Nuclear Engineering
THE UNIVERSITY OF UTAH

Absolute Dosimetry Model of the University of Washington Clinical Neutron Therapy System (CNTS)

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Outline

- Research background and motivation
- University of Washington (UW) cyclotron and clinical neutron therapy facility (CNTS)
- MCNP6 model of the CNTS treatment head
- Neutron dosimetry benchmarking of the MCNP6 CNTS model
  - IC-17 ion chamber absolute dose modeling
- Conclusions
- Future work

Fast Neutron Therapy Facilities

- Fast neutron therapy has shown improved clinical outcomes for:
  - Salivary gland tumors
  - Locally advanced prostate cancer
  - High-risk soft tissue sarcomas
- Other tumors show comparable outcomes as x-ray therapy
- The UW CNTS is only 1 of 2 fast neutron therapy facilities still treating patients left in the world
- Limited development of treatment planning software
  - Current treatment planning performed with a photon model fit with neutron data (Pinnacle^3 software)
- Little development of advanced therapy methods like intensity modulated neutron therapy (IMNT)

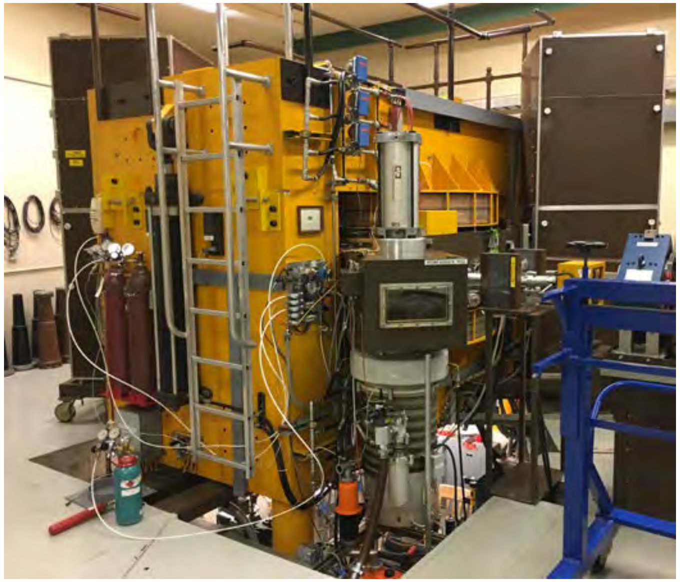
Research Objectives

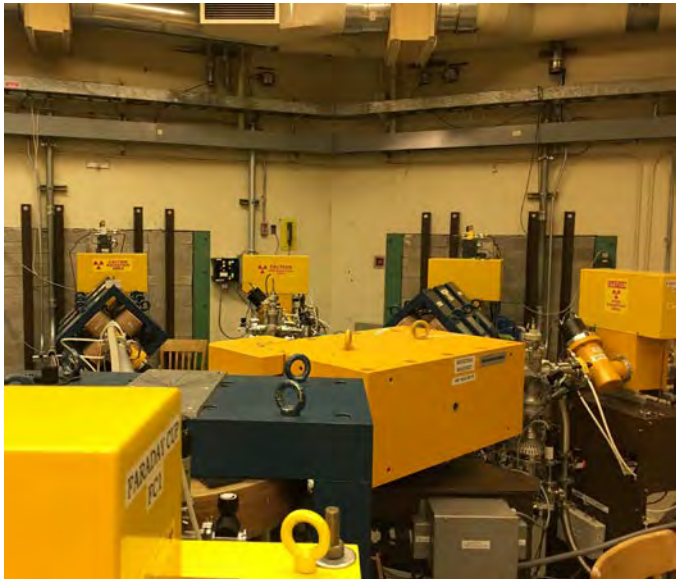
- Develop a fully benchmarked MCNP6 dosimetry model of the UW CNTS
  - Second checks of patient plans
  - Aid in the development of advanced fast neutron therapy methods (i.e. IMNT)
- Absolute dosimetry of the MCNP6 CNTS model requires the modeling of an IC-17 tissue-equivalent ion chamber
  - IC-17 TE ion chamber used for absolute calibration of the beam
  - Ensure that the dose response of the ion chamber compares similarly to the dose response of water across all treatment configurations

UW Cyclotron Facility

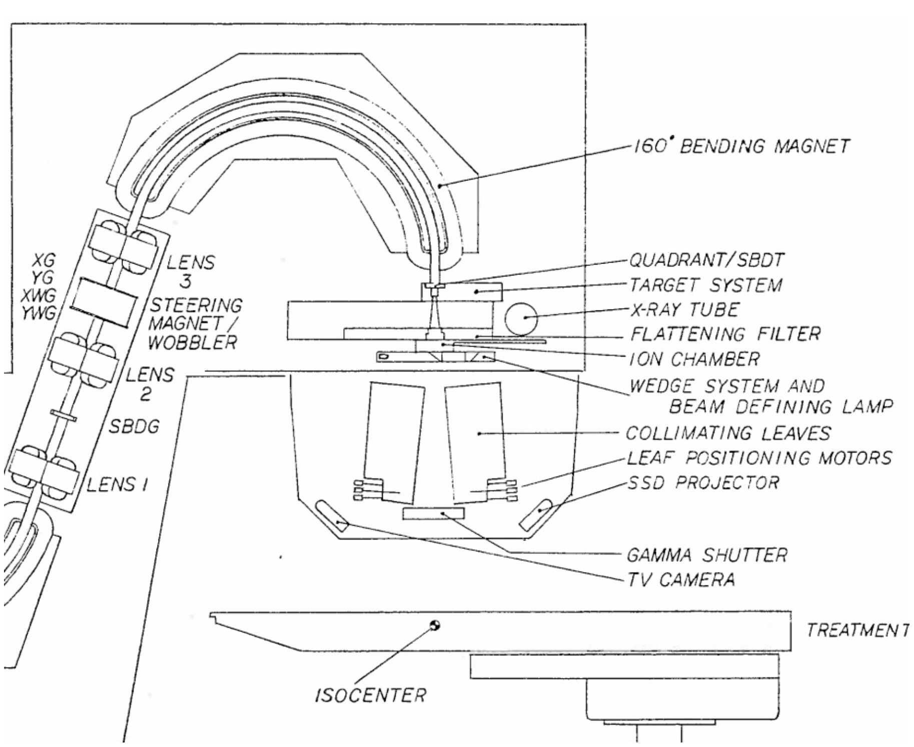
UW Clinical Cyclotron

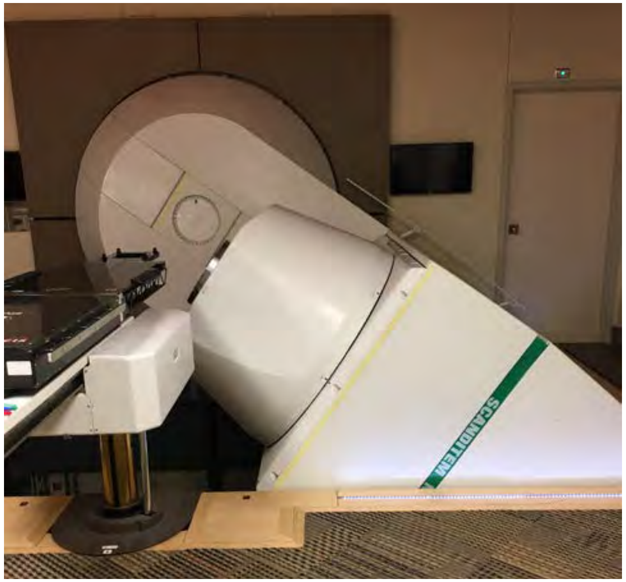
- Construction complete in 1984
- Built by Scanditronix
- Particles accelerated
  - 28.0-50.5 MeV $^{1}H^{+}$
  - 13.6-23.8 MeV $^{2}H^{+}$
  - 6.8-12.0 MeV H_2^{+}
  - 9.5-15.5 MeV $^{3}He^{+}$
  - 20.3-35.7 MeV $^{3}He^{++}$
  - 27.0-47.3 MeV $^{4}He^{++}$
- 4 beamlines
  - Neutron therapy line
  - 2 isotope production lines
  - Proton research line

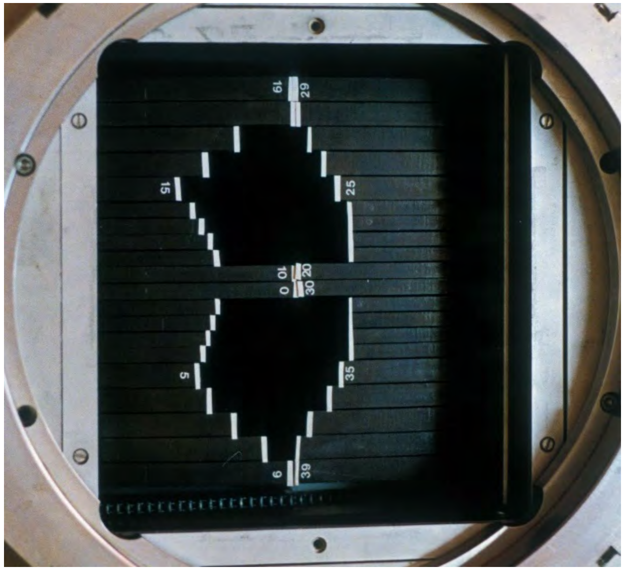




CNTS Treatment Head

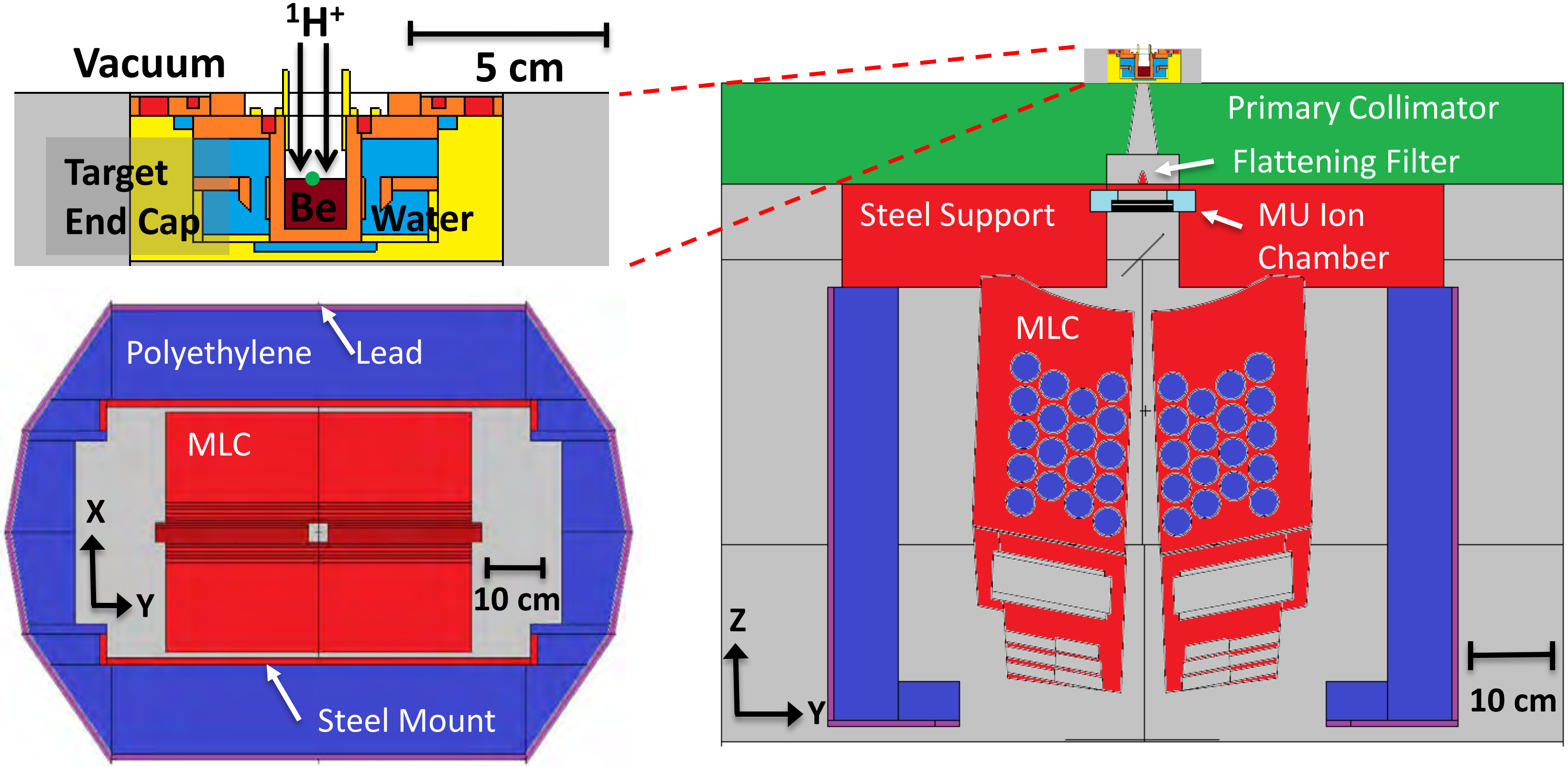




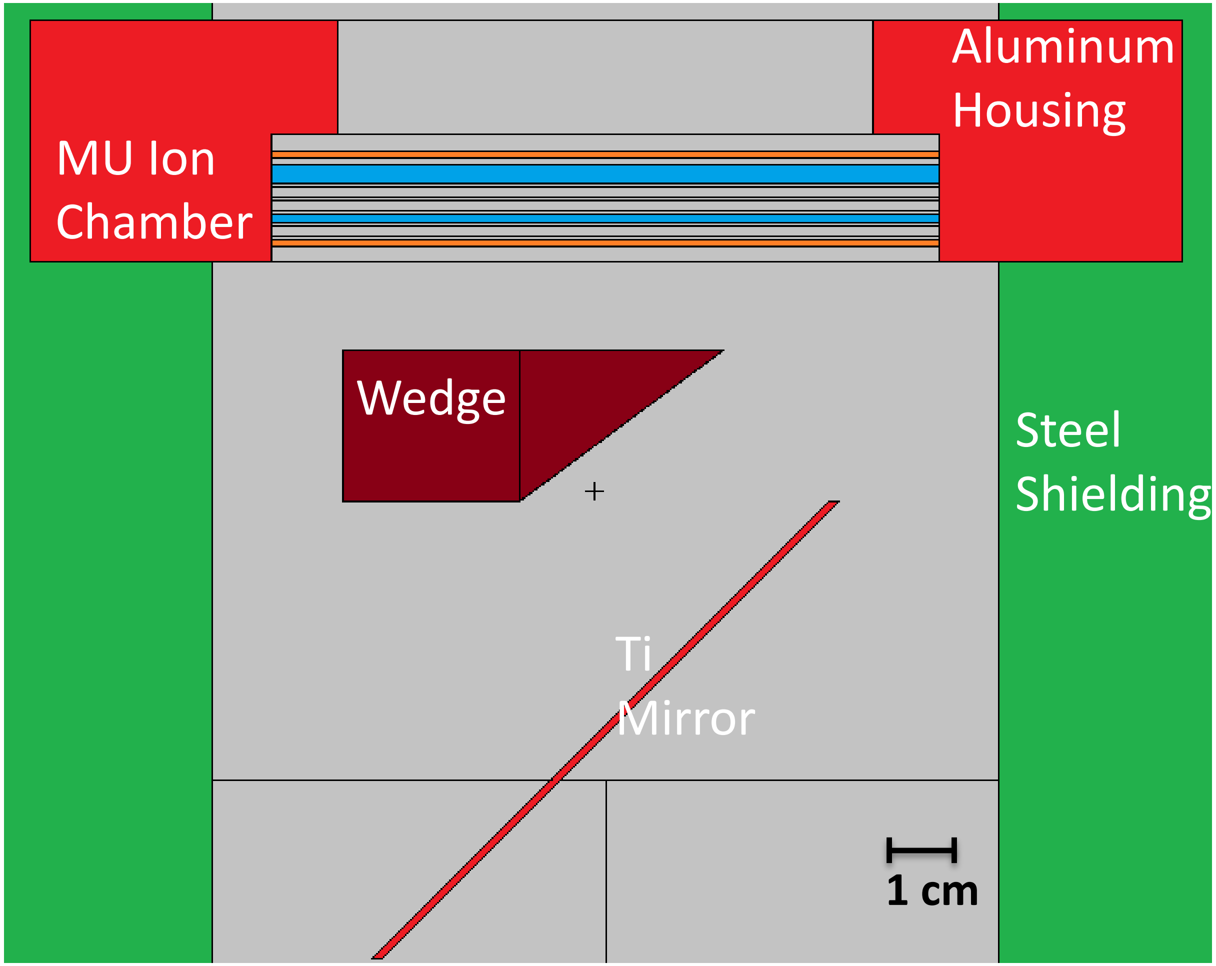


MCNP6 Model of the CNTS Treatment Head

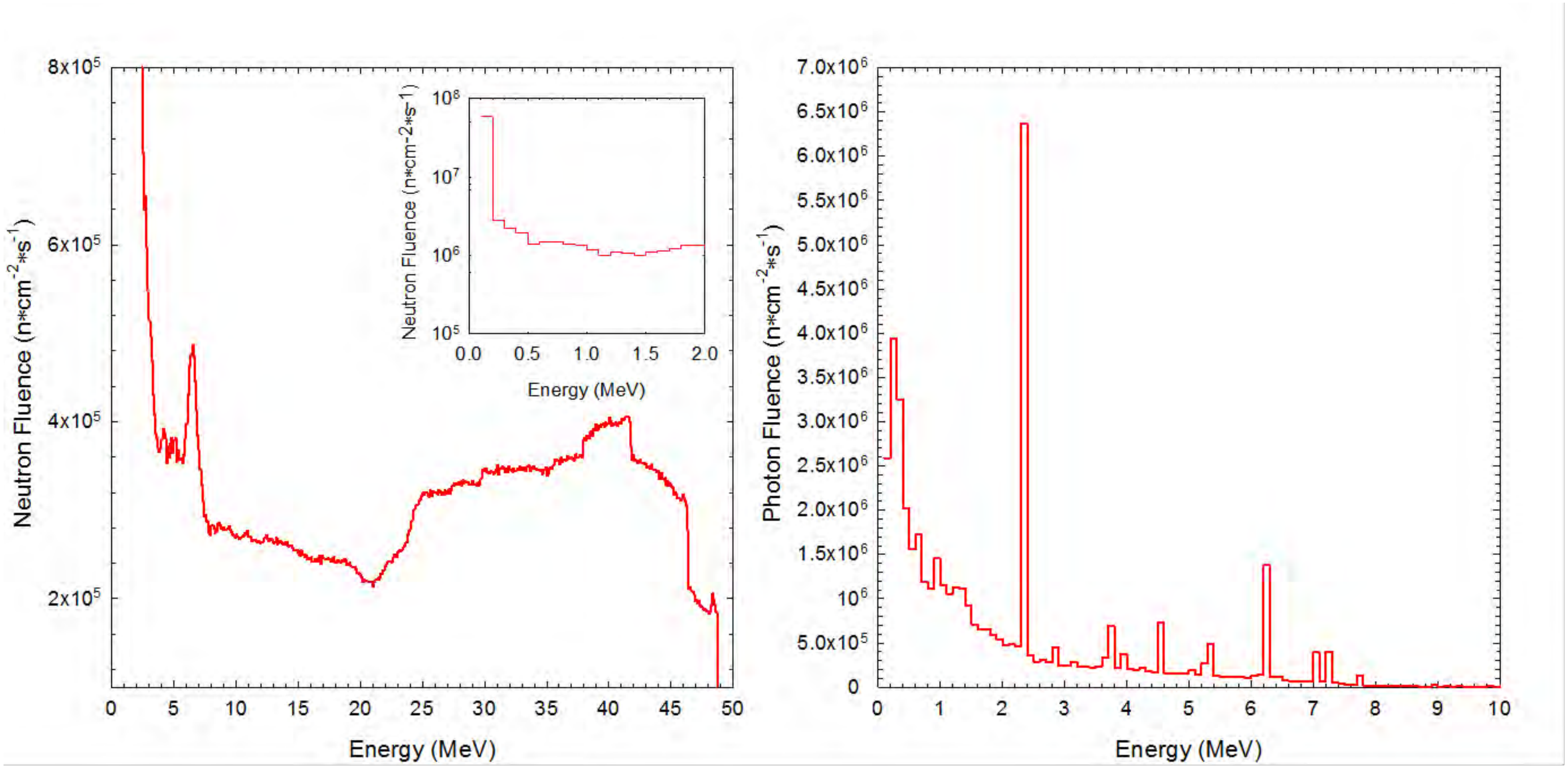
Treatment Head



MU Ion Chamber and Wedge Assembly



CNTS Neutron and Photon Energy Spectrum in Water

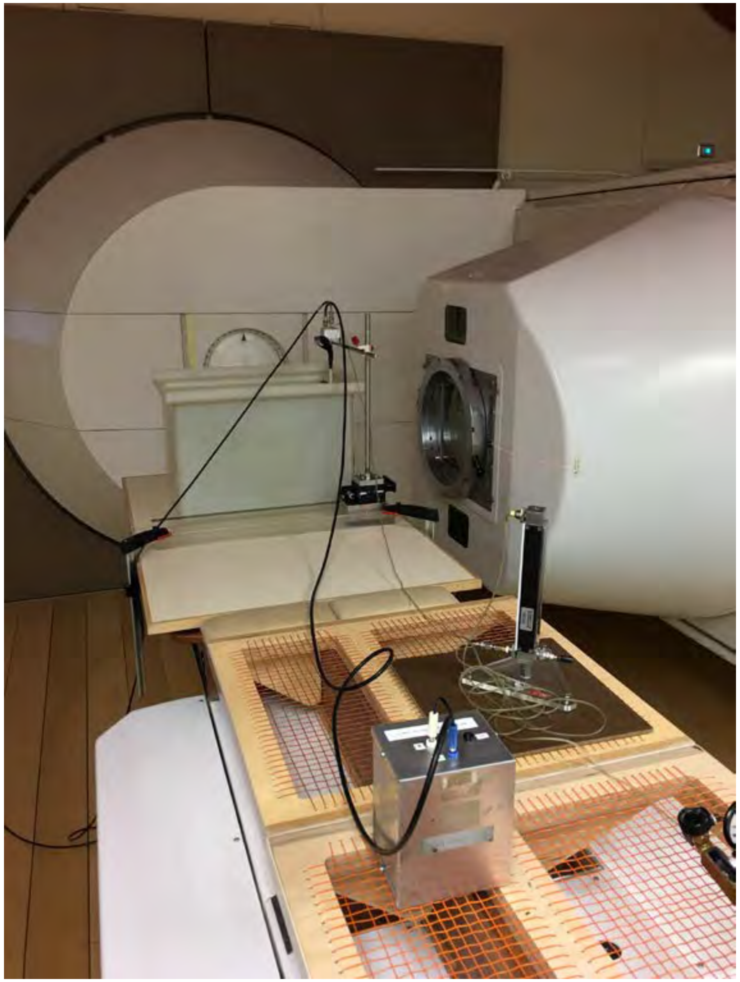


***Depth of 1.7 cm, 10.3 × 10.3 cm² field**

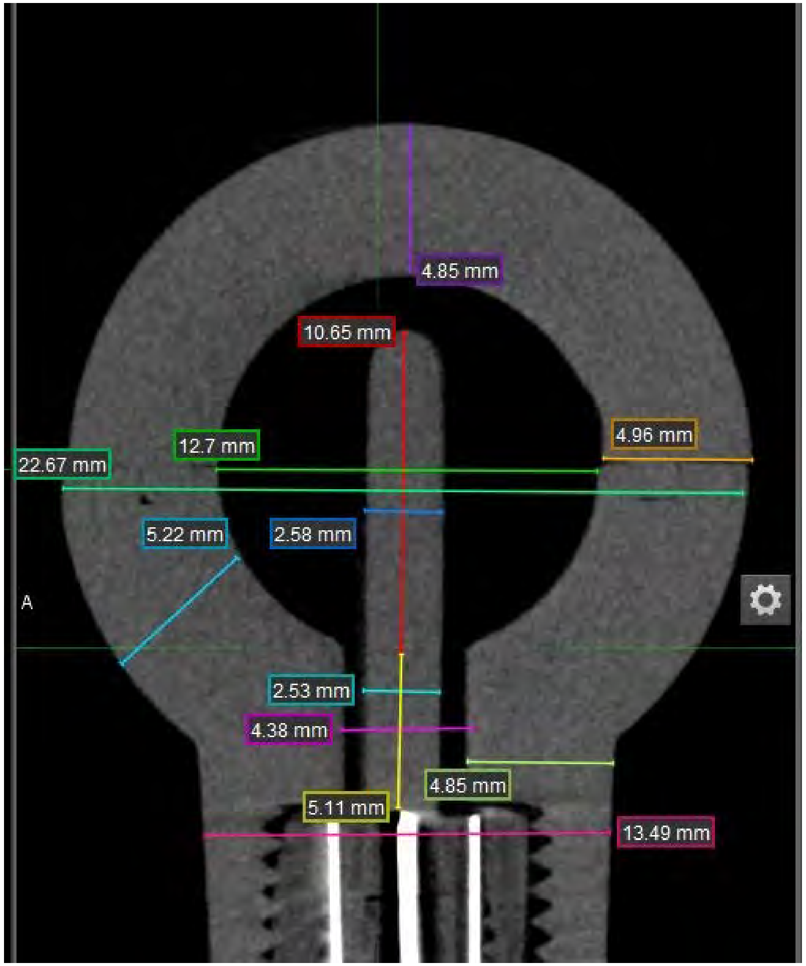
IC-17 Ion Chamber Modeling

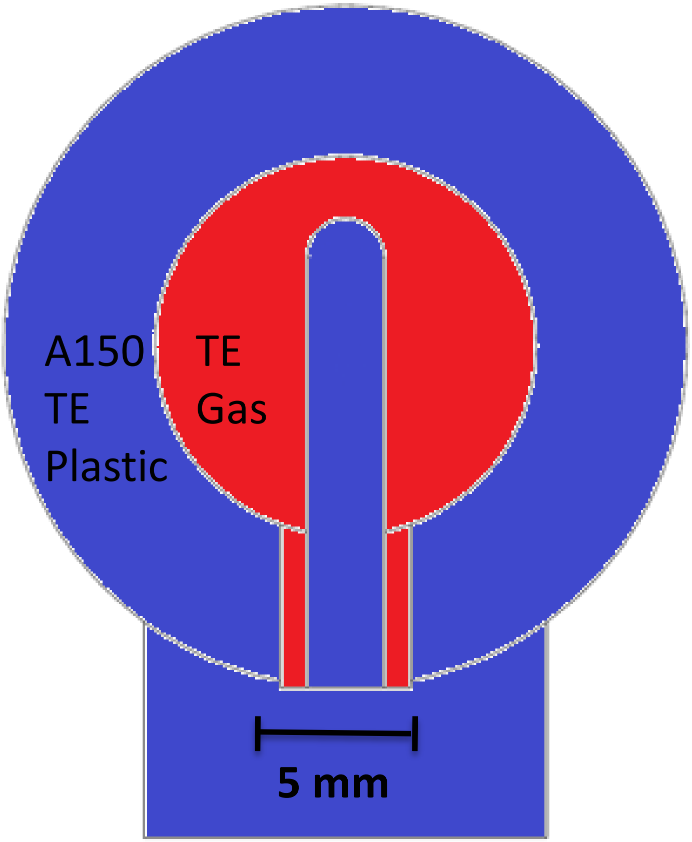
Absolute Dose Calibration

- Performed with an IC-17 tissue-equivalent (TE) ion chamber
  - Flowing 5 cc/min of methane-based TE gas
- Calibration field: 10.3 × 10.3 cm^2, open, small flattening filter
- 40 × 40 × 40 cm^3 water tank

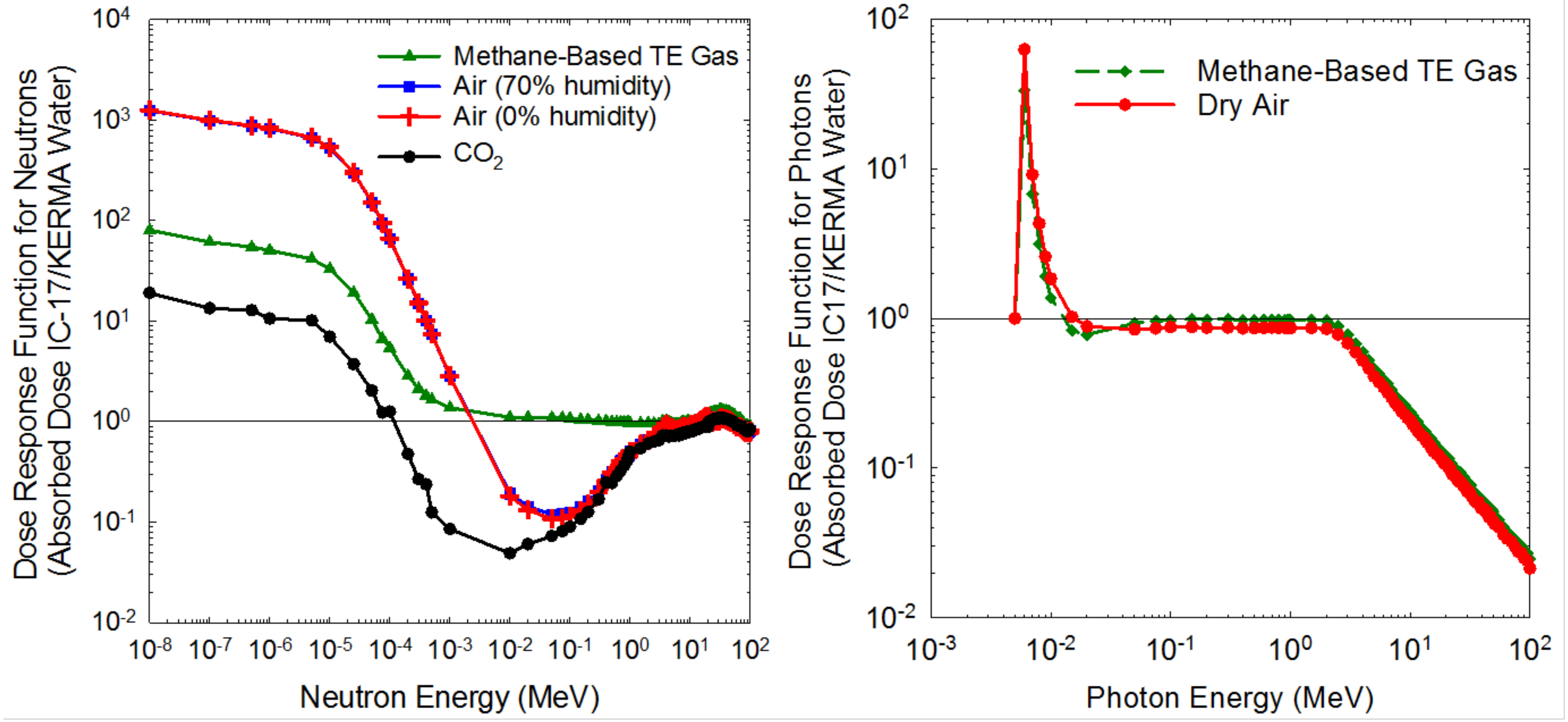


IC-17 Ion Chamber





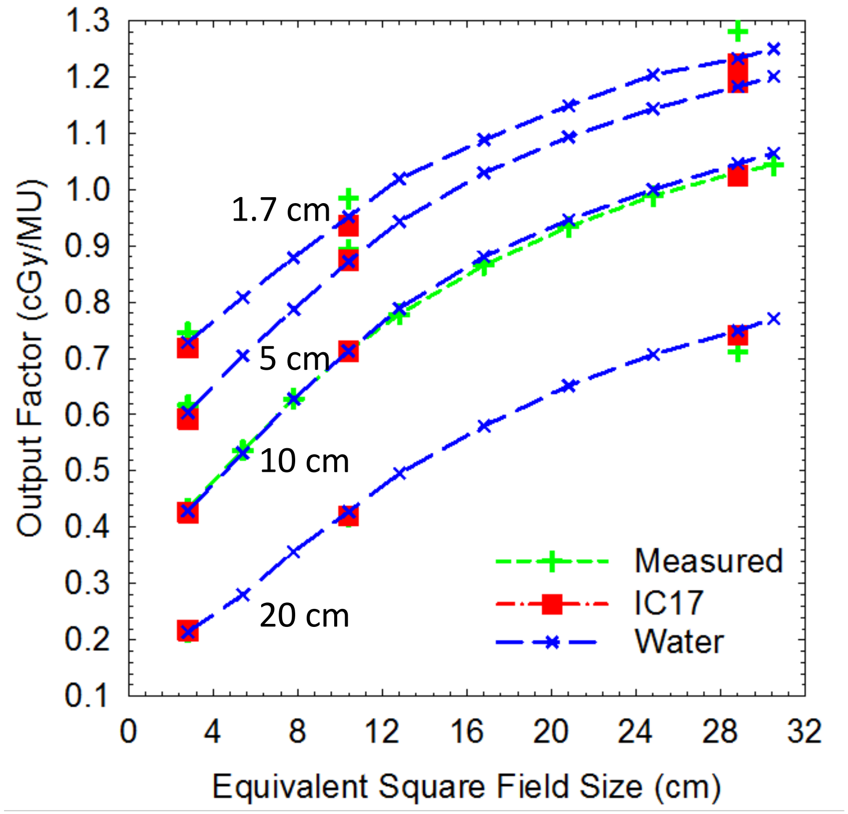
Monoenergetic Neutron and Photon Simulations



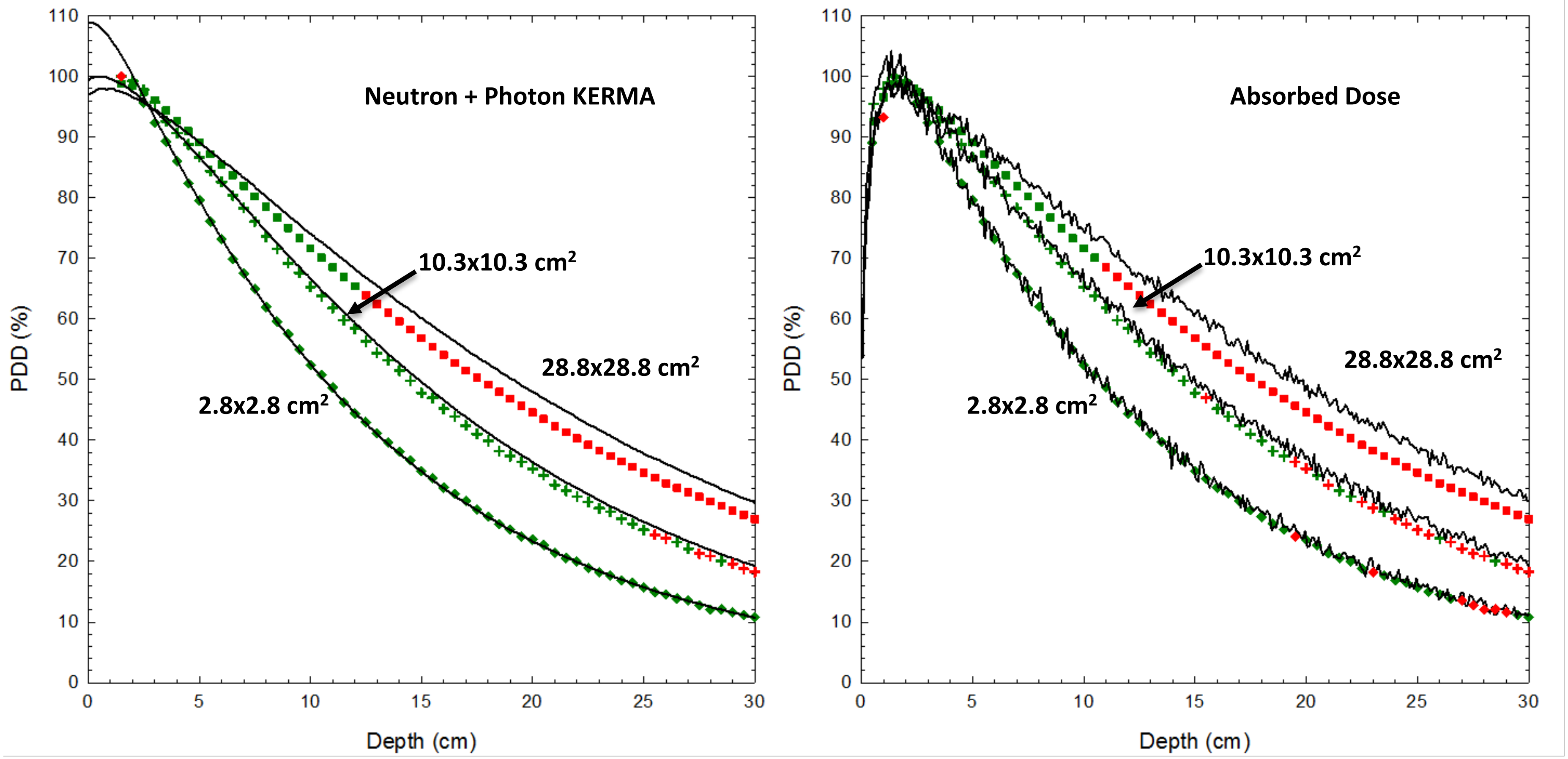
CNTS Model Benchmarking

Output Factors by Field Size

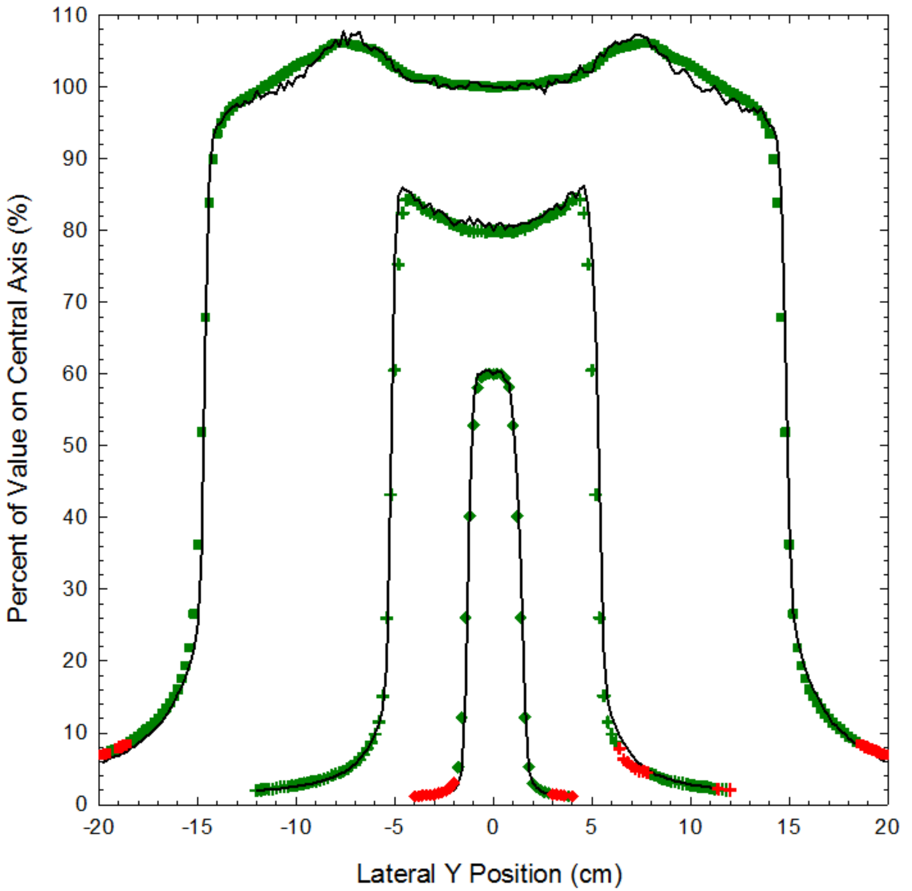
- All normalized to 10.3×10.3 cm^2 field at depth of 10 cm
- Less than 5.2% difference from measurements at all points (within 2.3% for all fields smaller than 28.8×28.8 cm^2)
  - Largest differences for the largest field
  - The largest field is typically not used for patient treatment



Percent Depth Dose (PDD) Profiles



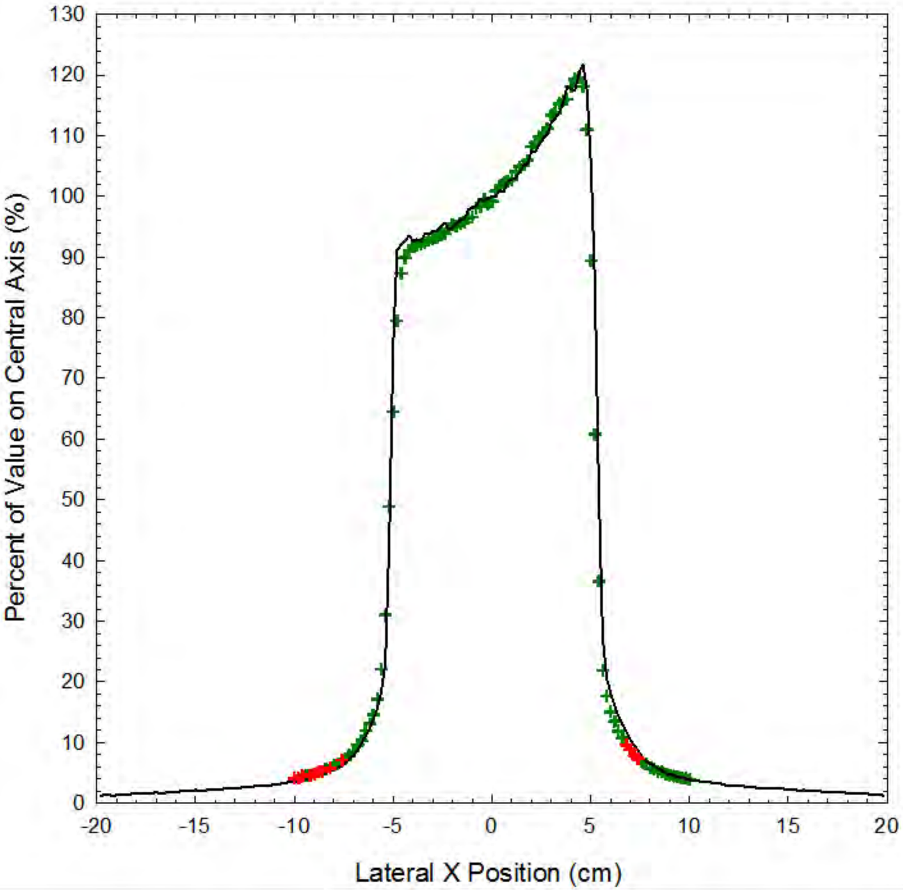
Lateral Dose Profiles at a Depth of 1.7 cm



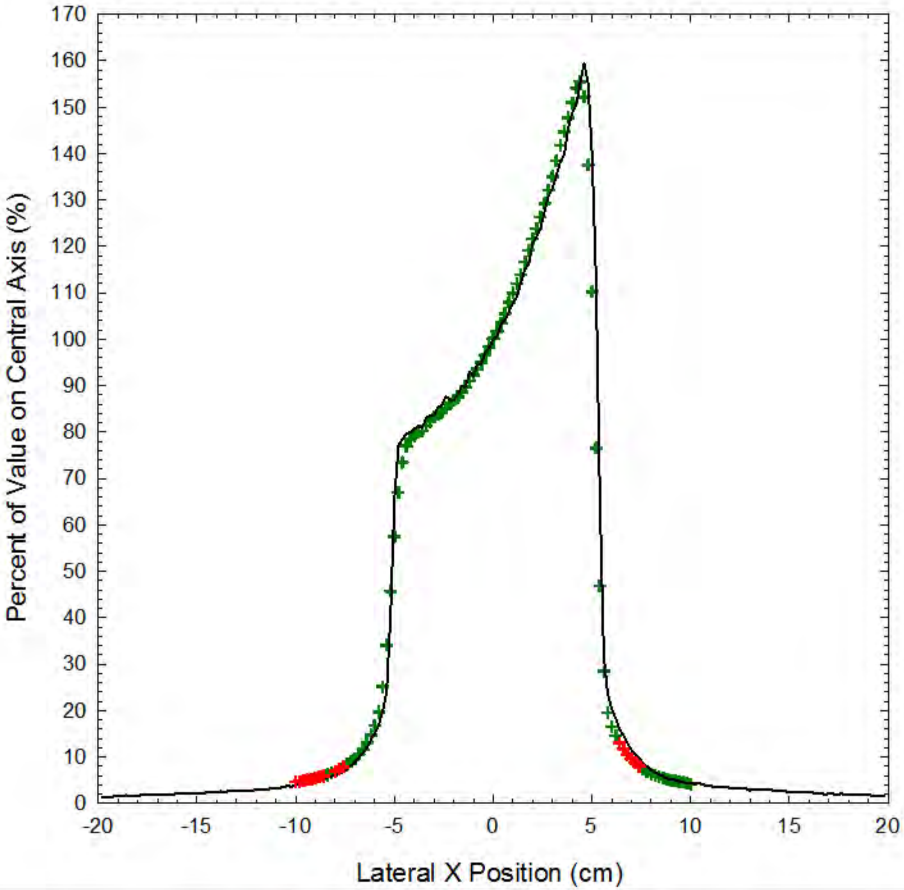
***Depth of 1.7 cm**

Wedge Profiles

30^o Wedge



60^o Wedge



Conclusions and Future Work

- Water is a good surrogate for the IC-17 ion chamber for neutron and photon dosimetry of the CNTS fast neutron beam
- MCNP6 model accurately reproduces beam profiles laterally, with depth, and with changing field size
- Neutron dosimetry for the CNTS matches measurements within:
  - 2.3% for all calibration field points
  - 5.2% for all square open fields
  - 1.6% for all wedge factors simulated
  - 6.8% for all irregular fields tested
- Neutron dosimetry shows improved agreement over Pinnacle
- Model applications
  - Second checks of treatment plans
  - Analysis of non-homogeneous tissue types and geometries (with patient CT scans)
  - Aid in the development of advanced therapy methods like IMNT and boron-neutron capture enhanced fast neutron therapy

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Additional Slides

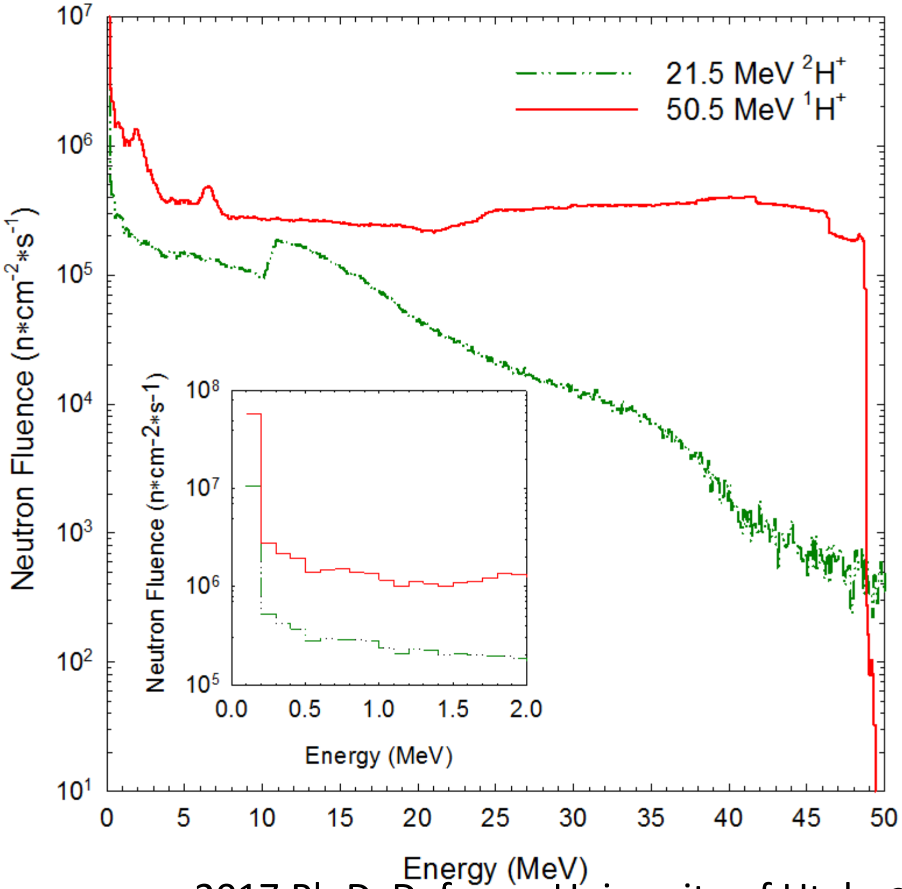
Material Composition Effects

- Sphere of given material at a depth of 1.7 cm in water (r=1.0 cm)
  - Absorbed dose tallied in sphere
- Water simulated at different densities to demonstrate that differences are due to material not density

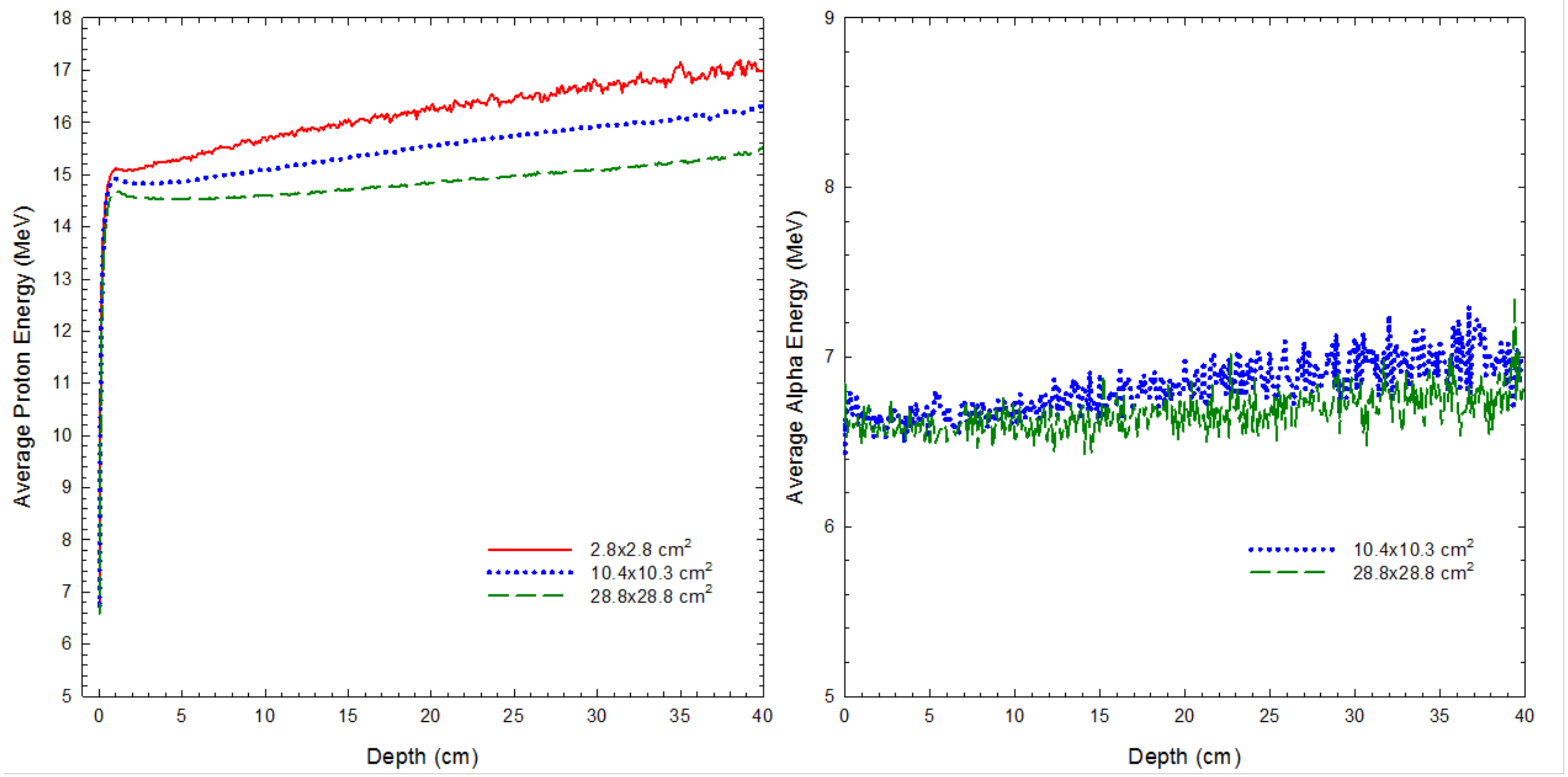
Material	**Density (g cm^{-3})**	**Simulated Output Factor (cGy/MU)**	**Percent Difference from Water**
Water	1.00	0.984	0.0%
Adipose Tissue	0.92	1.000	1.6%
Muscle	1.04	0.870	-11.6%
Bone	1.85	0.596	-39.5%
Air	0.001225	0.873	-11.3%
Water	0.001225	0.977	-0.7%
Water	0.92	0.983	-0.1%
Water	1.04	0.989	0.5%
Water	1.85	0.987	0.3%

Historical 21.5 MeV $^2H^+$ Generated Neutron Beam

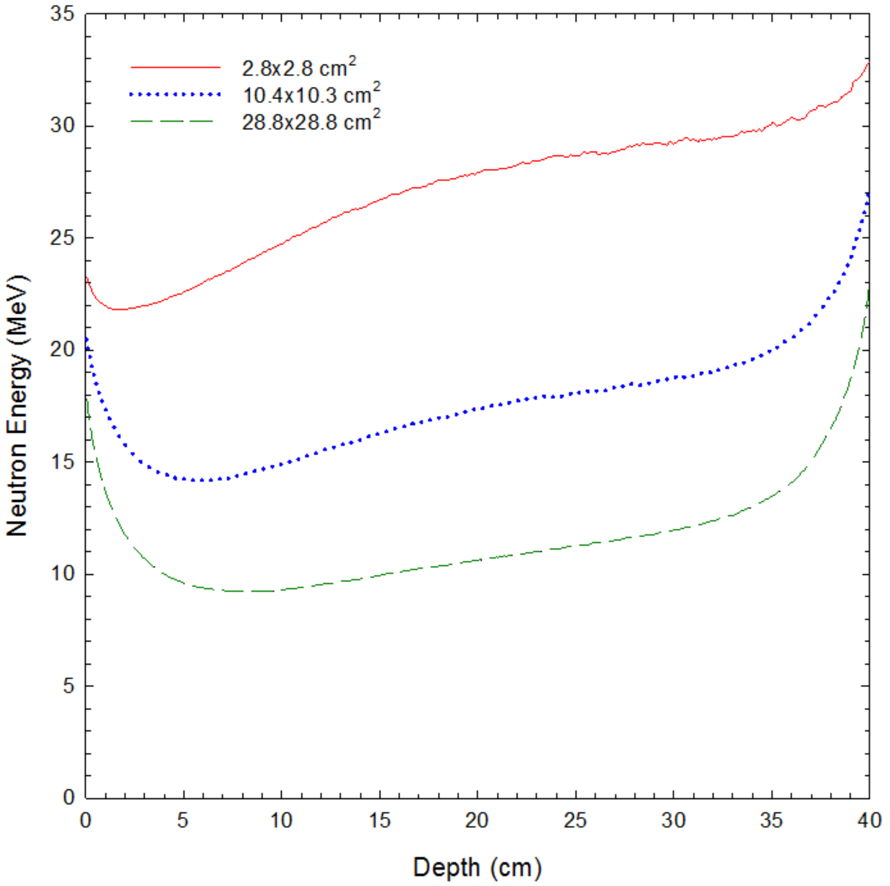
- Early clinical trials at the UW were with a fast neutron beam generated by 21.5 MeV deuterons (over 600 patients)
- Beam was switched to 50.5 MeV protons for higher dose rate (reduce treatment times)
- Deuteron generated neutron beam simulated in MCNP6 for RBE comparison to proton generated neutron beam

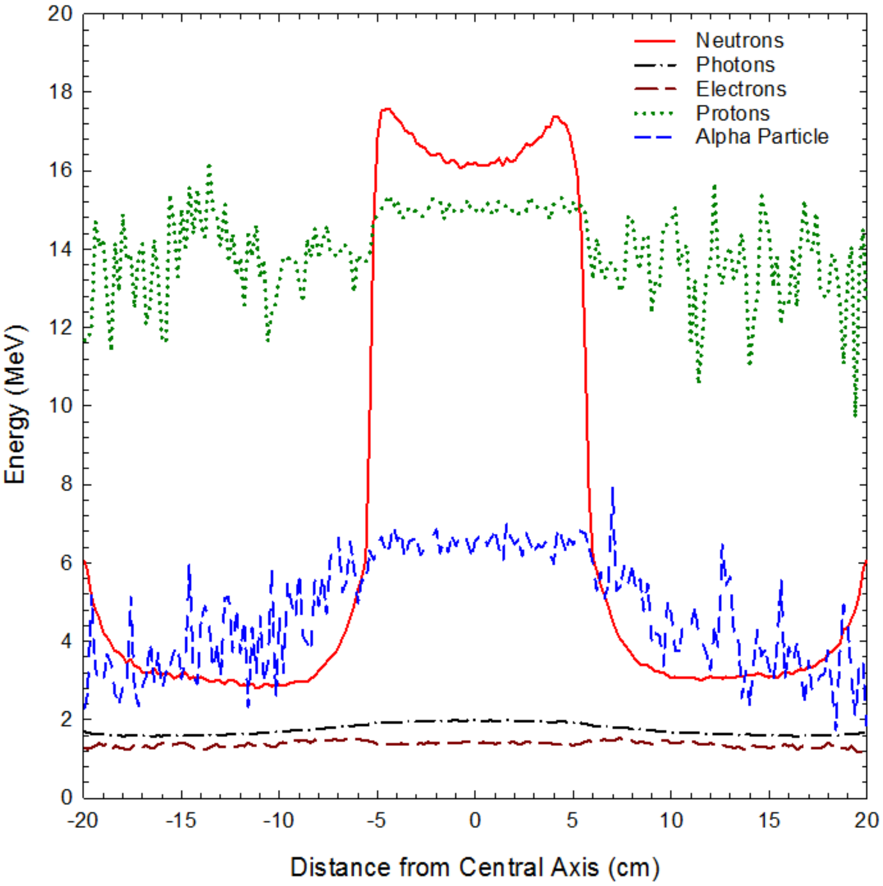


Average Proton and Alpha Particle Energy



Average Neutron Energy





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