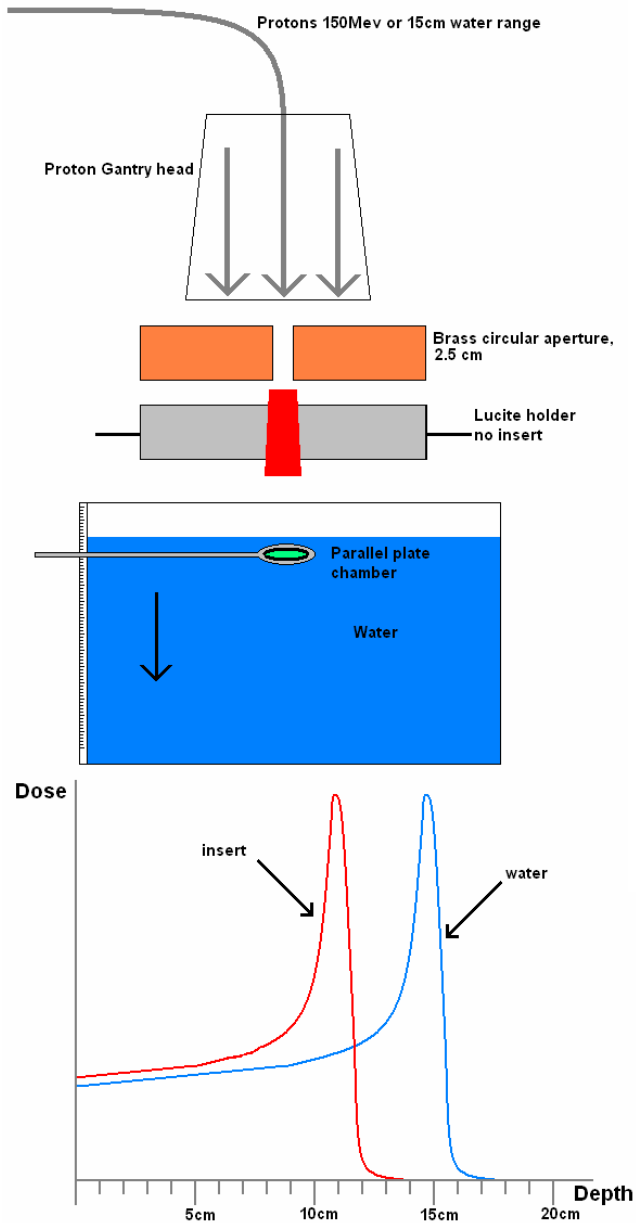


# Relative stopping power measurements



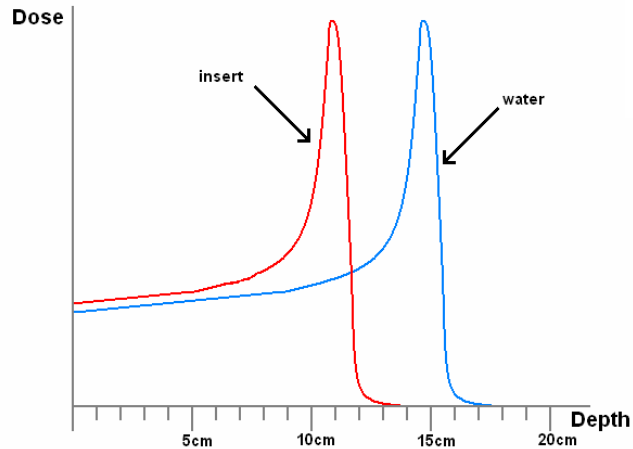
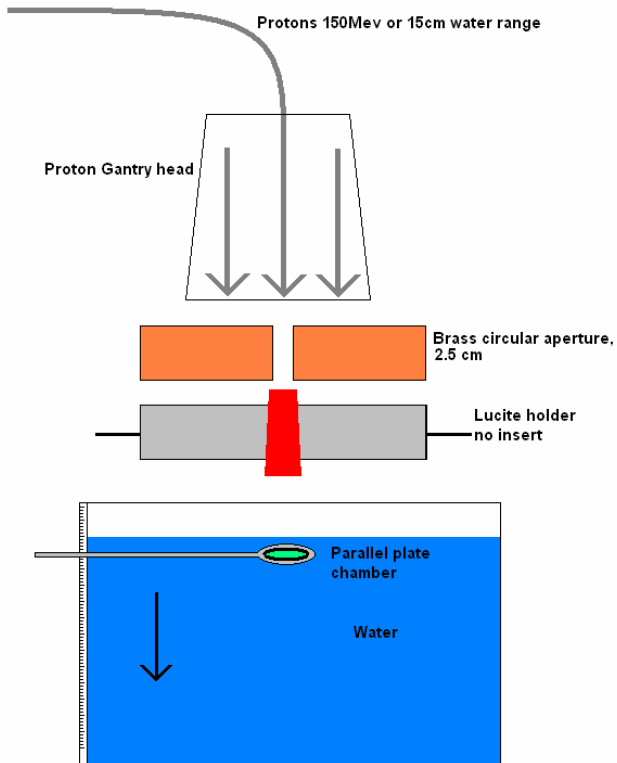


# Relative stopping power measurements





# Relative stopping power measurements



$$RSP = \frac{R_{water} - R_{insert}}{L_{insert}}$$



# Relative stopping power measurements

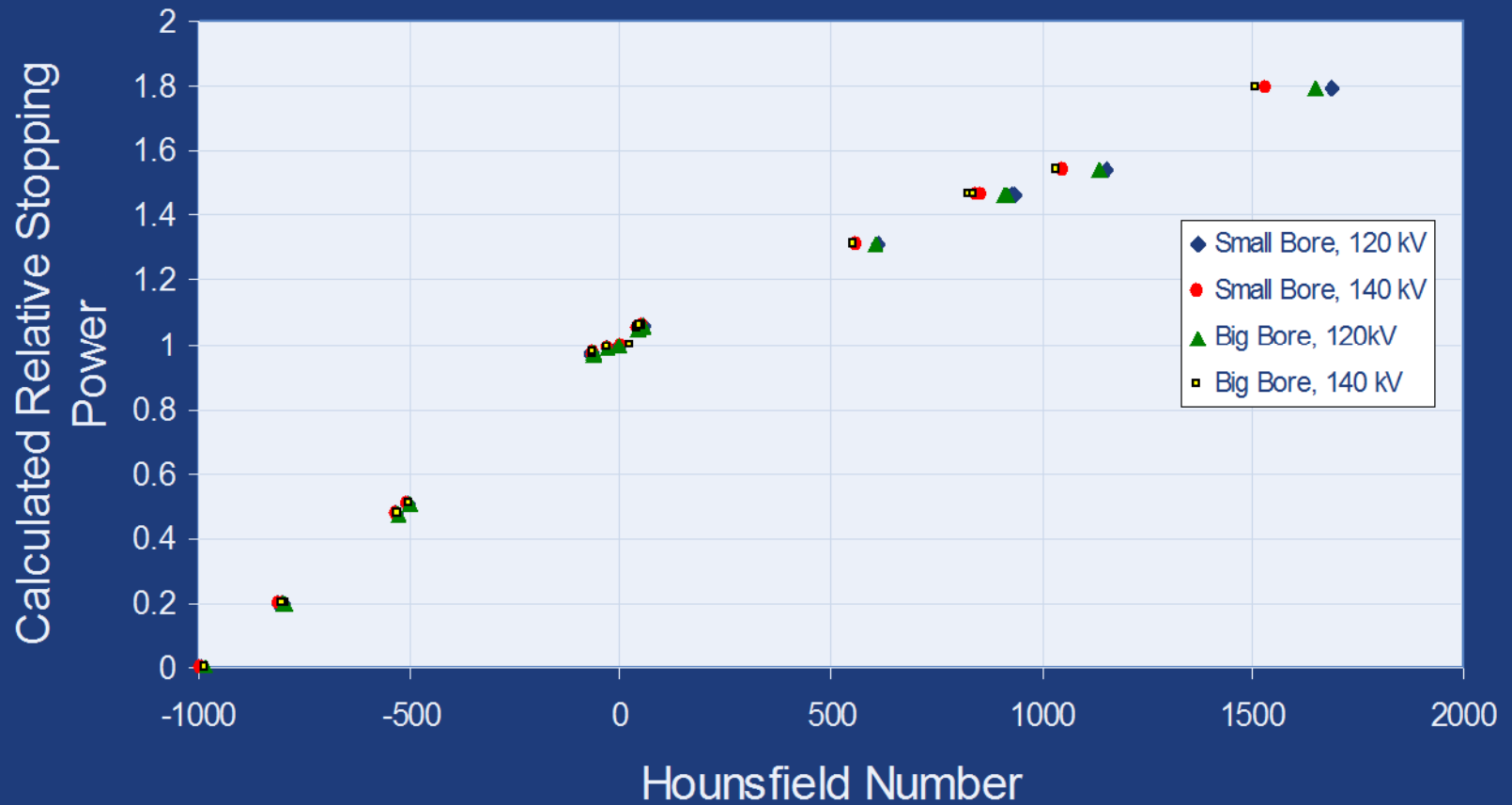
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- Measurements repeated few times
  - ❖ Various proton ranges, airgaps, etc
- Proton range (  $R_{water} - R_{insert}$  ) for all full inserts within **0.5 mm** for all measurements
- Assuming 0.1 mm uncertainty in the insert length  $L_{insert}$
- Uncertainty in RSP for all inserts <1%
  - ❖ Inhale Lung (0.2 g/cm<sup>3</sup>): 0.62% RSP
  - ❖ Muscle (1.06 g/cm<sup>3</sup>): 0.63% RSP
  - ❖ Bone (2.06 g/cm<sup>3</sup>): 0.65% RSP
- Max difference between measurement and calculation: **0.7%**



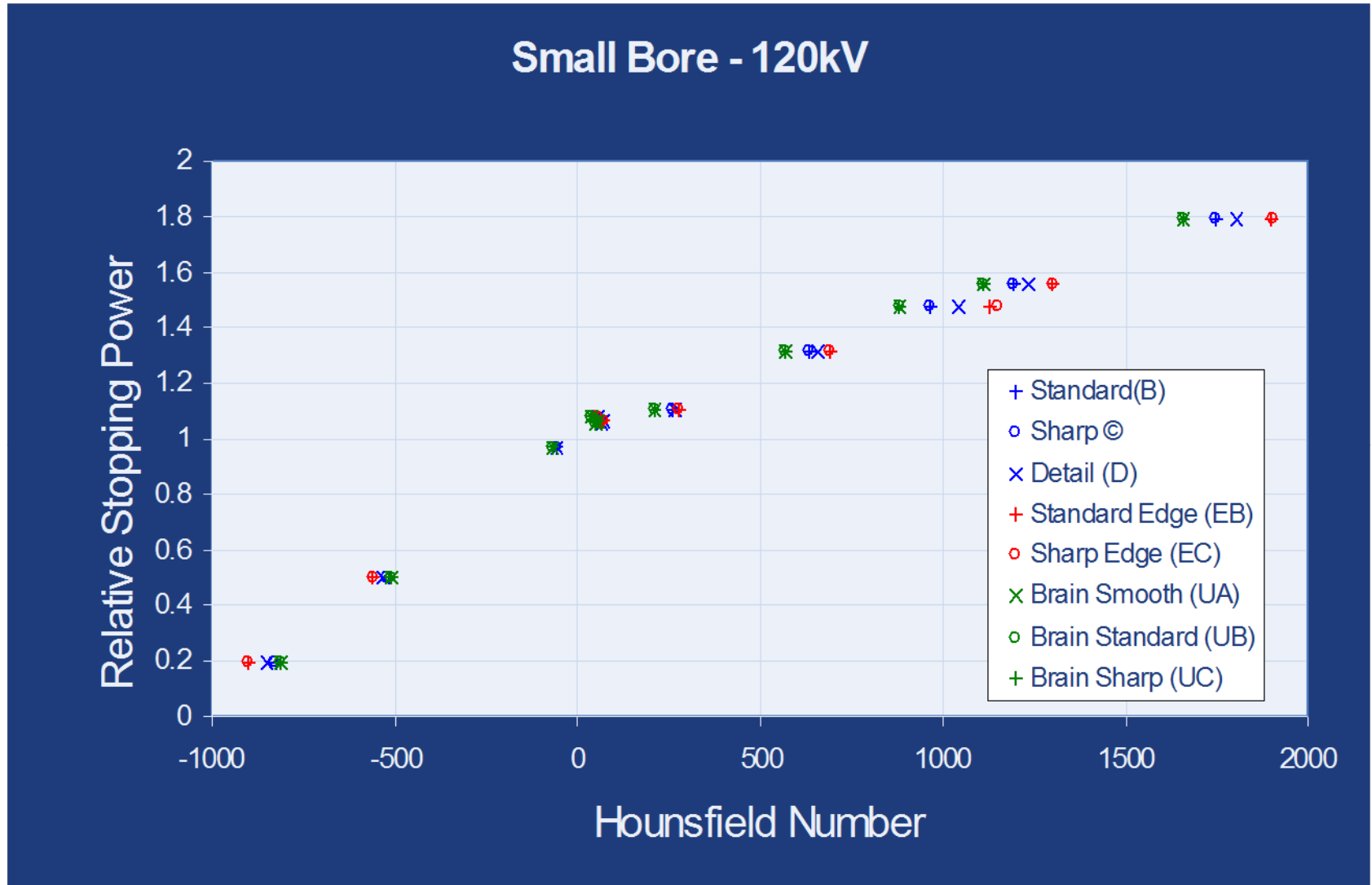
# Hounsfield number – Scanner and energy

Mean (all phantoms and positions) Hounsfield number



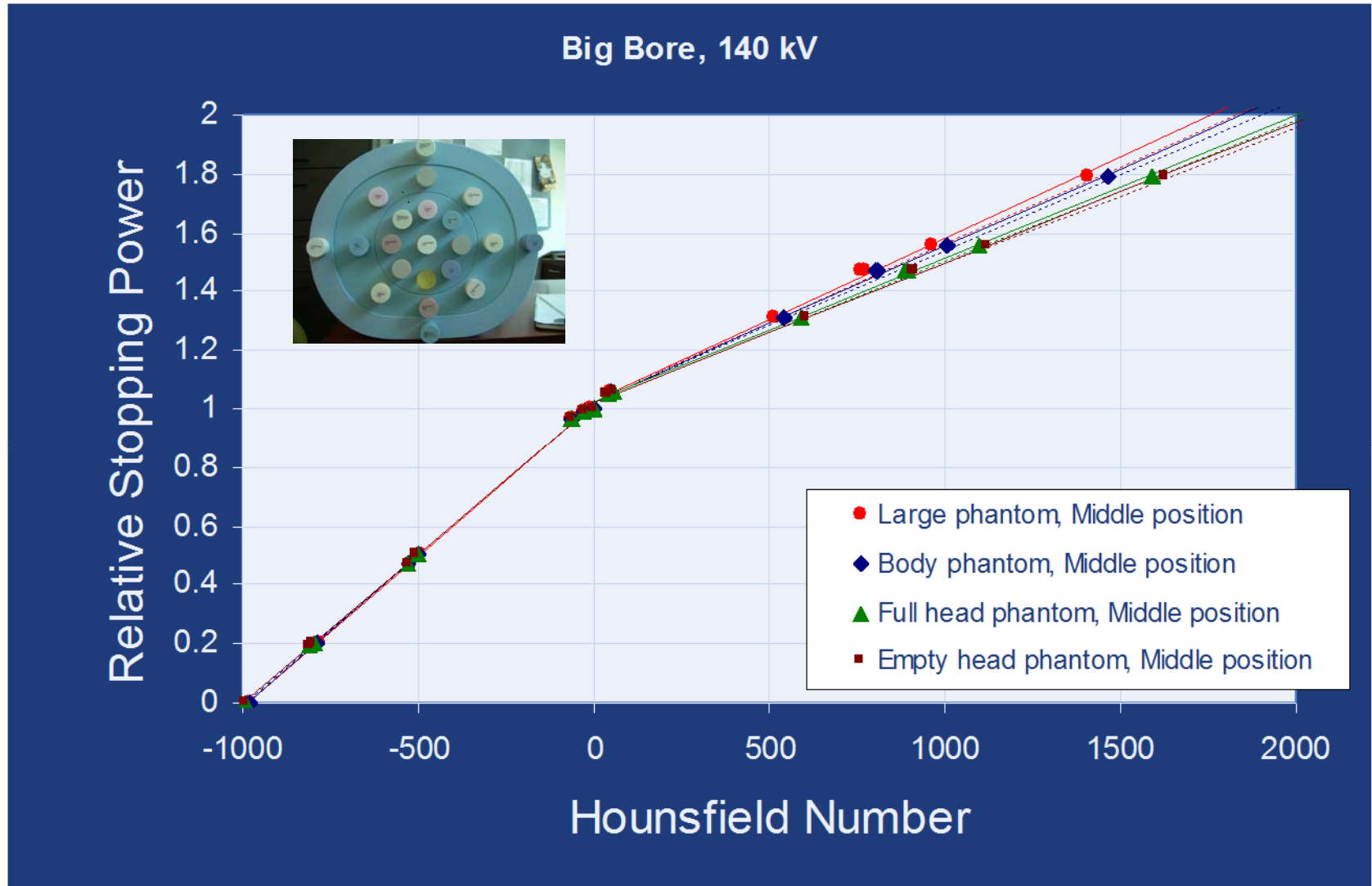


# Hounsfield number – Recon





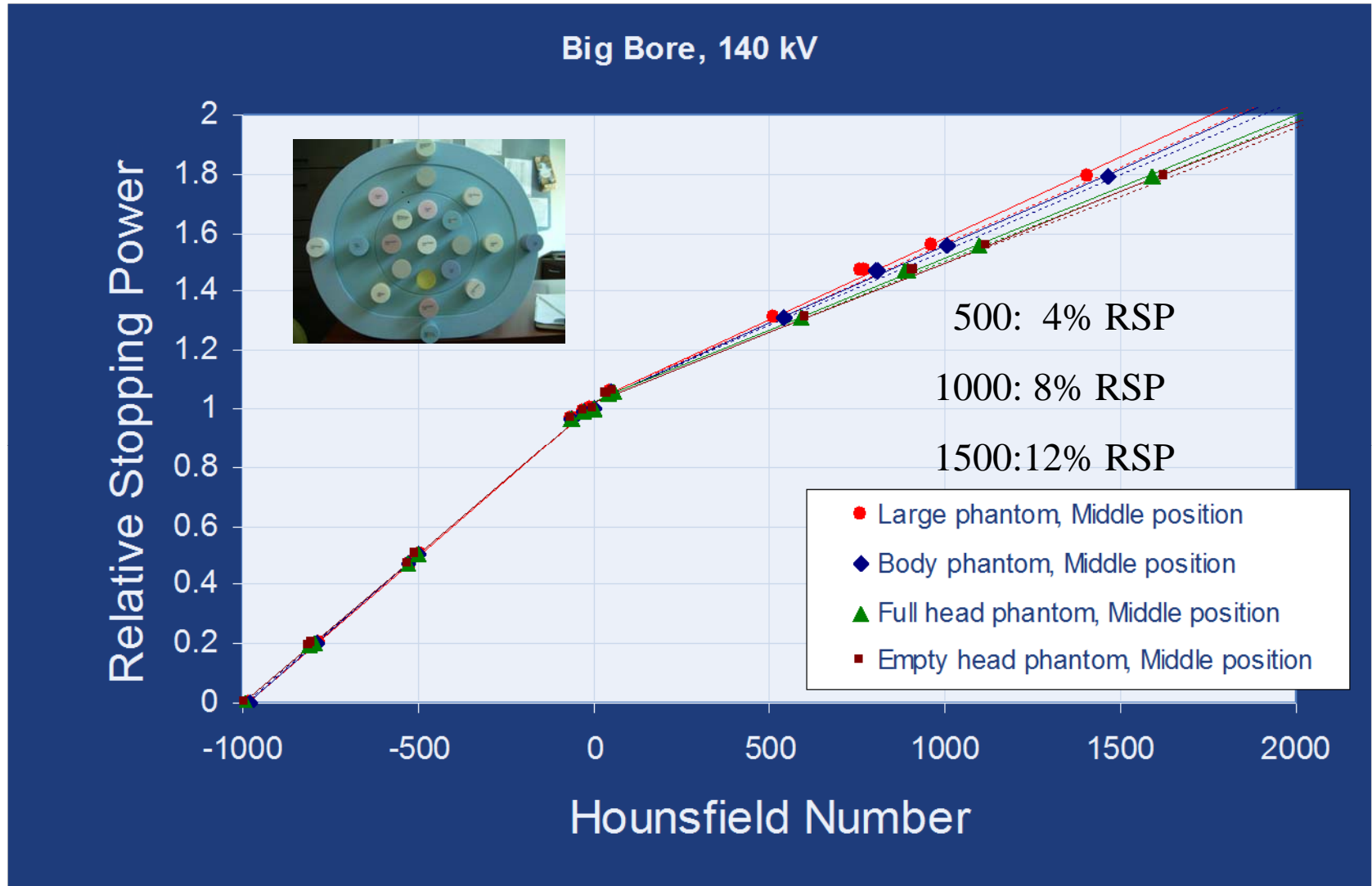
# Hounsfield number – Phantom size





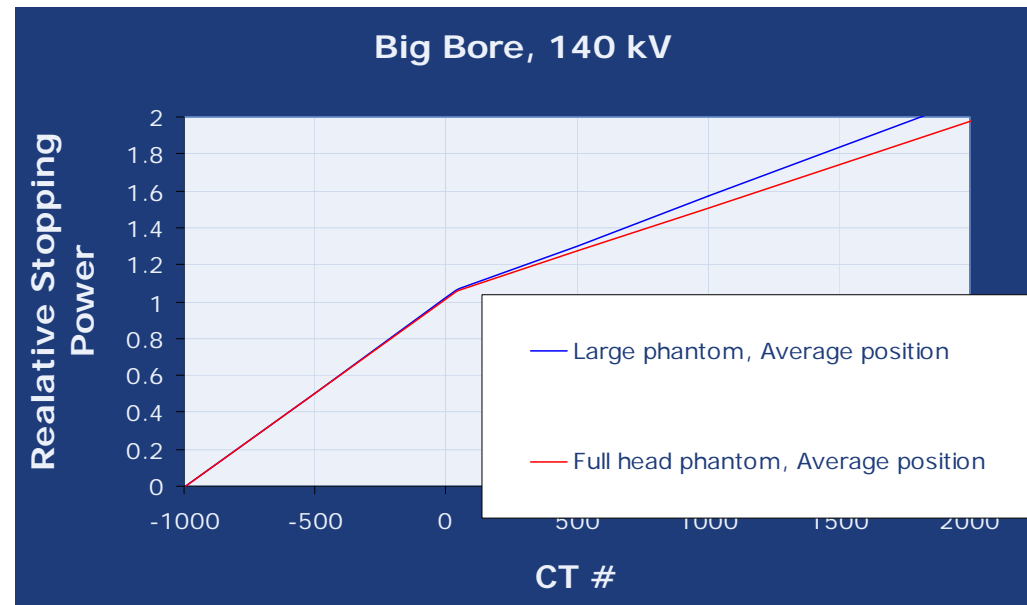


# Hounsfield number – Phantom size

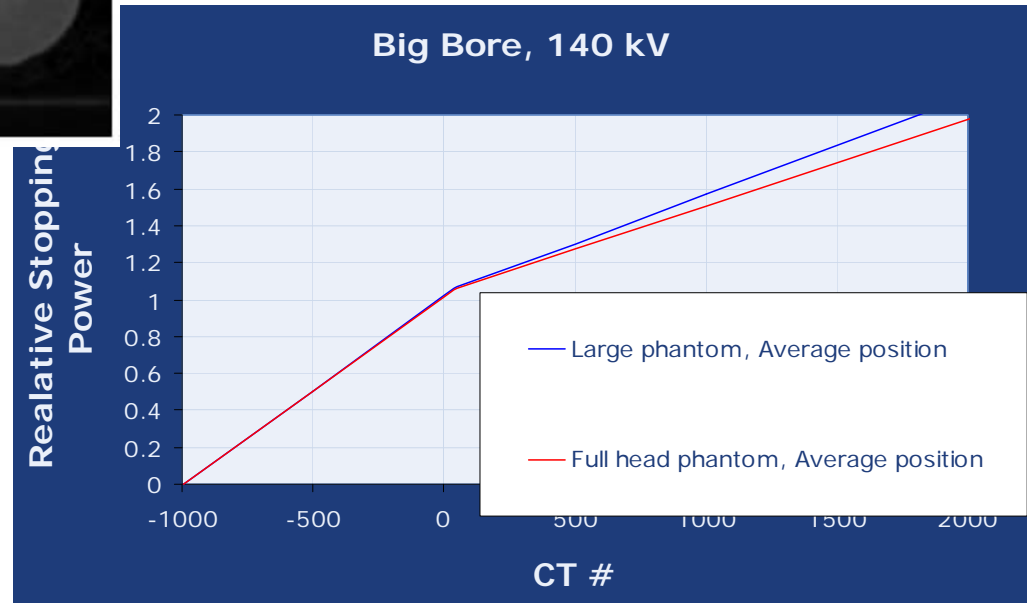
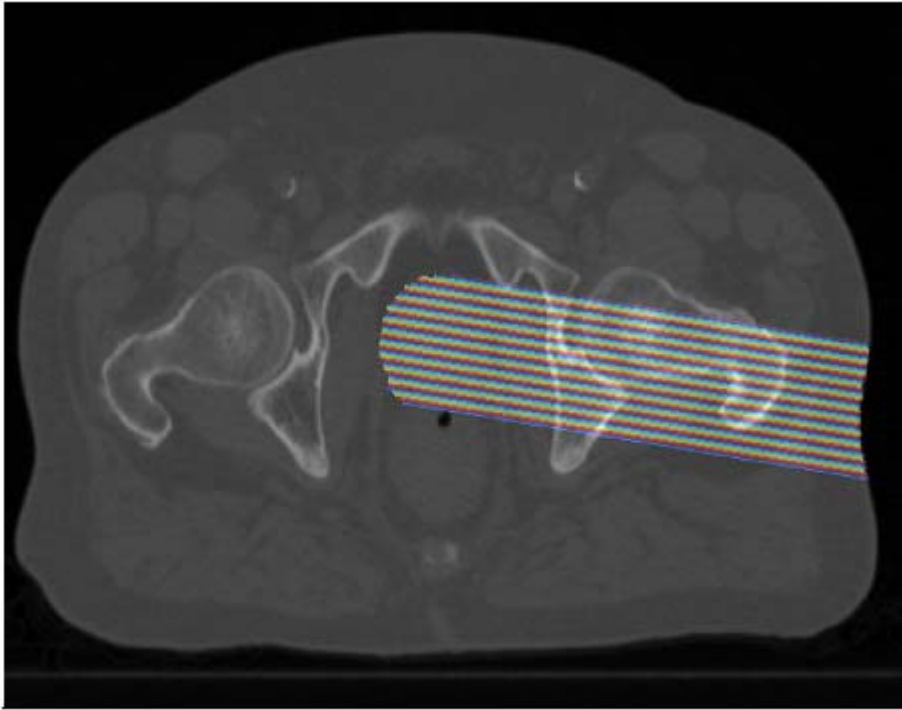




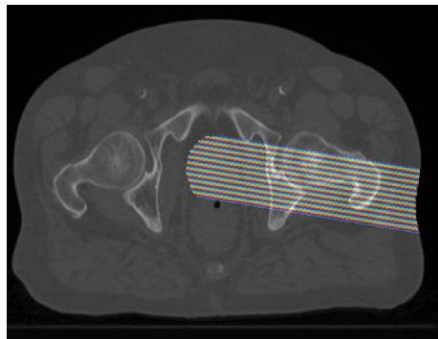
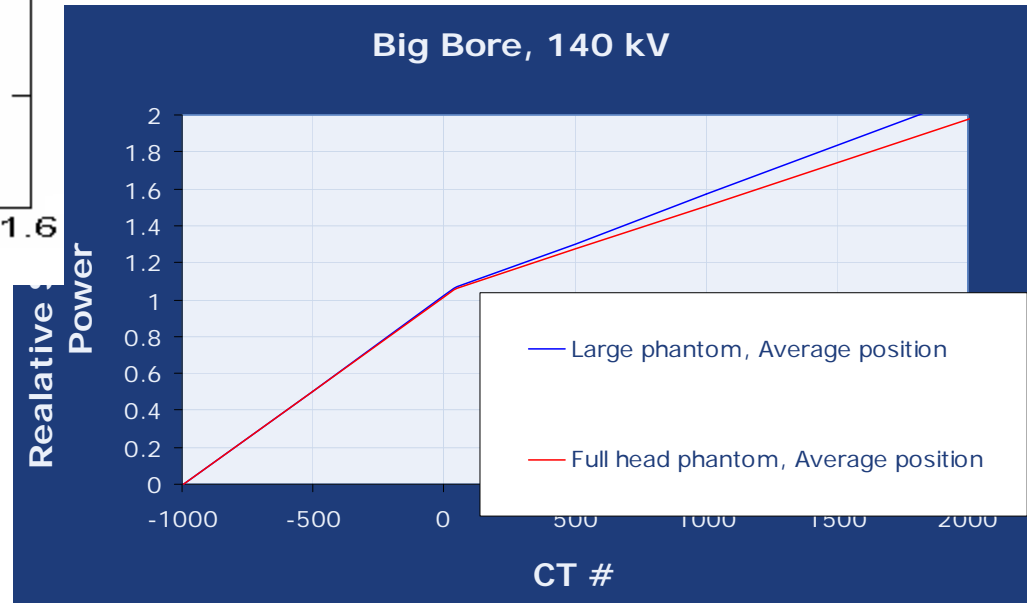
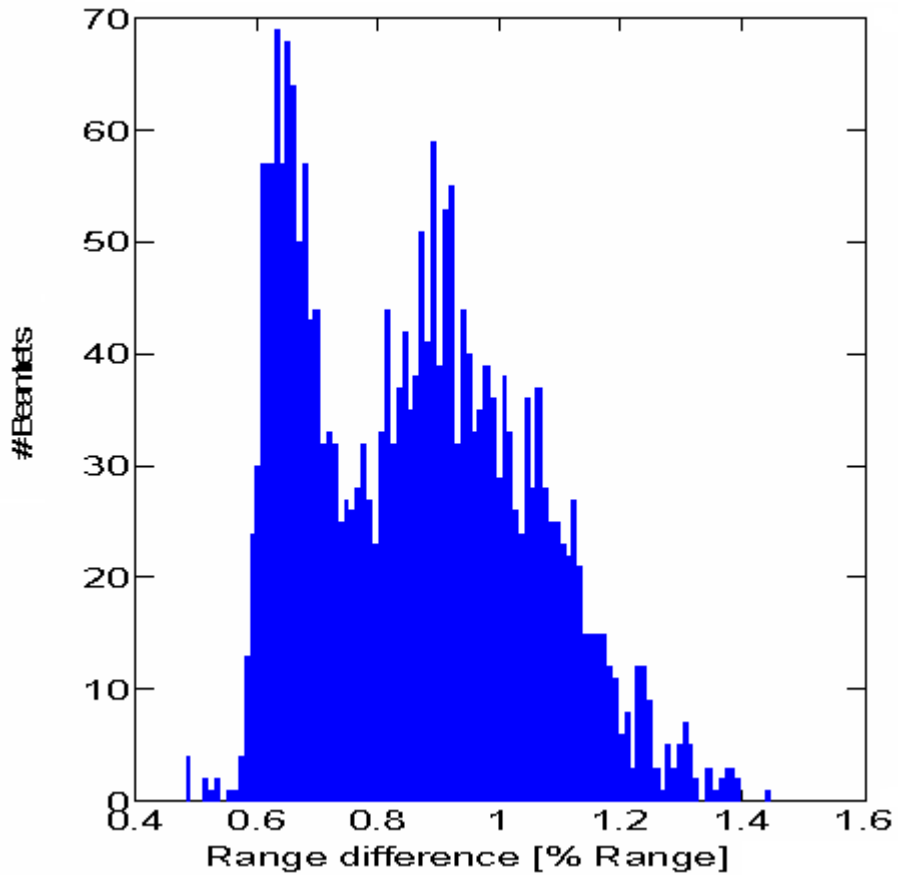
# Calibration phantom size effect on proton range



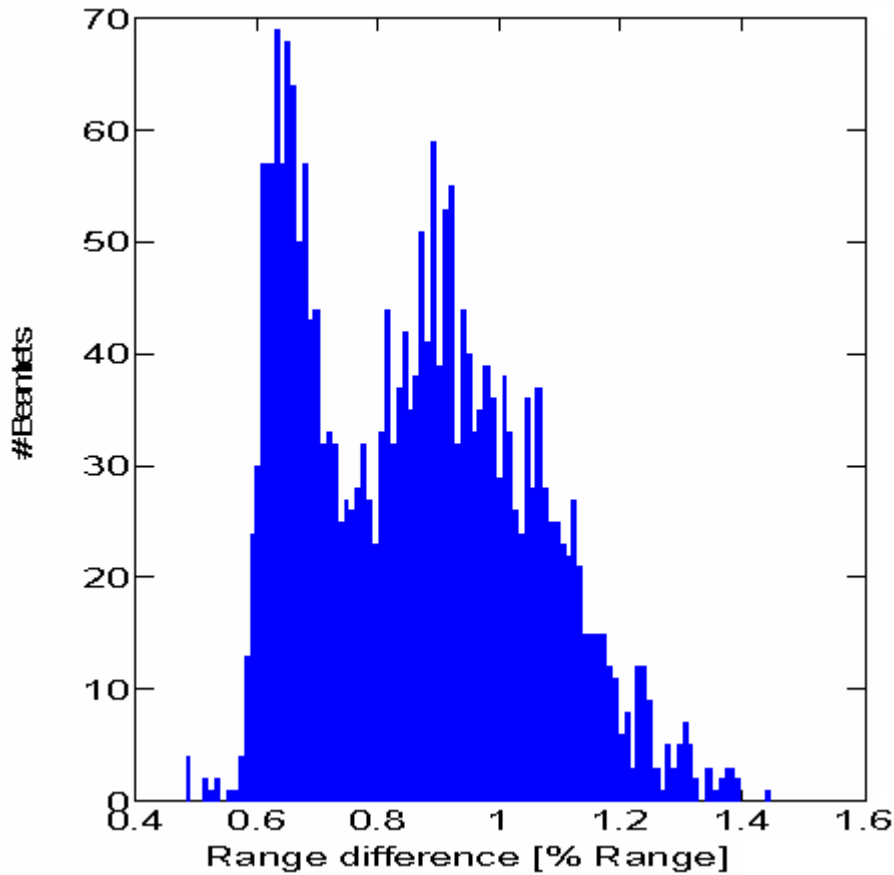
# Calibration phantom size effect on proton range



# Calibration phantom size effect on proton range



# Calibration phantom size effect on proton range



Range difference [%]

mean

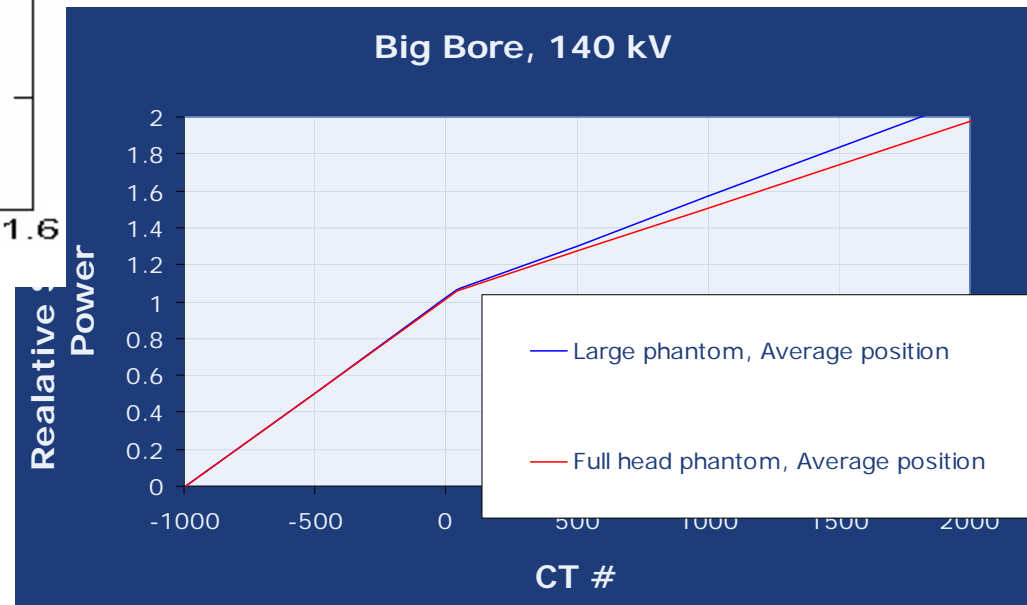
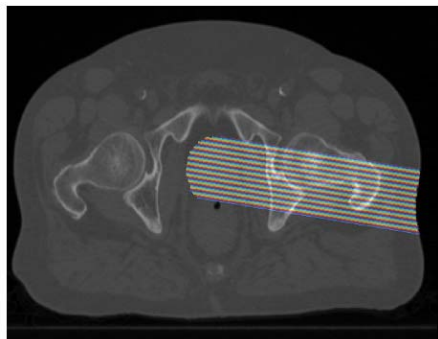
max

**0.9**

**1.5**

(2.1 mm)

(3.5 mm)

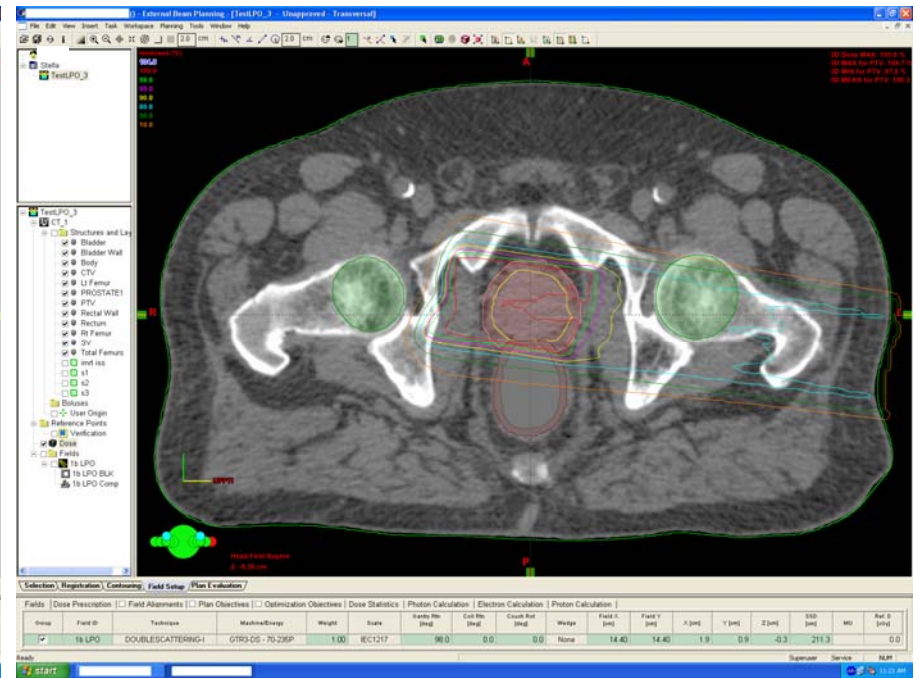
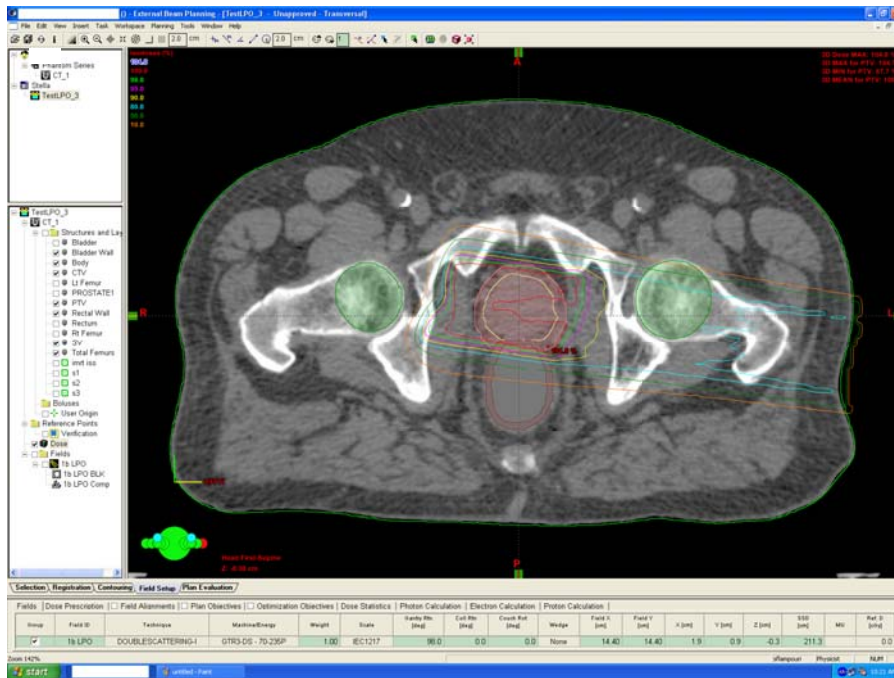




# Calibration phantom size effect on dosemap

Calibration curve based on large body phantom

Calibration curve based on head phantom

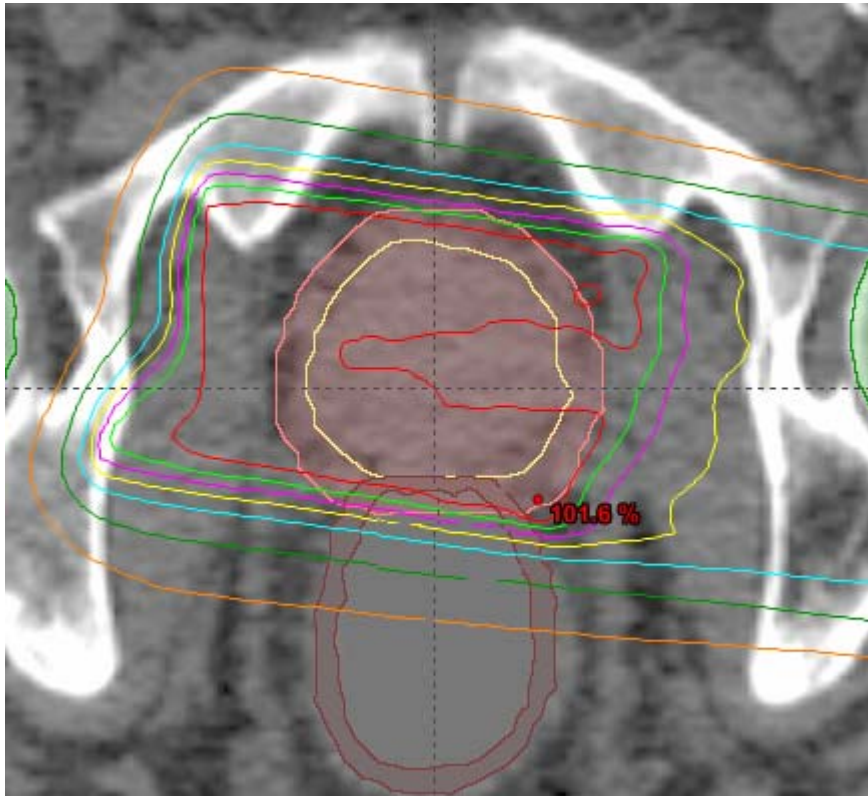




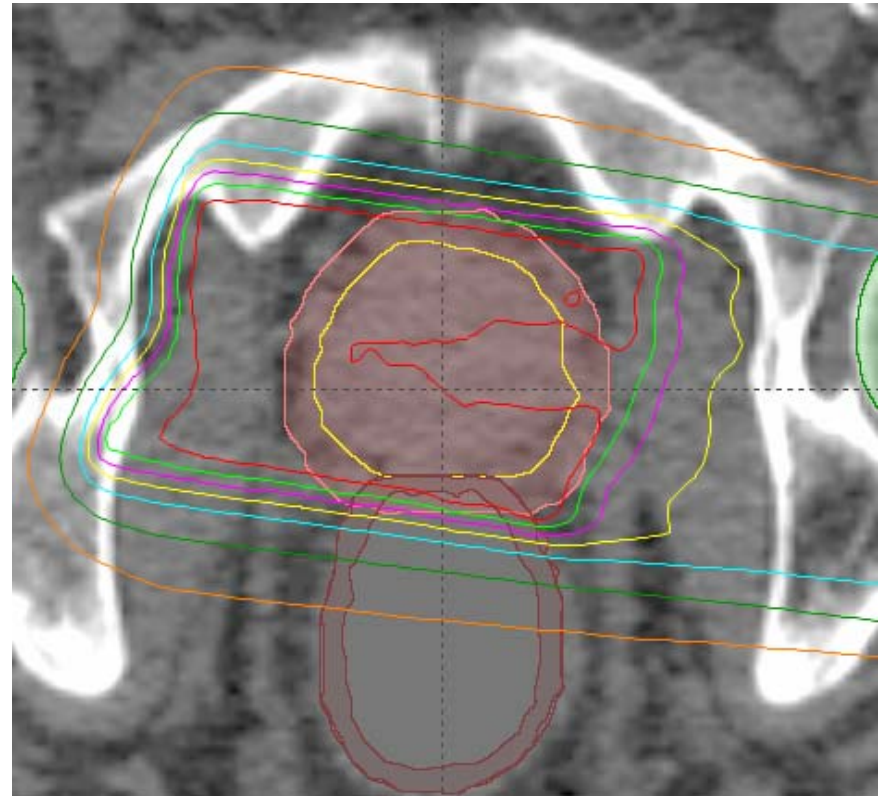
# Calibration phantom size effect on dosemap

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Calibration curve based on large body phantom

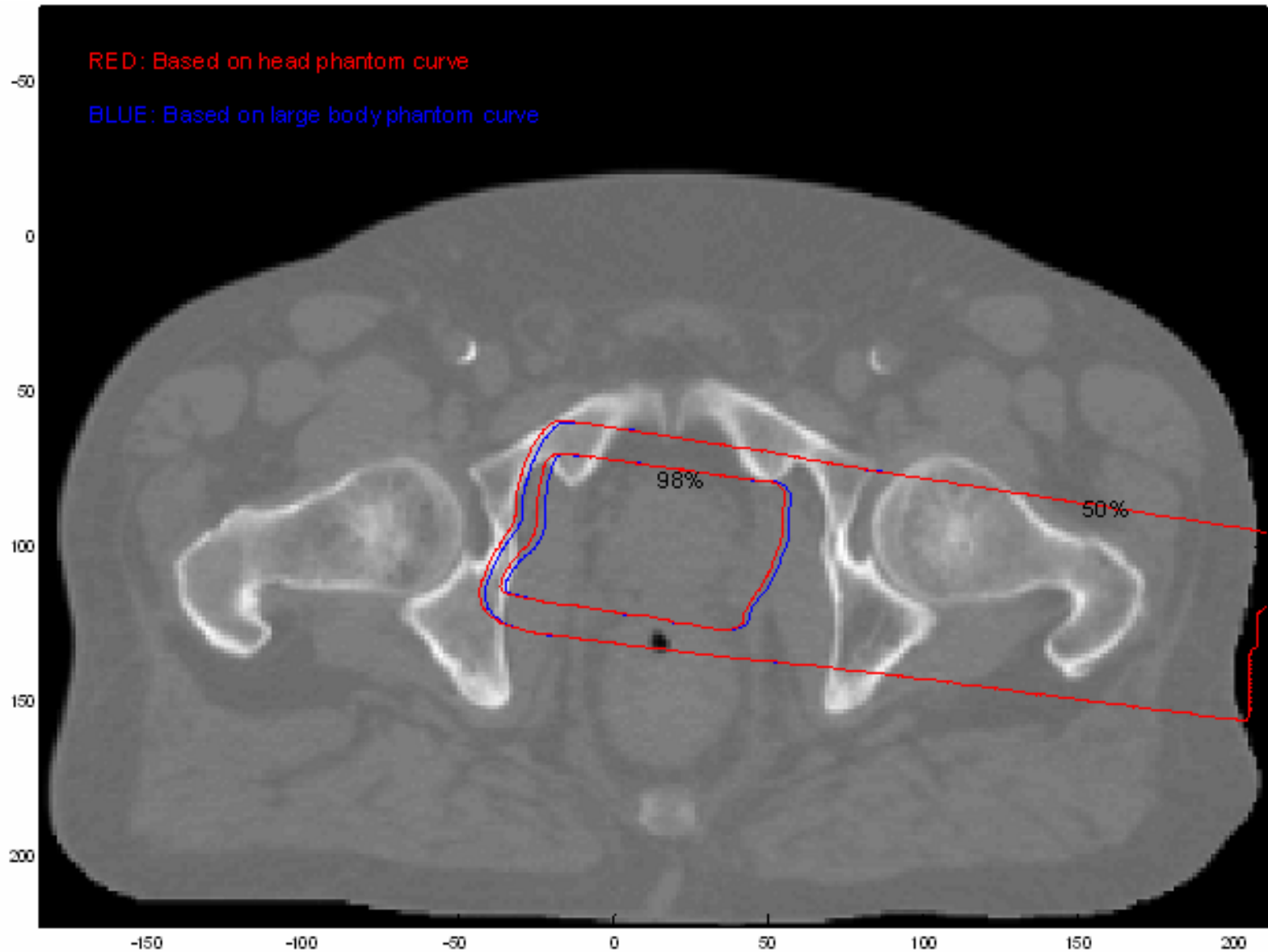


Calibration curve based on head phantom





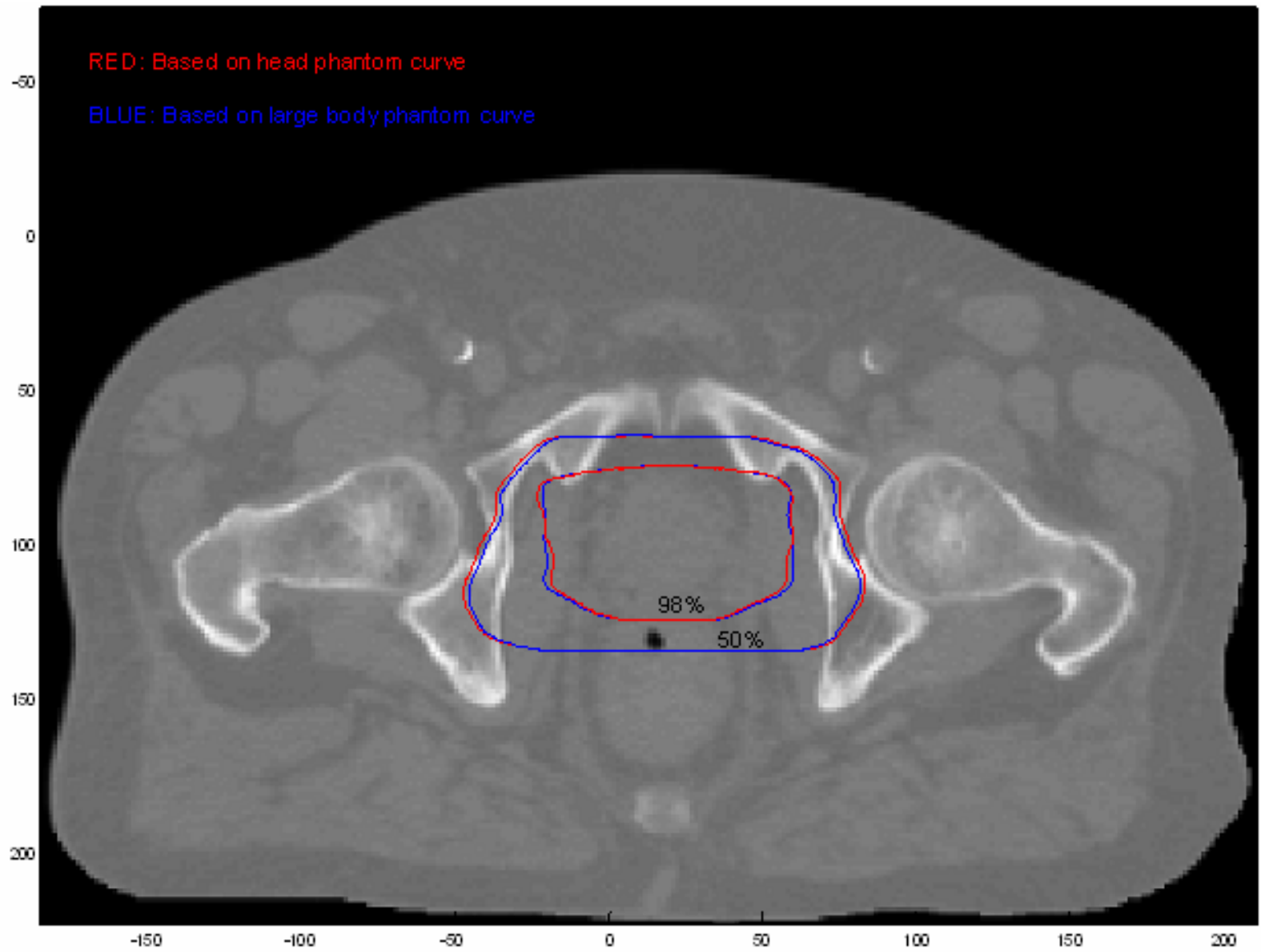
# Calibration phantom size effect on dosemap





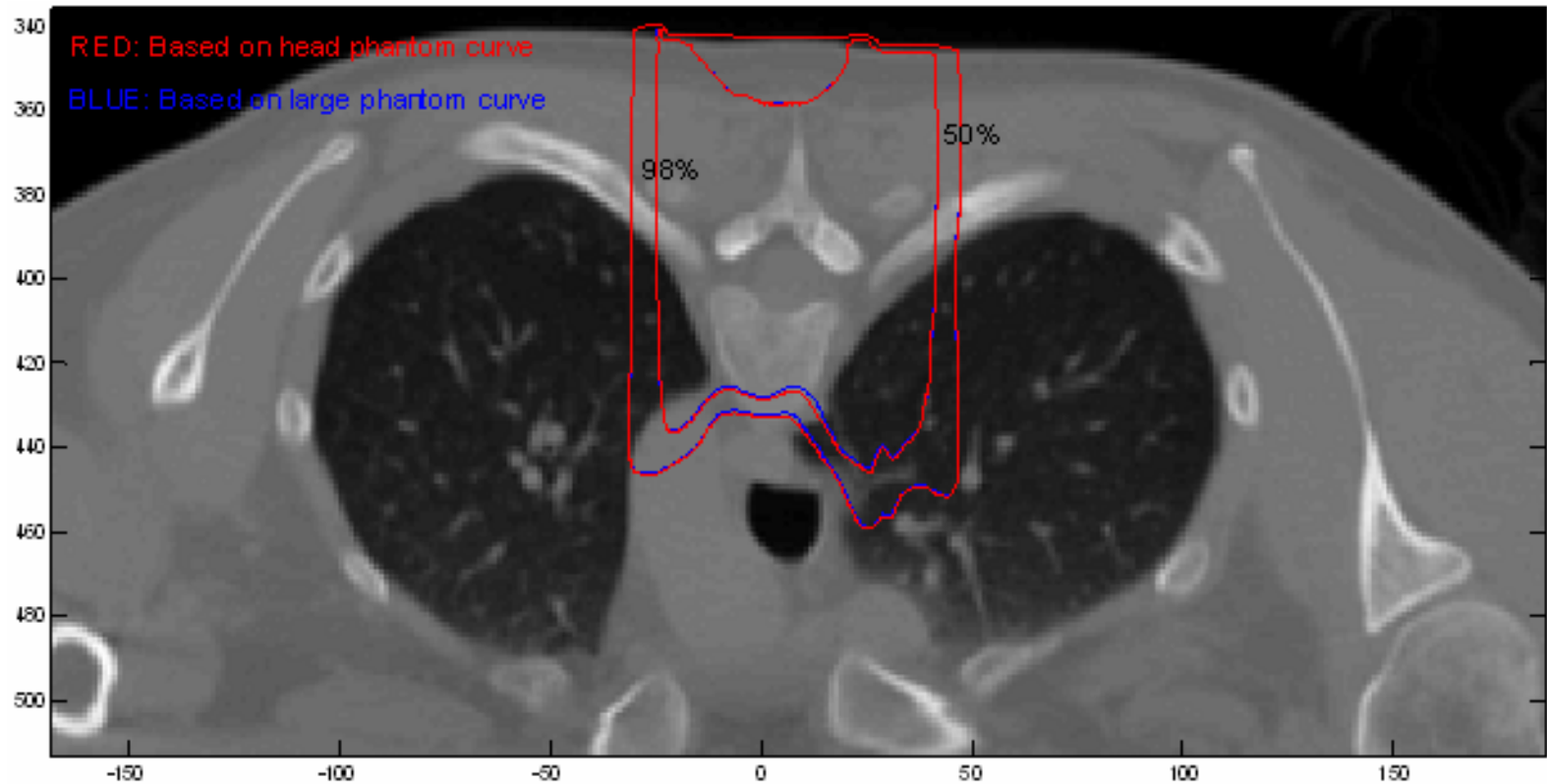


# Calibration phantom size effect on dosemap



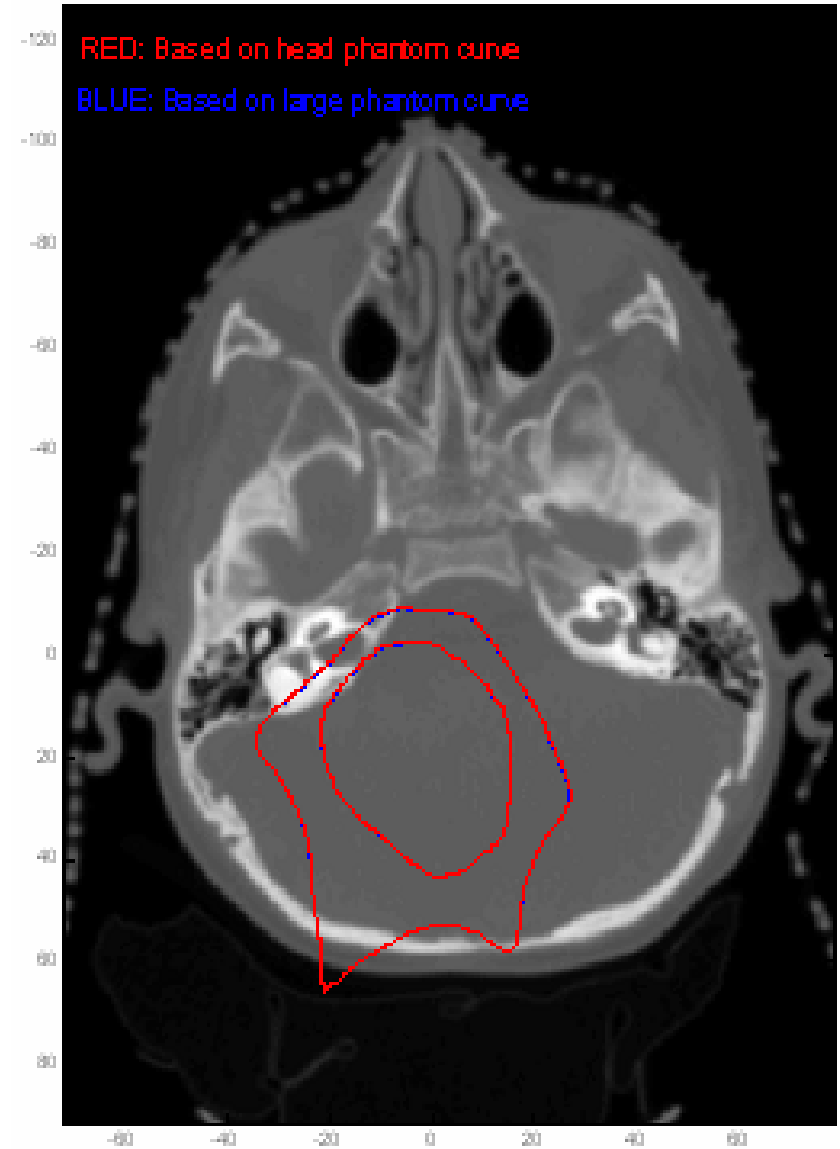
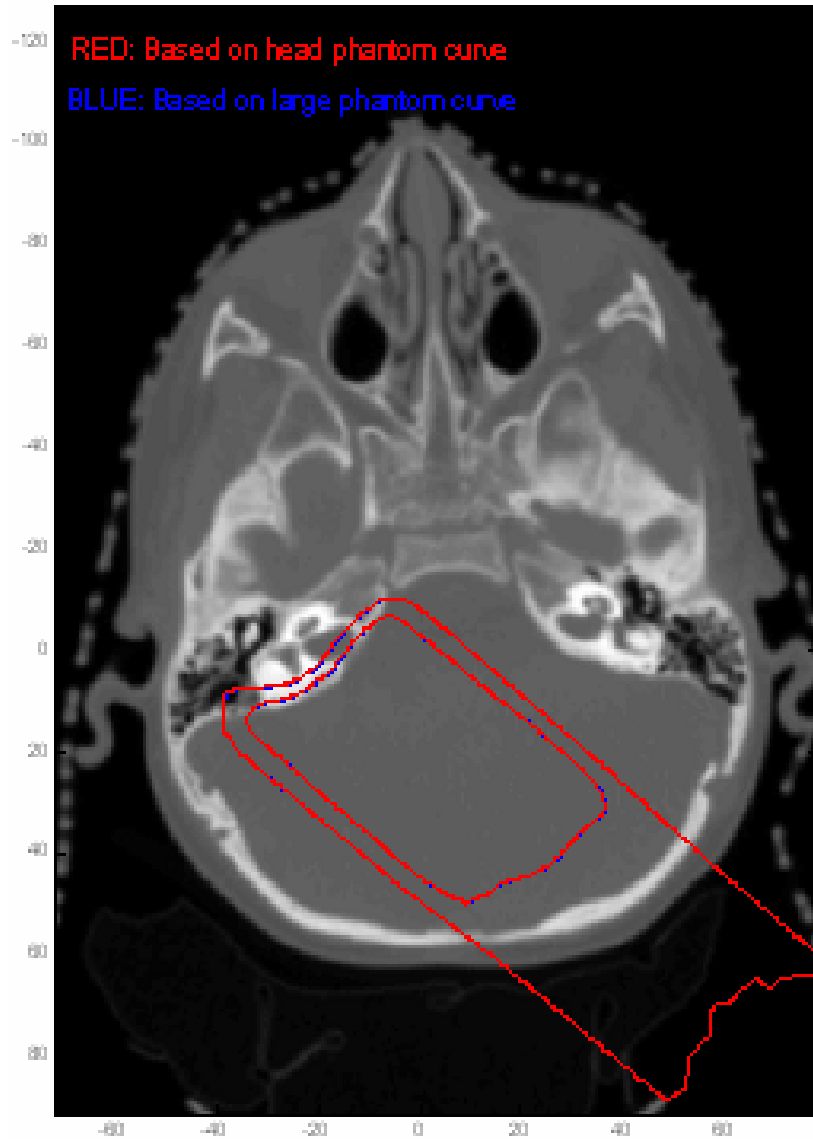


# Calibration phantom size effect on dosemap



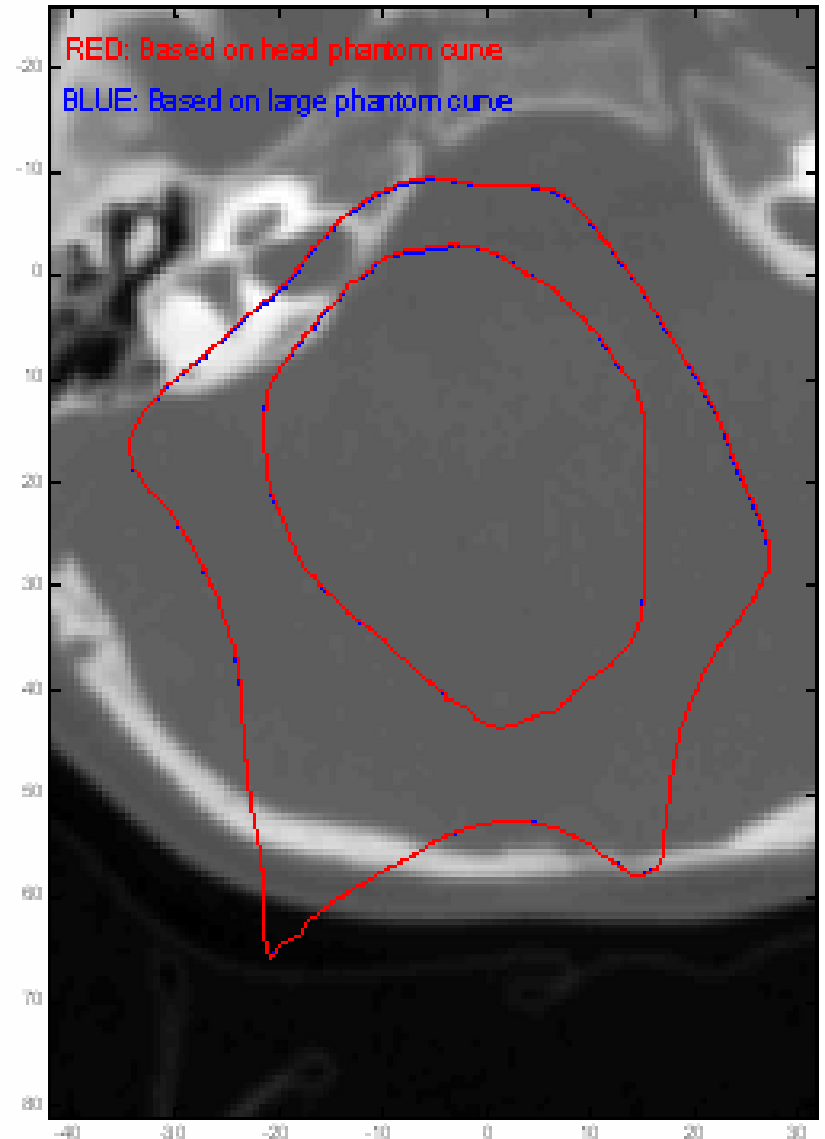
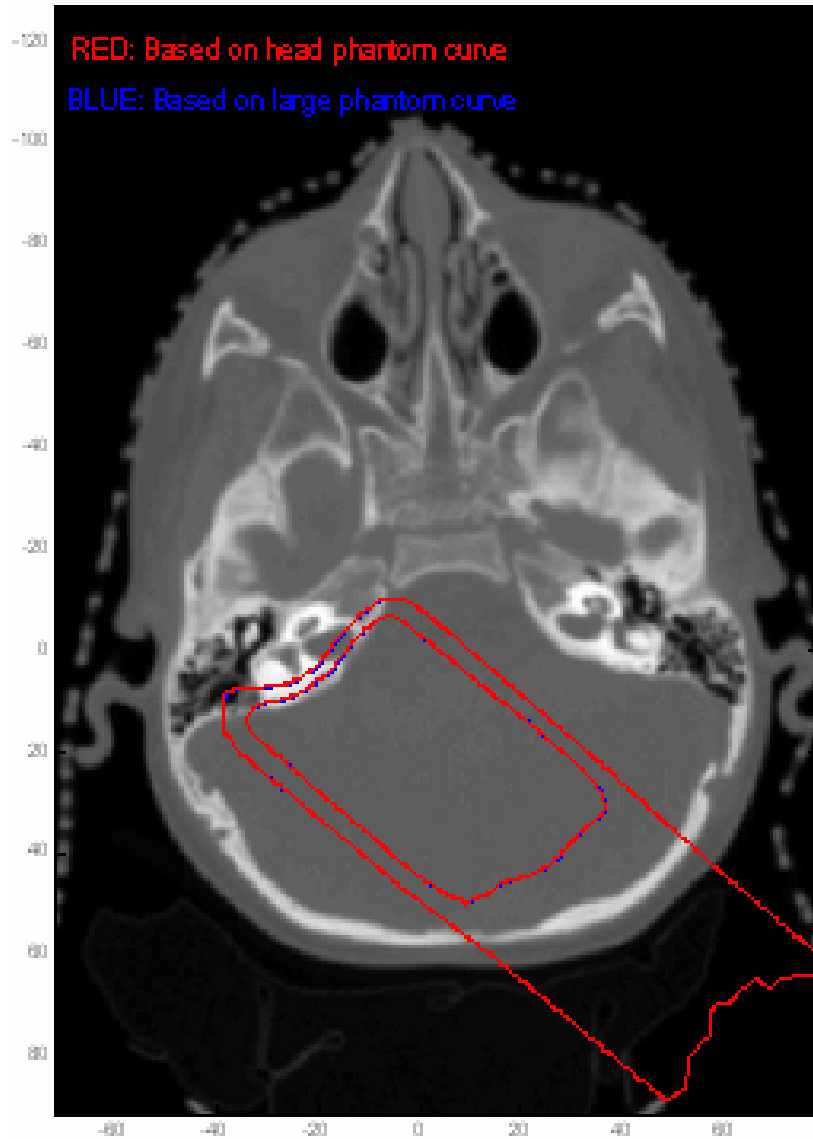


# Calibration phantom size effect on dosemap





# Calibration phantom size effect on dosemap





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- We investigated parameters that influence the CT# - relative proton stopping power conversion curve
  - We found that variation on the CT# due to beam hardening effects has a major contribution on the uncertainty of the calibration curve
  - Depending on the size of the phantom used for the creation of the curve the water equivalent range for a prostate posterior oblique field could vary by 3.5mm
  - This effect was less severe for other cases