Physical Aspects of Radiation Therapy Exposures of Relevance to Second Cancers

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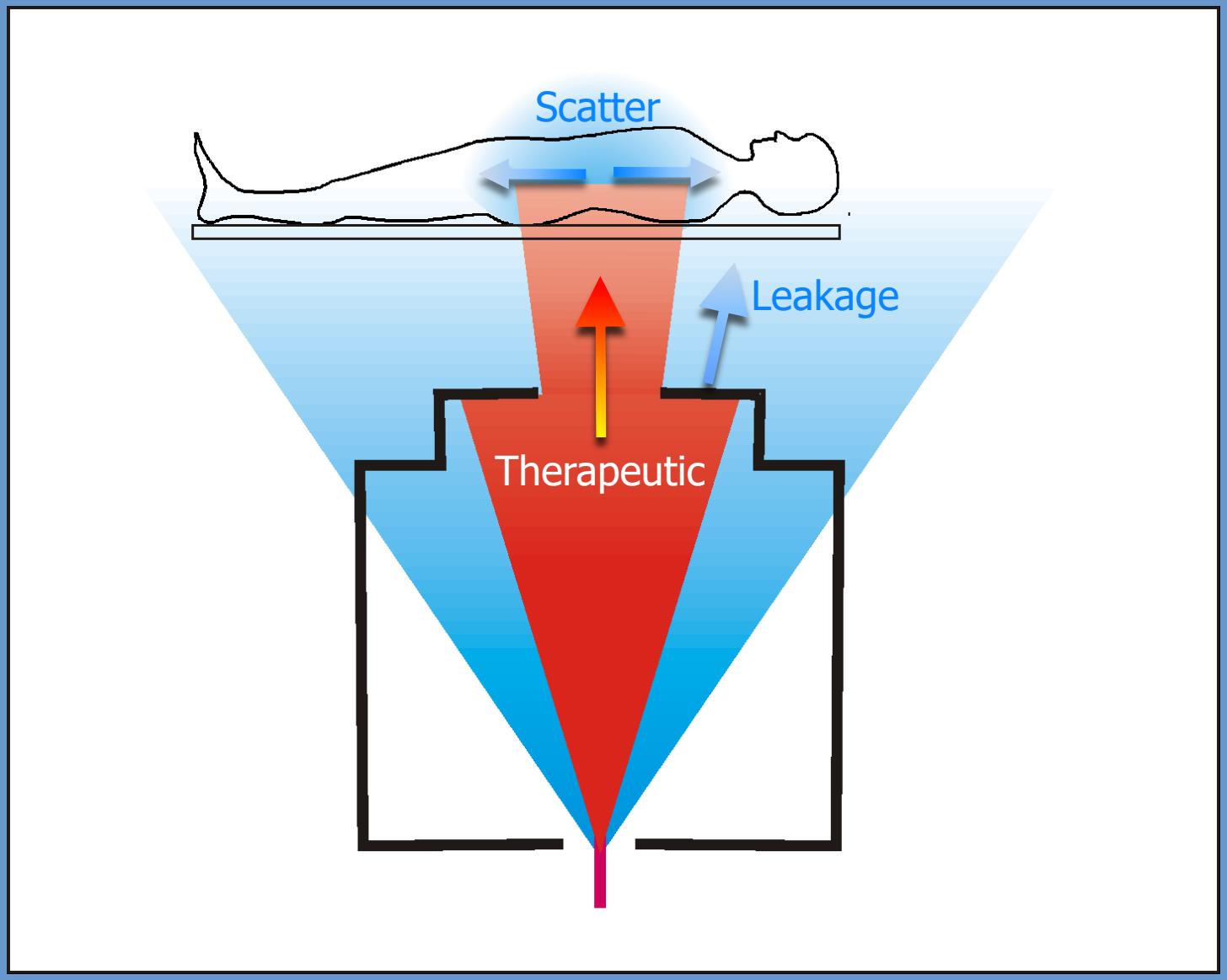
Acknowledgements

- Lydia Jagetic, Chris Schneider, John Eley, Laura Rechner, Rui Zhang, Phil Taddei, Yuanshui Zheng, and many other former trainees and colleagues

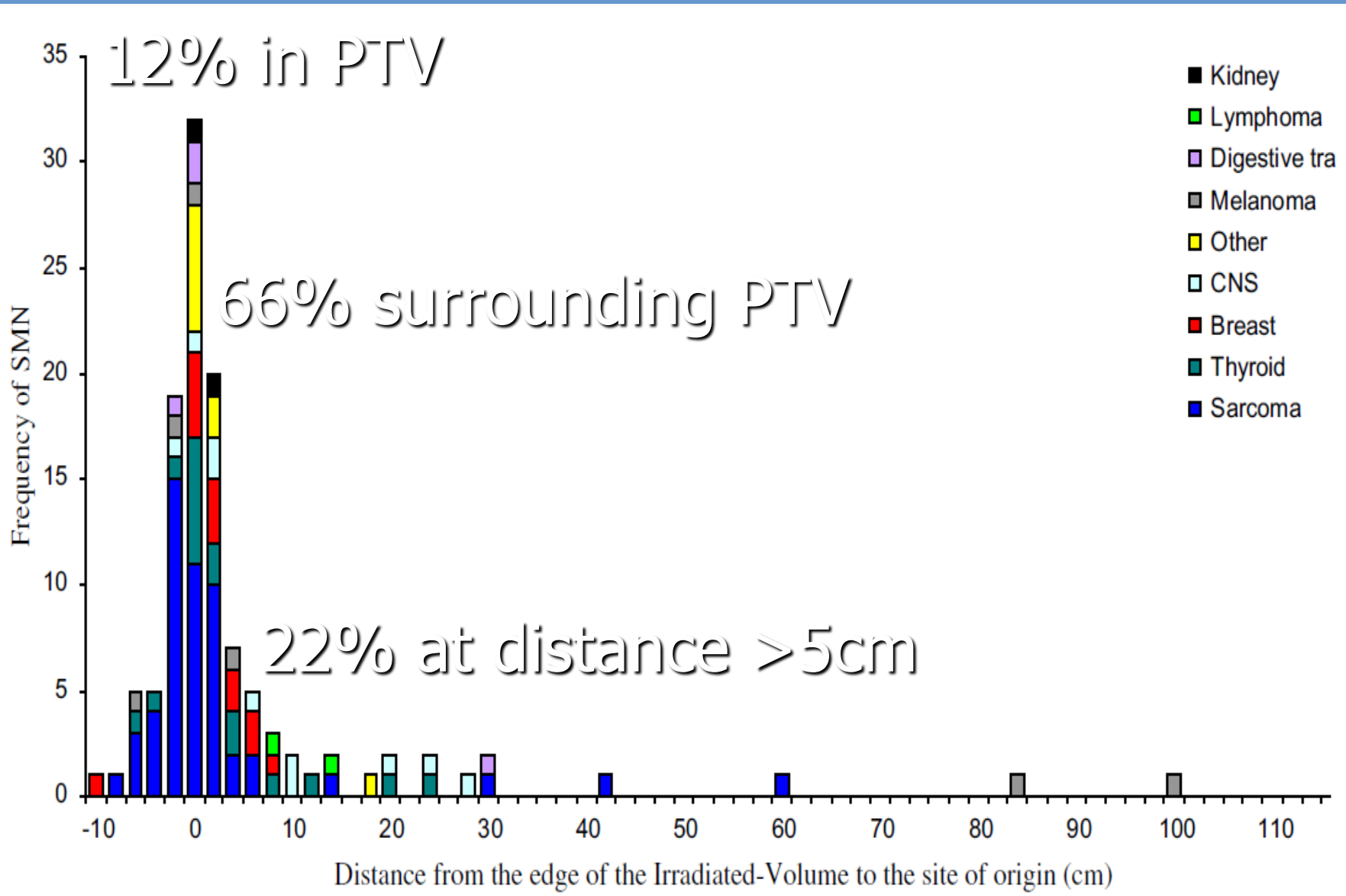
- Conference organizers

Radiation: Therapeutic, Scatter, Leakage



Newhauser and Durante, Newhauser WD, Durante M. Assessing the risk of second malignancies after modern radiotherapy. Nat Rev Cancer 11(6):438-48, 2011

Where Do Second Cancers Develop?



Diallo et al Int. J. Radiation Oncology Biol. Phys., Vol. 74, No. 3, pp. 876–883, 2009

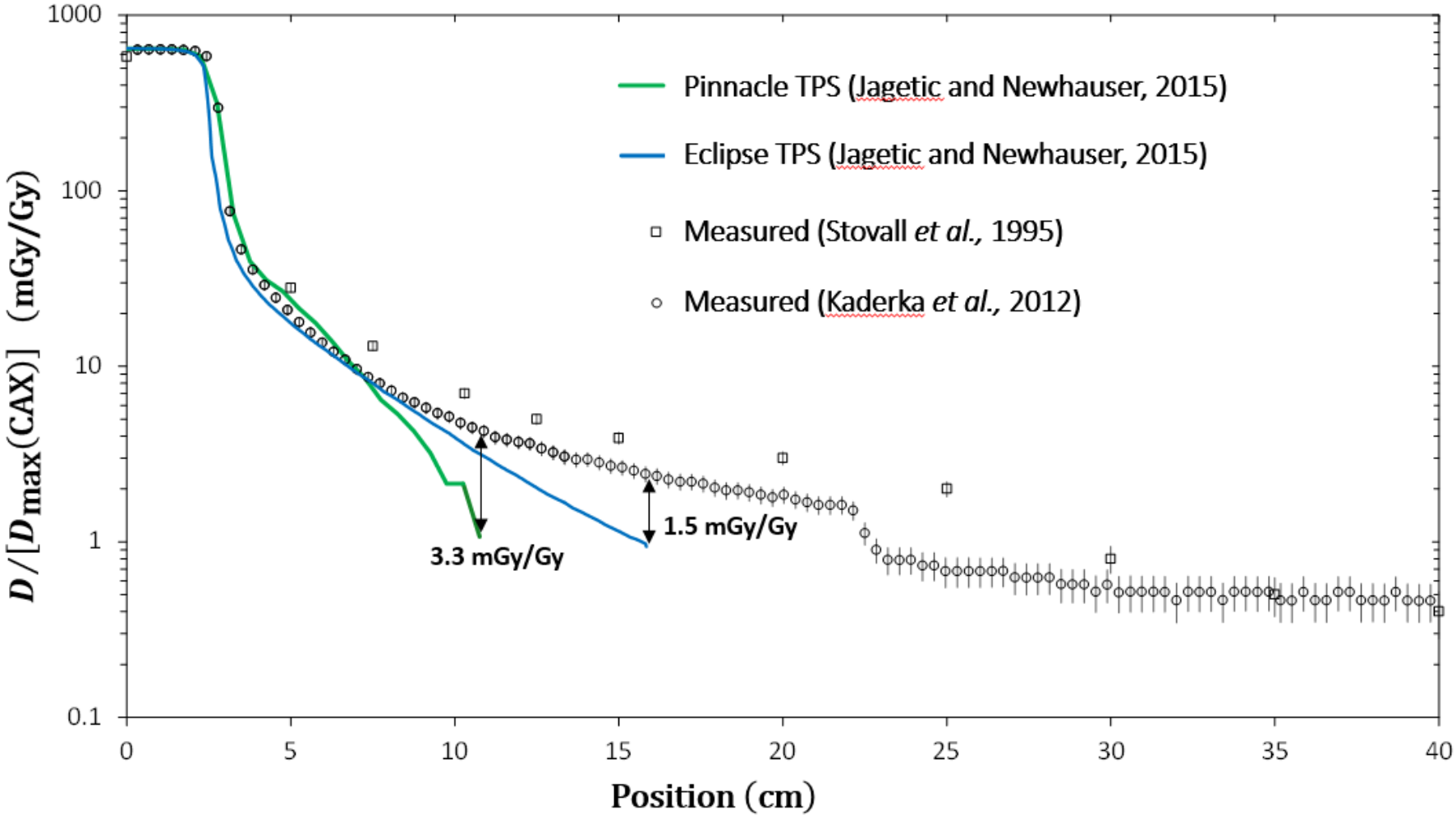
Biologic Uncertainties are Huge. Why Worry About Physical Aspects?

"A large number of studies involving ionizing radiation … have increased our general knowledge of risk… Many studies lack the sample size and high-quality dosimetry that are necessary for the precise estimate of risk as a function of dose …"

NAS BEIR VII (2006)

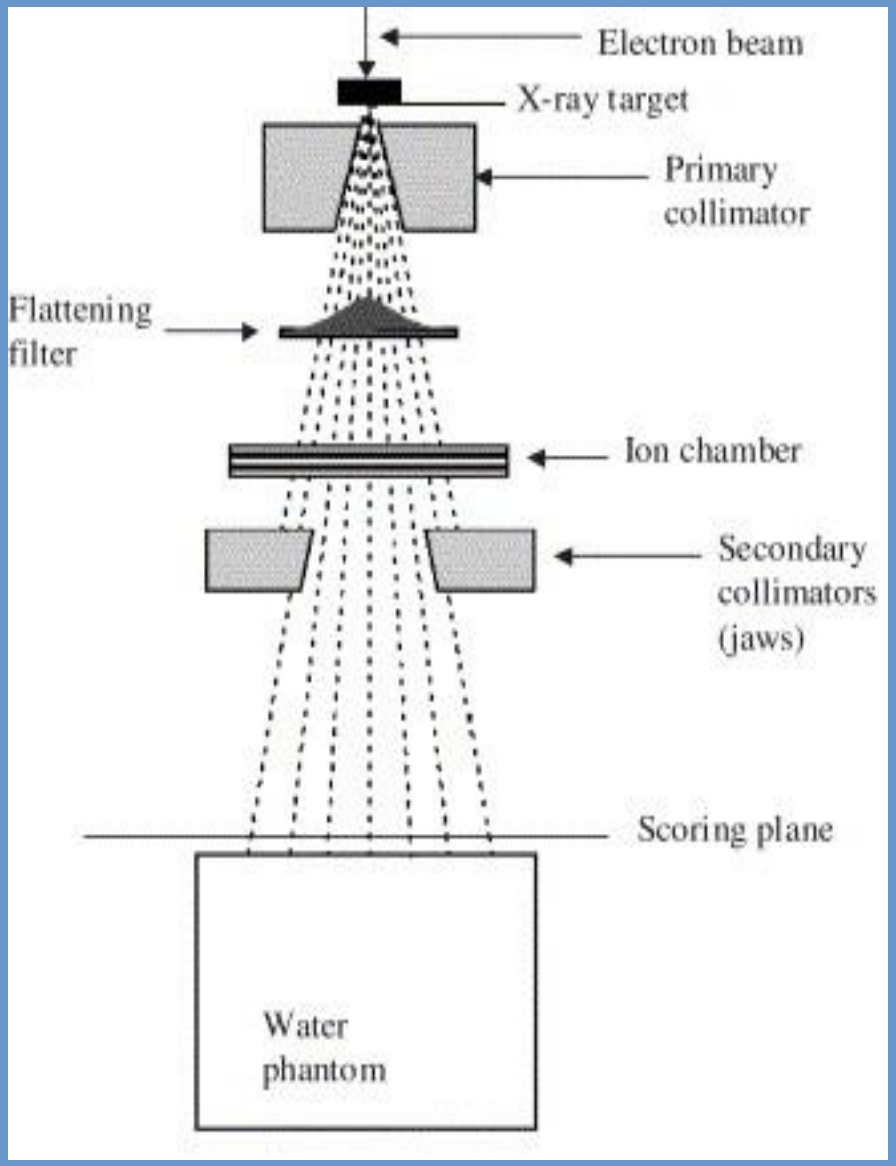
Radiation Exposure

Clinical Photon Dose Models



From Jagetic et al (in preparation)

Methods: New Physics Model



Sources (primary and scatter)

Photon Fluence in air

Attenuation in head, phantom

Scattering in head, phantom

Convert fluence to dose

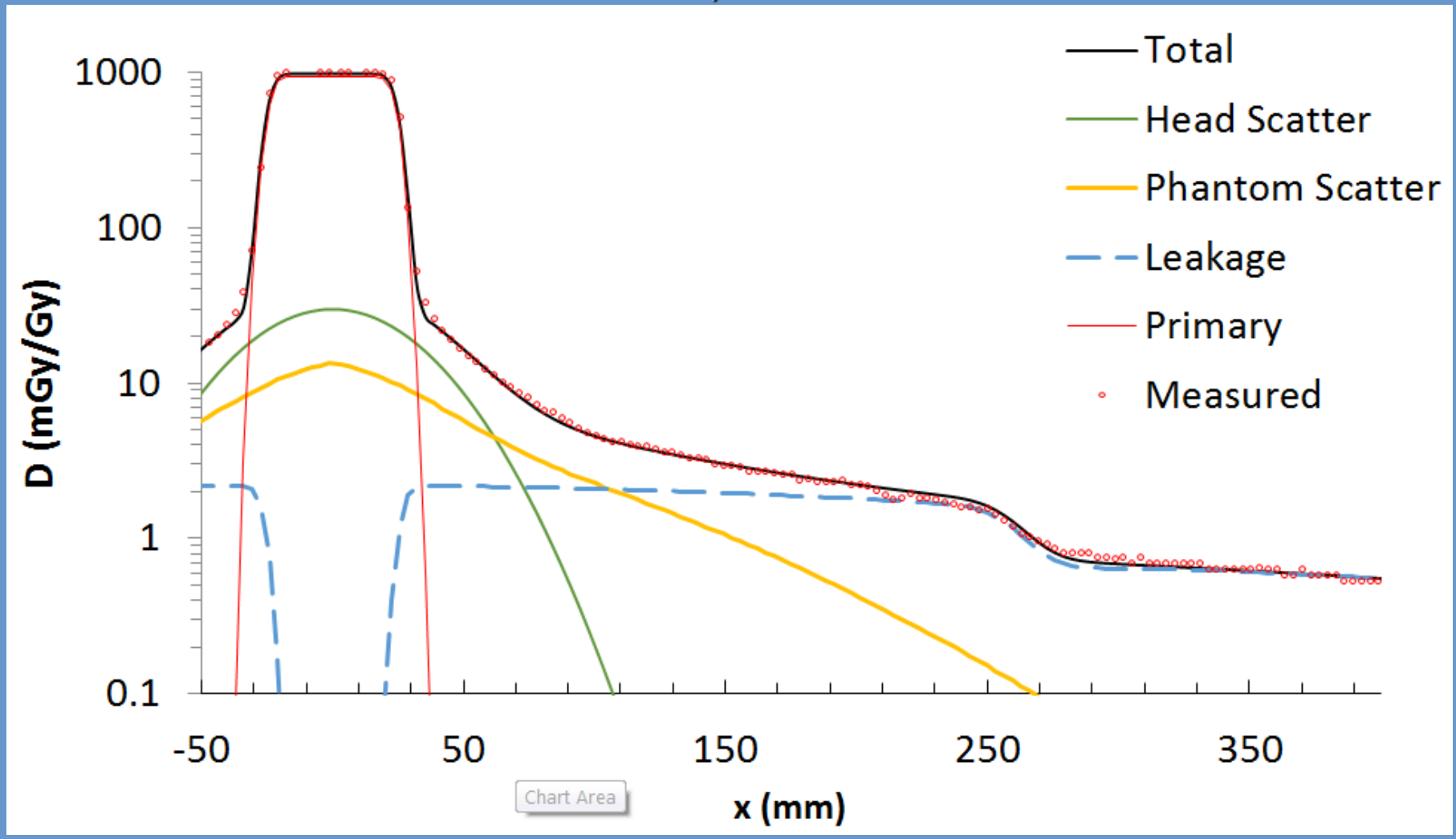
Combine doses

$$D_T = D_P + D_L + D_S$$

Jagetic L and Newhauser WD, A simple and fast analytical method to calculate doses to the whole body from external beam, megavoltage x-ray therapy. Phys Med Biol. 60 (2015) 4753–4775

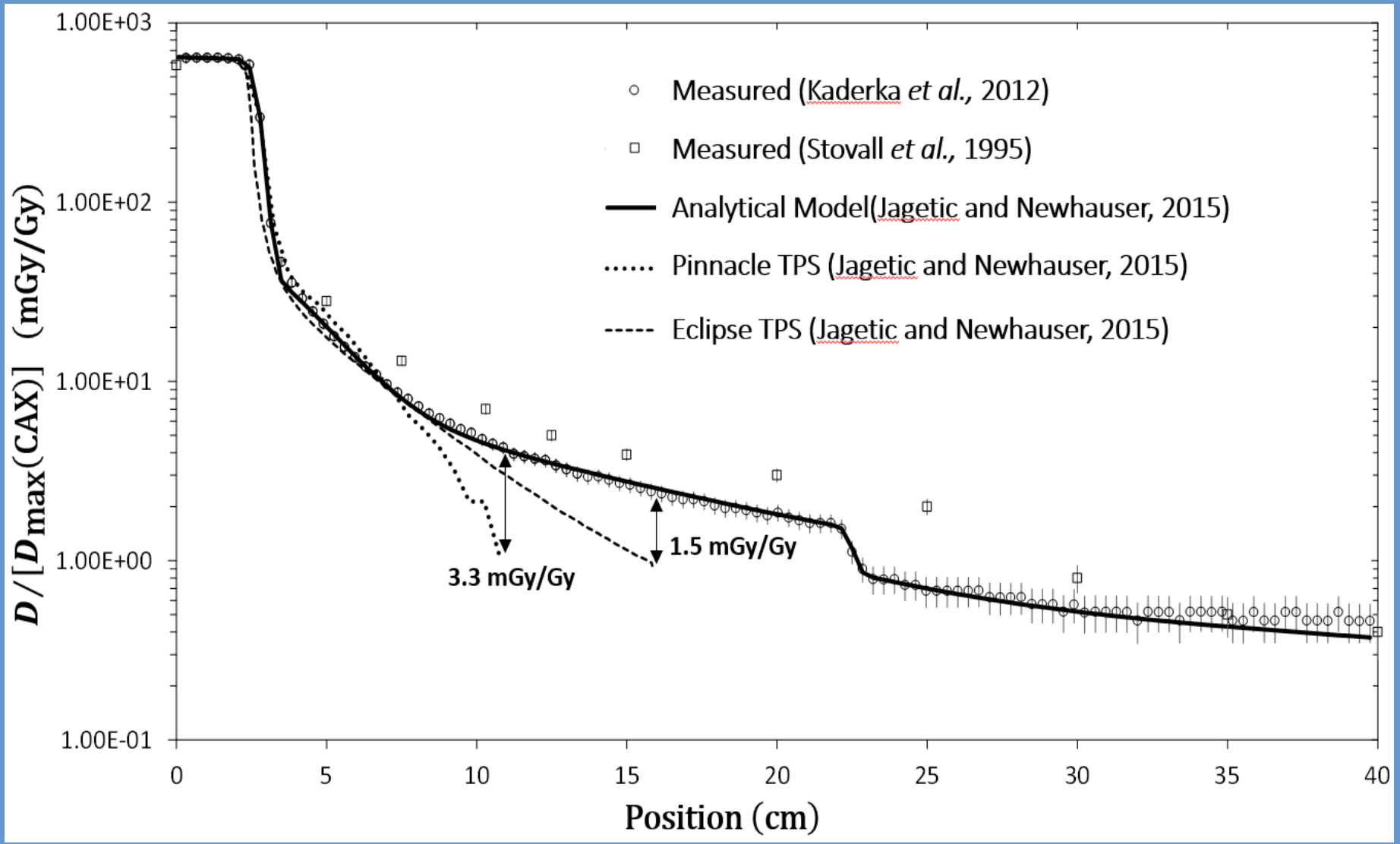
Results: Components of Dose

5x5 cm², d=1.5 cm



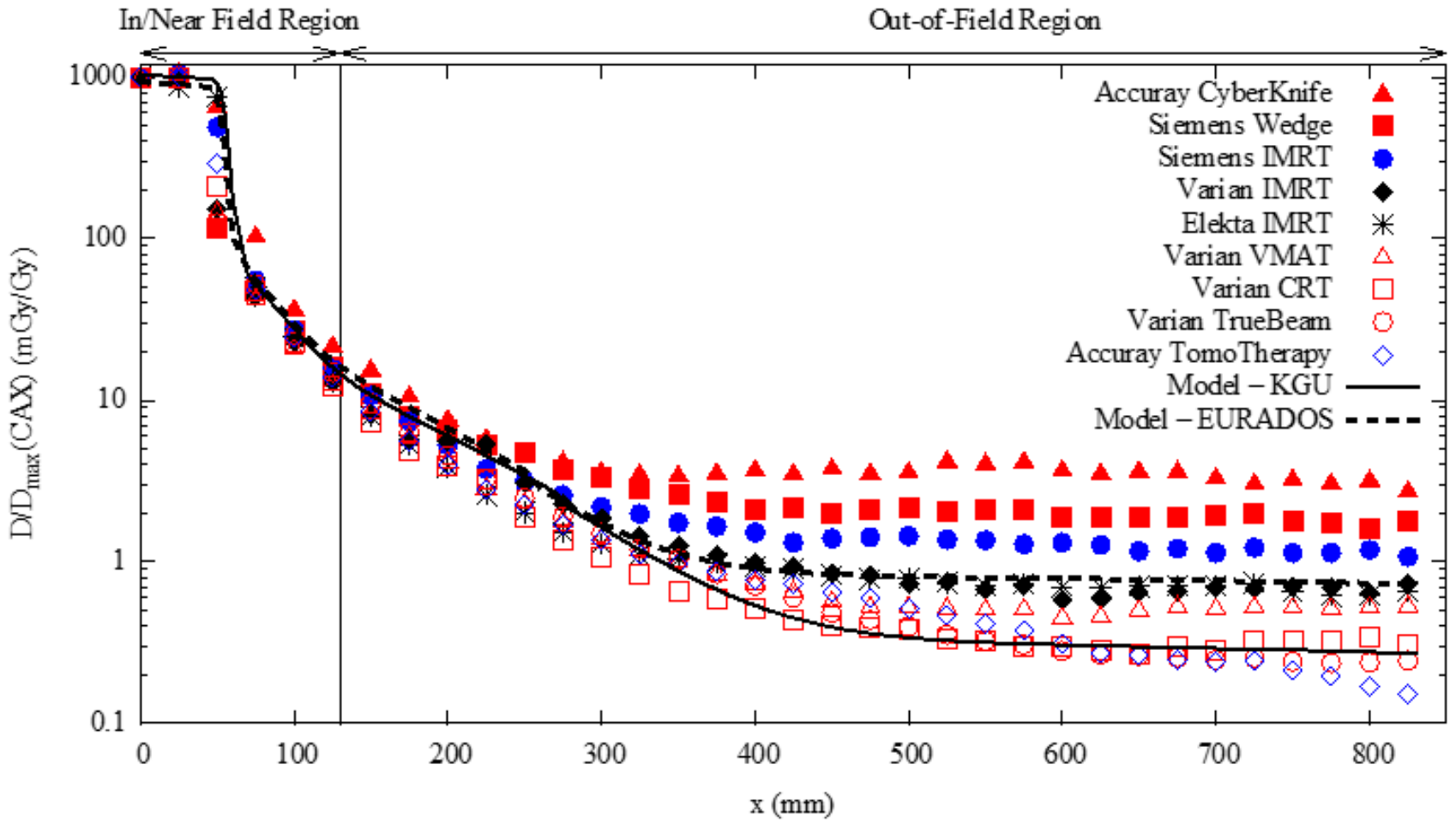
Predictions: Jagetic L and Newhauser WD, A simple and fast analytical method to calculate doses to the whole body from external beam, megavoltage x-ray therapy. Phys Med Biol. 60 (2015) 4753–4775.
Measurements: R Kaderka et al. Out-of-field dose measurements in a water phantom using different radiotherapy modalities. Phys Med Biol 57 5059-5074 (2012).

Accuracy of New Model



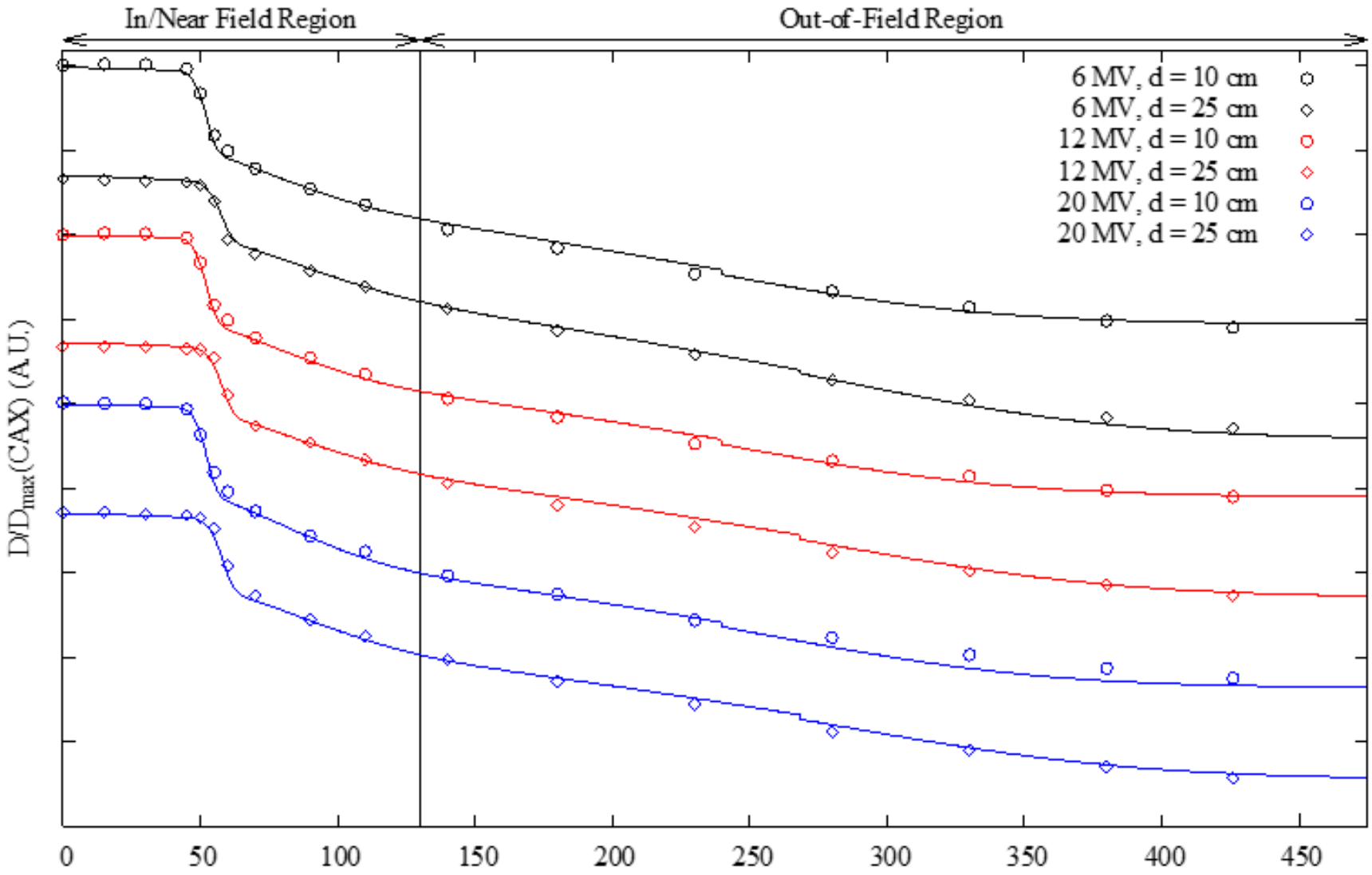
Jagetic et al, in preparation

Variation with Treatment Technique



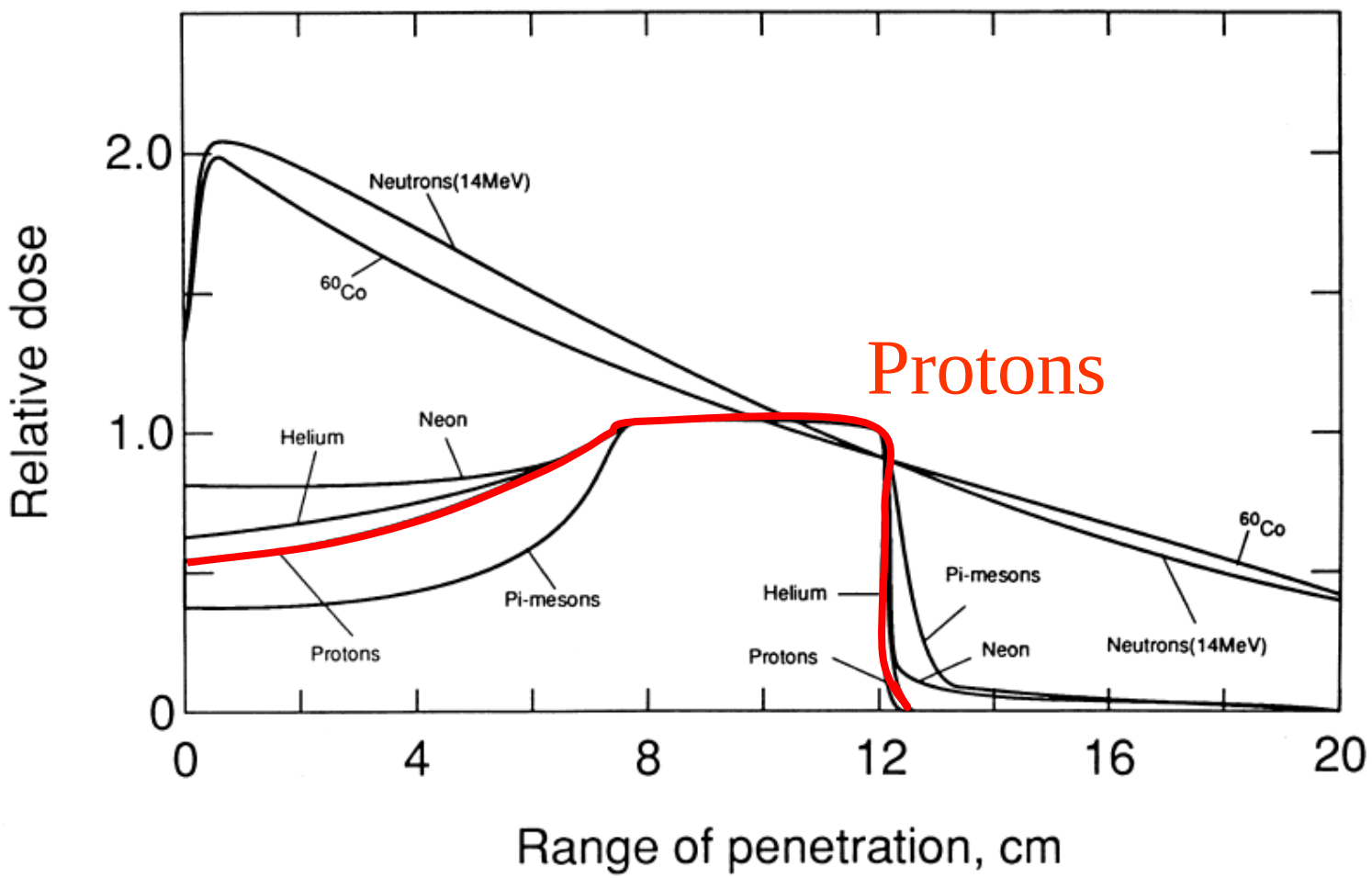
C Schneider, W Newhauser, L Jagetic, U Schneider, R Kaderka, S Miljanić, Ž Knežević, L Stolarcyzk, M Durante, and R Harrison. A simple, descriptive, and broadly applicable model of therapeutic and stray absorbed dose from 6 MV to 25 MV photon beams. (in review)

Variation with Treatment Technique

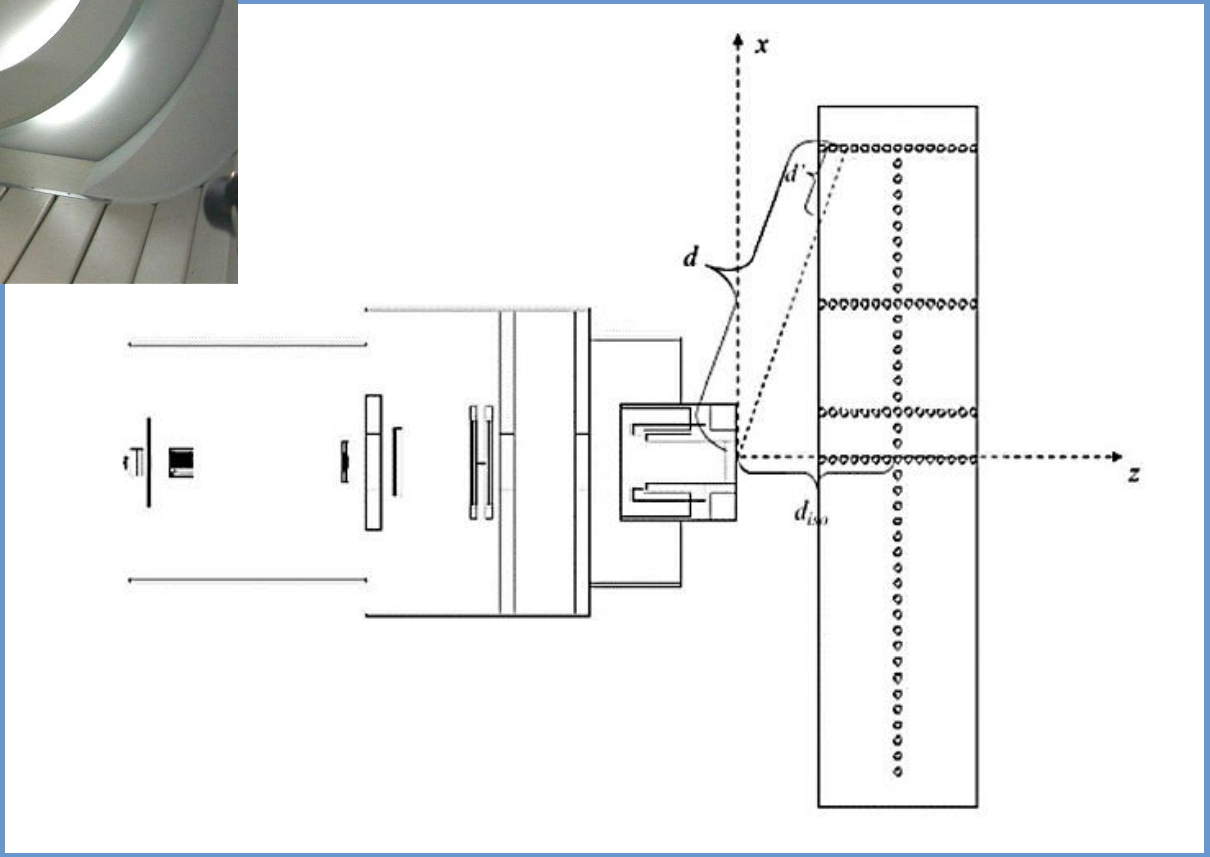


C Schneider, W Newhauser, L Jagetic, U Schneider, R Kaderka, S Miljanić, Ž Knežević, L Stolarcyzk, M Durante, and R Harrison. A simple, descriptive, and broadly applicable model of therapeutic and stray absorbed dose from 6 MV to 25 MV photon beams. (in review)

Approach to Reduce Late Effects: Start By Reducing Physical Dose to Normal tissues



Neutron Leakage Exposure From Proton RT



Schneider, C. Newhauser WD, Farah J. An analytical model of leakage neutron equivalent dose for passively-scattered proton therapy and validation with measurements. Cancers 7, 795-810 (2015).

Proton Therapy: New Analytical Model of Neutron Leakage

$$\left(\frac{H}{D}\right)_p = \left(\frac{H}{D}\right)_{E,iso} \left(\frac{d}{d_{iso}}\right)^{-q} \sum_{i=1}^{4} C_i(E) \exp[-\alpha_i(d' - d'_{iso})] \exp\left[\frac{-(x^2+y^2)d_{iso}^2}{2\sigma_i^2 z^2}\right]$$

Divergence

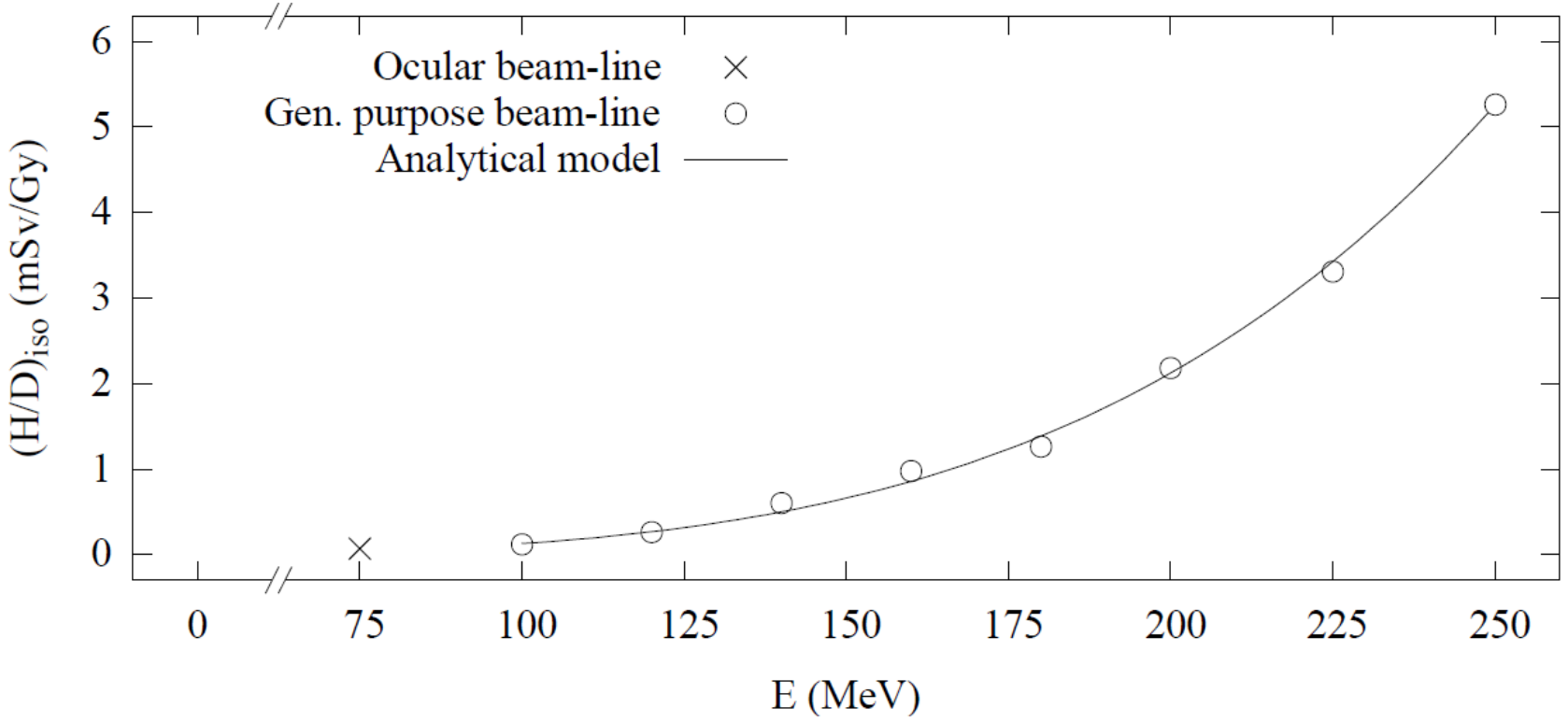
Shape of neutron energy distribution

Attenuation in Phantom

Relative Lateral Intensity

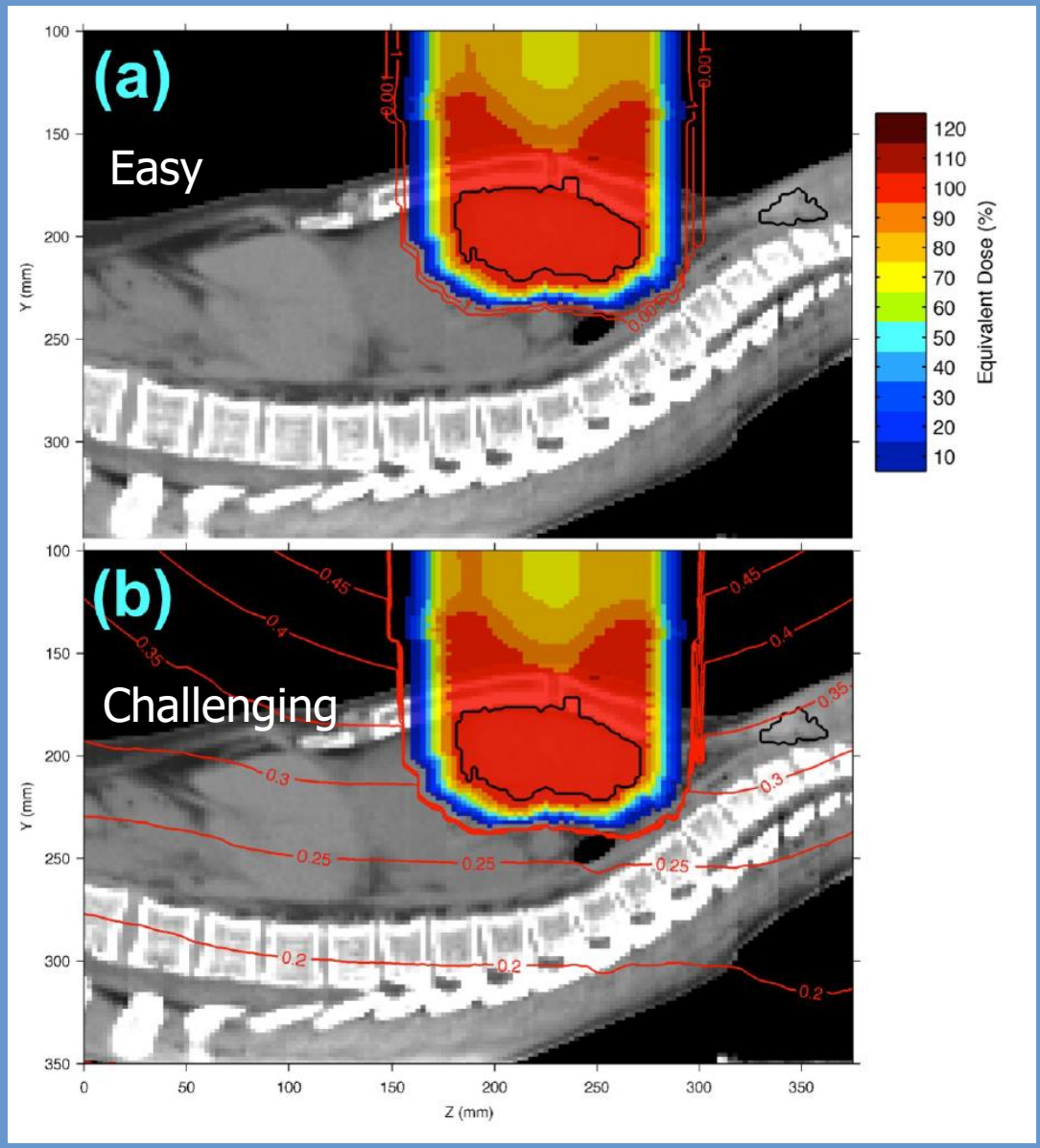
Schneider, C. Newhauser WD, Farah J. An analytical model of leakage neutron equivalent dose for passively-scattered proton therapy and validation with measurements. Cancers 7, 795-810 (2015).

Accuracy of Model of Neutron Leakage



Schneider, C. Newhauser WD, Farah J. An analytical model of leakage neutron equivalent dose for passively-scattered proton therapy and validation with measurements. Cancers 7, 795-810 (2015).

Routine Prospective Calculation of Stray Neutron Dose to is *Feasible*

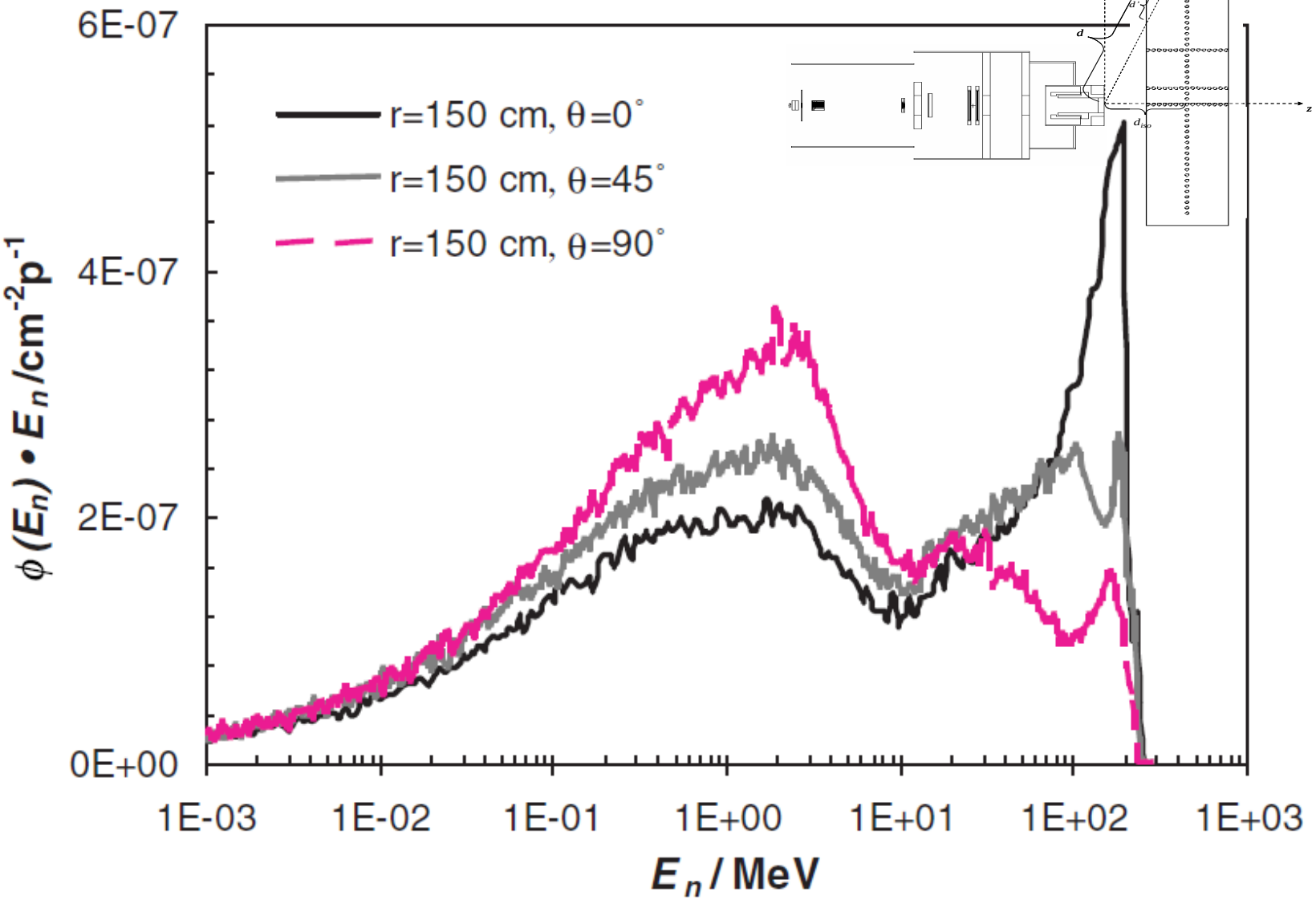


Sagittal equivalent dose planes overlaying a thoracic CT image of the HL patient showing (a) proton equivalent dose and (b) combined proton and neutron equivalent dose. Equivalent dose values are percentages of the prescribed target equivalent dose, i.e., 36 Sv. The mediastinal tumor and healthy thyroid are contoured in black.

Eley, Newhauser, Homann, Howell, Schneider, Durante Bert. Cancers 2015, 7, 427-438

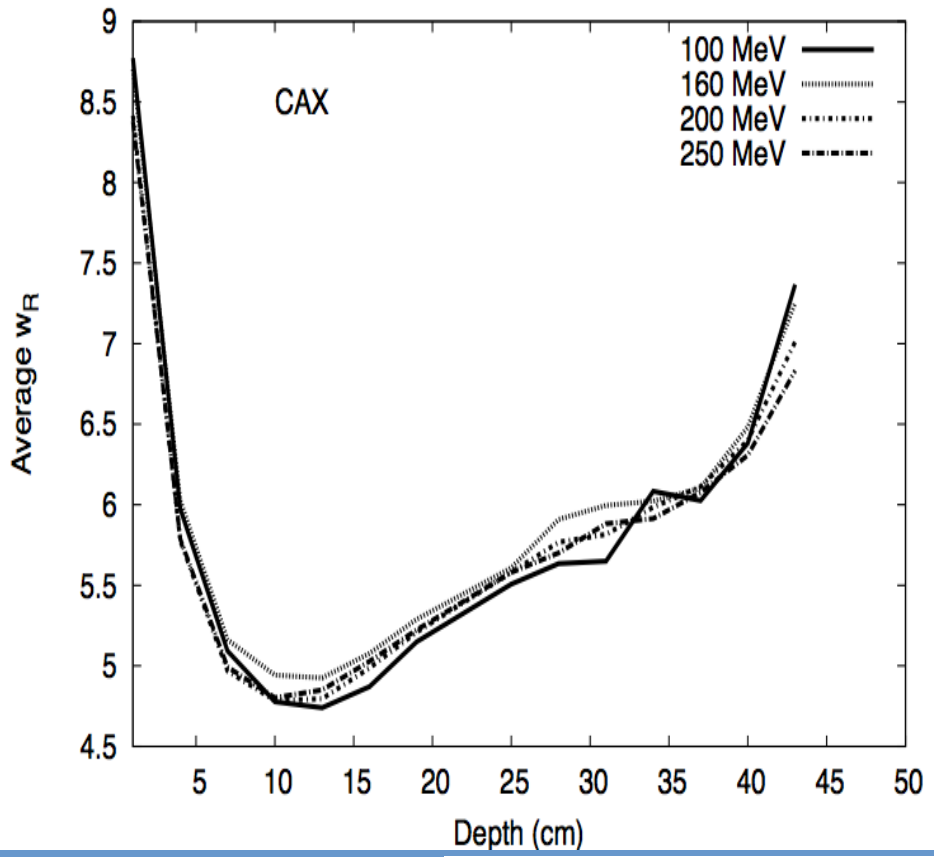
Estimation of Mean Radiation Quality of Neutrons

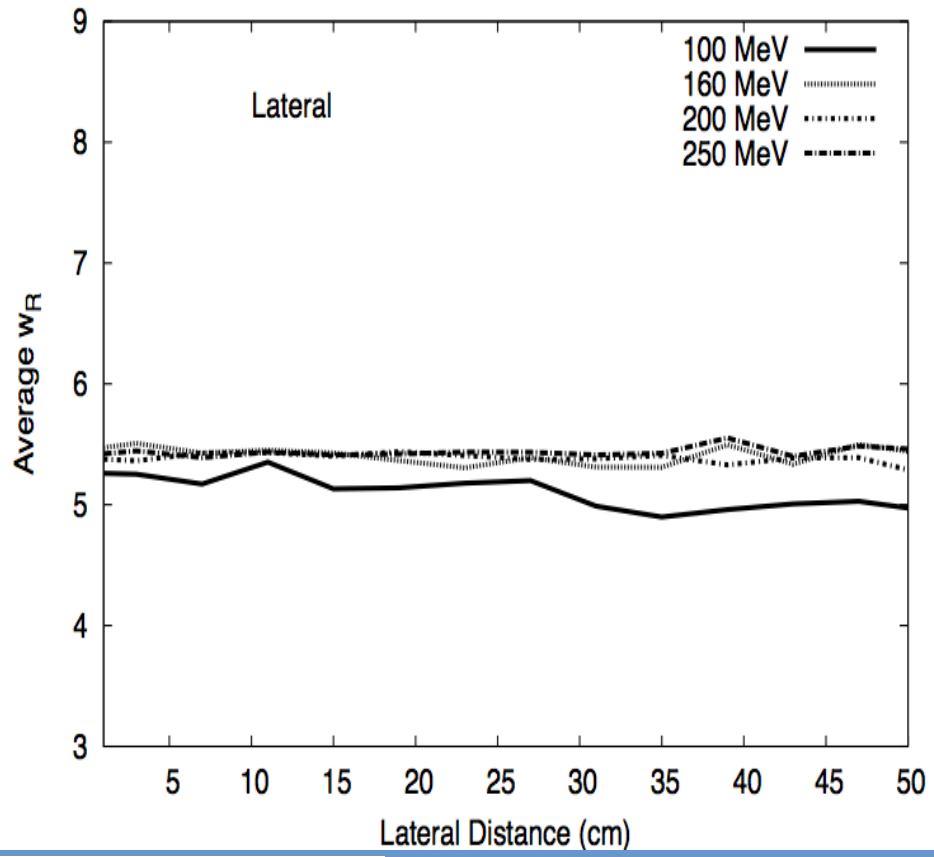
Neutron Spectral Fluence



Zheng et al Journal of Nuclear Materials 361 (2007) 289–297

Neutron Weighting Factor



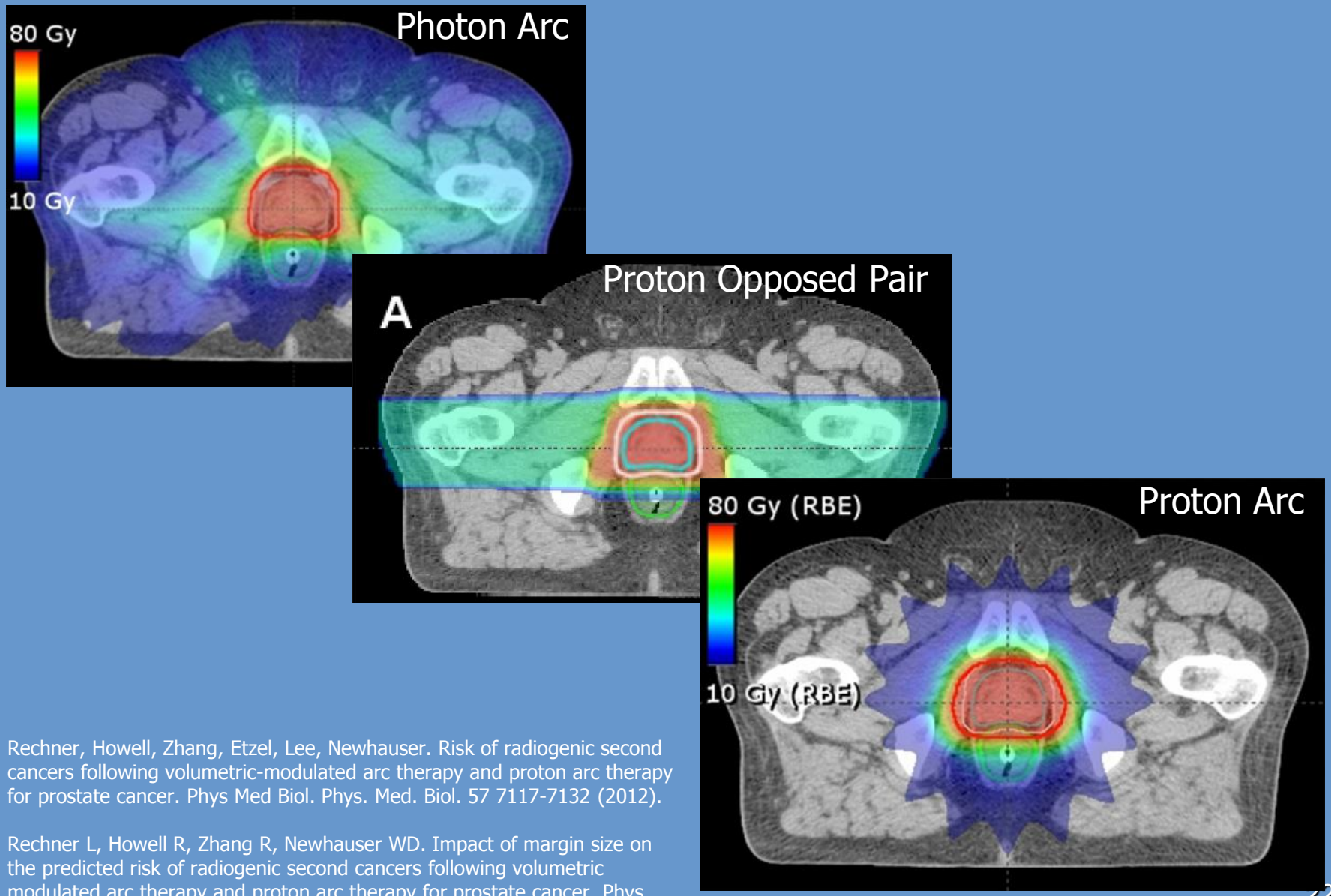


$$\overline{w}_R(x) = a(1 - e^{-b(x-d)^2}) + c$$

Perez-Andujar A, Zhang R, Taddei P, Newhauser W. Prediction of neutron dose equivalent dose source terms for radioprotection in proton therapy. Med. Phys 40, 121714 (2013)

Comparative Assessment of Radiation Risk

Predict & reduce risk radiation late effects …

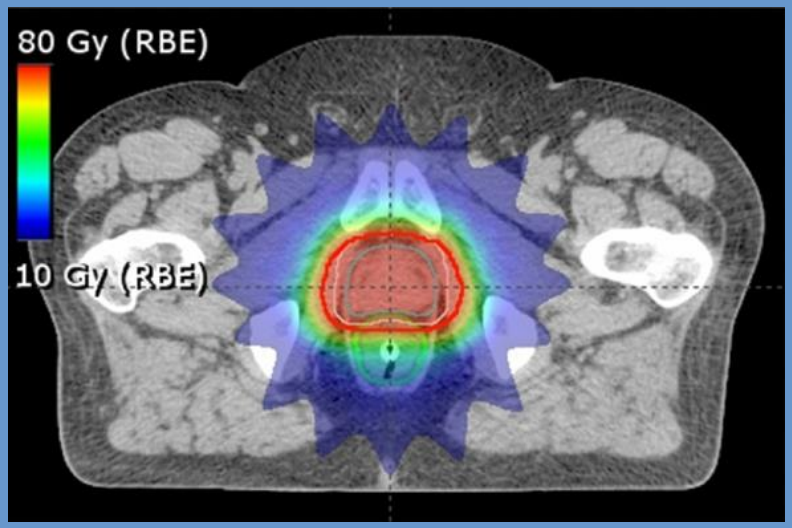


Rechner, Howell, Zhang, Etzel, Lee, Newhauser. Risk of radiogenic second cancers following volumetric-modulated arc therapy and proton arc therapy for prostate cancer. Phys Med Biol. Phys. Med. Biol. 57 7117-7132 (2012).

Rechner L, Howell R, Zhang R, Newhauser WD. Impact of margin size on the predicted risk of radiogenic second cancers following volumetric modulated arc therapy and proton arc therapy for prostate cancer. Phys Med Biol Phys Med Biol. 2012 Dec 7;57(23):N469-79.

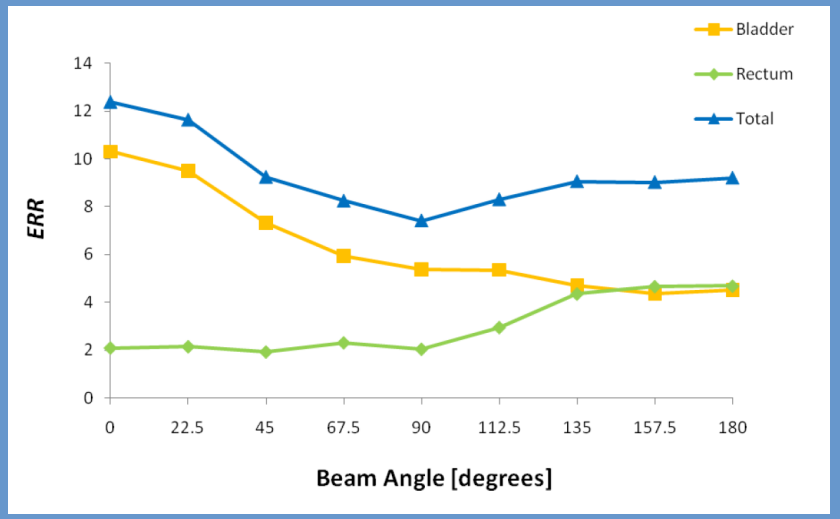
Algorithmic Minimization of Risk of Late Effects

Proton Arc (not risk optimized)

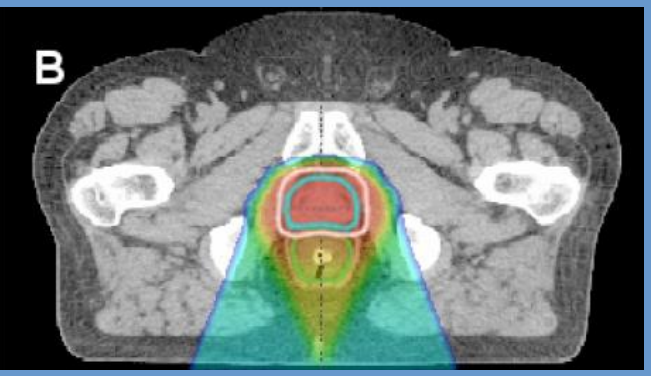


+

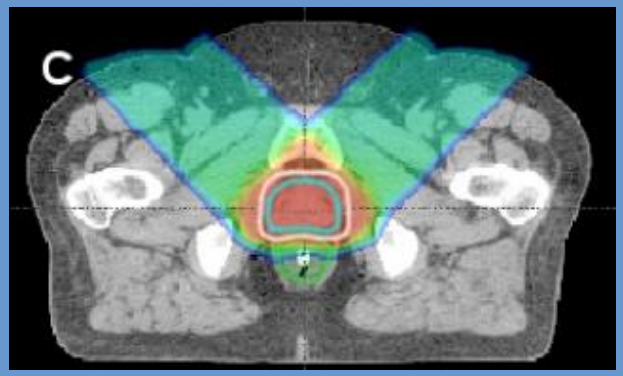
Proton risk versus beam angle



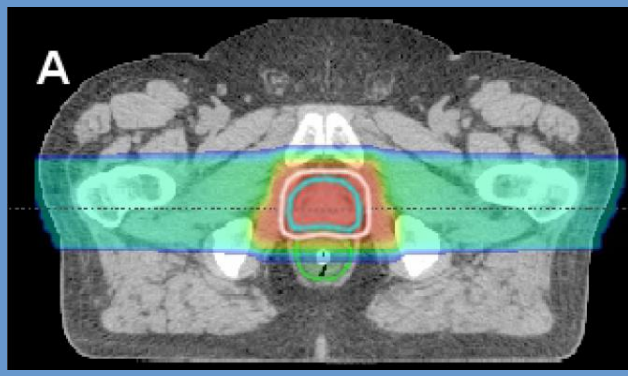
= Risk-Optimized Proton Plans



Bladder Only



Rectum Only



Bladder + Rectum

Rechner L, Zhang R, Eley J, Howell R, Mirkovic D, Newhauser WD. Minimization of the incidence of radiogenic second cancers with risk-optimized proton therapy, Phys Med Biol, 60 3999–4013 (2015).

A Few of the Many Remaining Tasks

- Anatomy (missing, moving, not visible)
- Translate to clinical planning systems
- Standardize terminology and reporting
- Validation
- Work more closely with all the disciplines that are contributing to improving RT outcomes

End