UW Medicine
DEPARTMENT OF RADIATION ONCOLOGY

Neutron Dosimetry and Intensity Modulated Neutron Therapy (IMNT)

Adrienne Lehnert Ph.D., C.H.P.

UW MCF

CIRMS 2026 — Need

Annual Meeting · April 13–15, 2026

Progress in **advancing fast neutron patient treatment planning** is currently blocked because we lack **updated measurements of absolute dose to water, air, tissue, and bone**, which prevents **accurate patient dose calculations**.

Basically, an update to AAPM Report 7 Protocol for Neutron Beam Dosimetry (1980)

OUTLINE

- Introduction to UW Medical Cyclotron Facility (UWMCF)
- History of fast neutron therapy at UWMCF
- Characteristics of our neutron beam
- Patient treatment and planning
- Patient-Specific Quality Assurance
- Other activities:
  - Isotope production
  - Radiation Effects Testing
  - Preclinical research
- Opportunities and Challenges/Future directions

UW Medical Center

The cyclotron facility is housed within the Department of Radiation Oncology at the University of Washington Medical Center (UWMC).

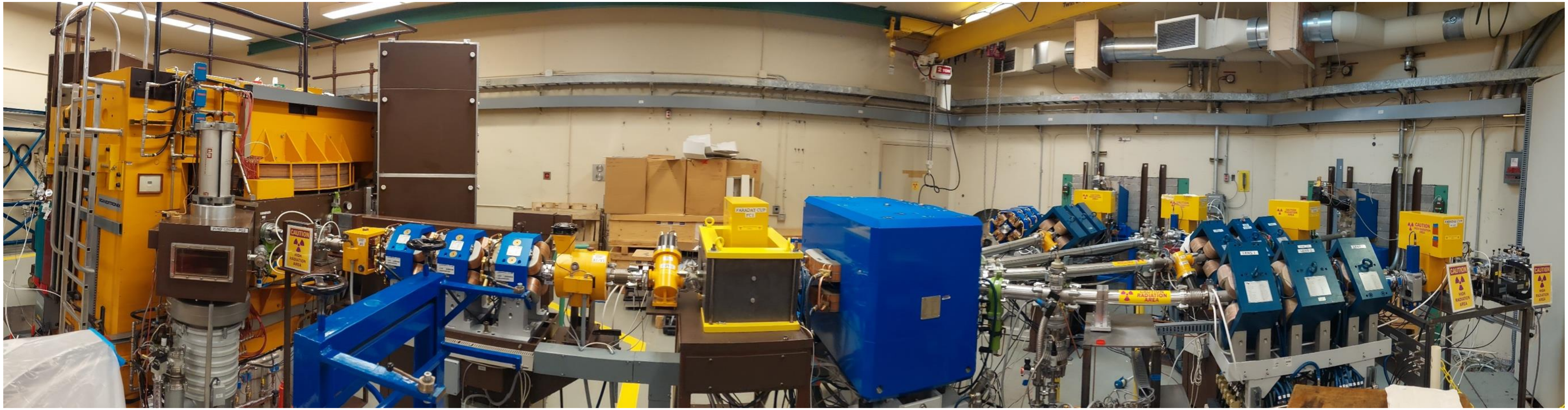
Our primary mission at the UW Medical Cyclotron Facility (UWMCF) is treating cancer patients with our fast-neutron beam. We also have a substantial radio-isotope production program, supported by the DOE's Isotope Program.

UWMCF Cyclotron

Particle acceleration capabilities:

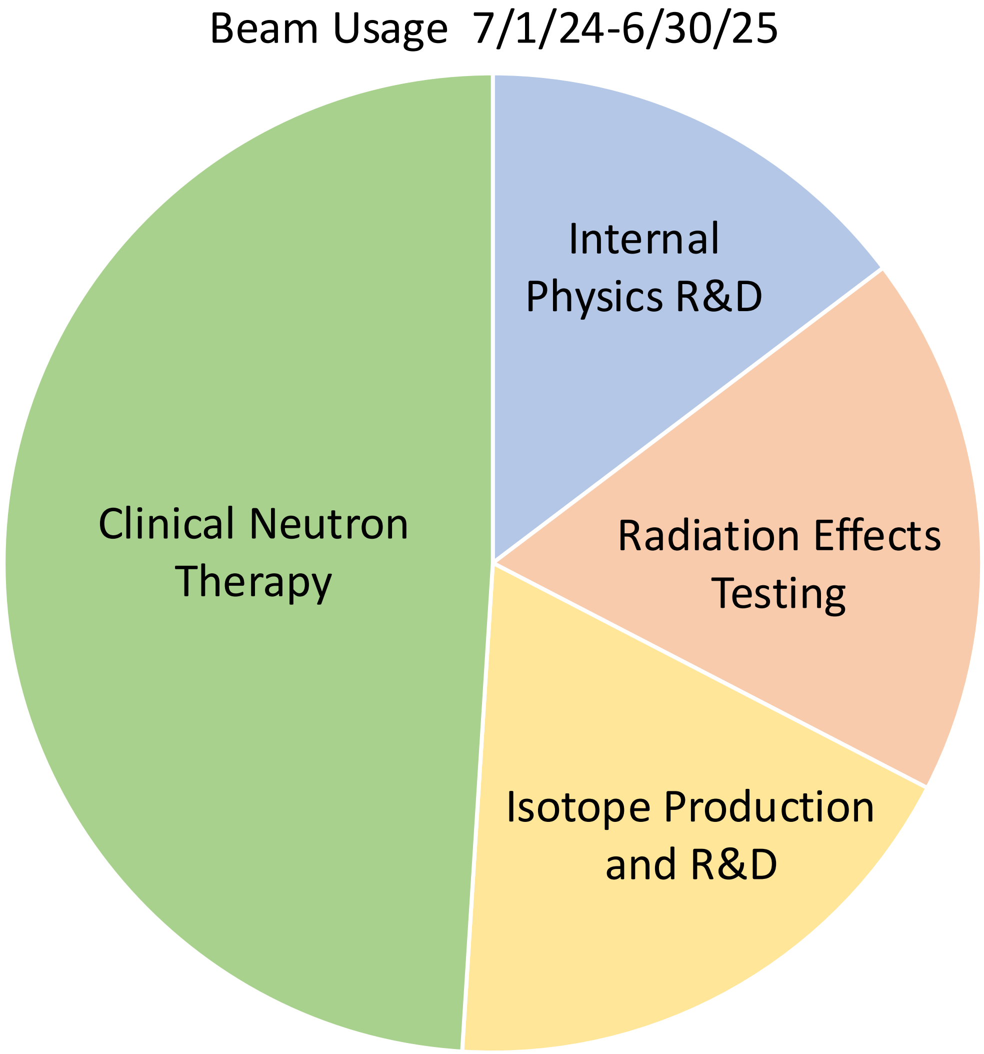
- Protons (28-50.5 MeV)
- Alphas (27-47.3 MeV)
- Deuterons (13.6-23.8 MeV)

Four beam lines in operation, with another in the works



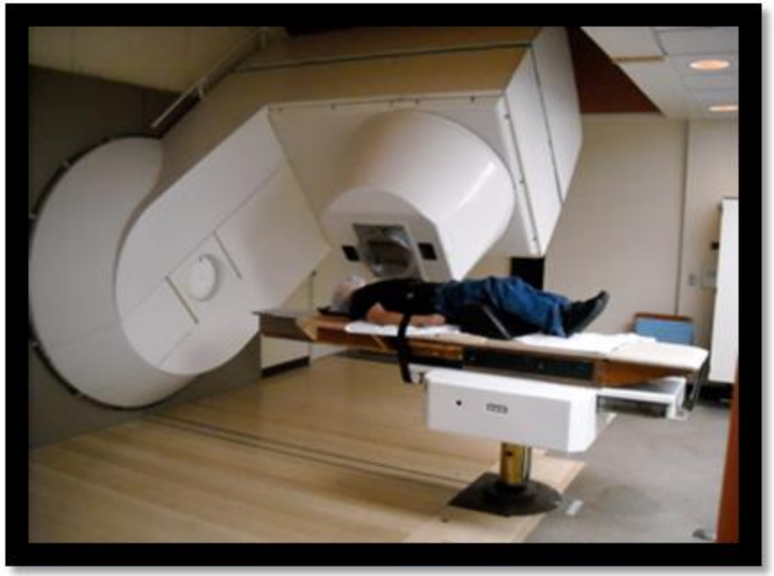
UWMCF beam time usage

- Clinical treatment with fast neutrons
  - Mainly head and neck cancers
- Isotope Production
  - Part of Dept of Energy NIDC
  - Isotopes used in preclinical research and clinical trials
- Radiation Effects Testing
  - Space and Energy industrial customers
  - Proton, neutron, and alpha
- Preclinical proton FLASH research



History of fast neutron treatment

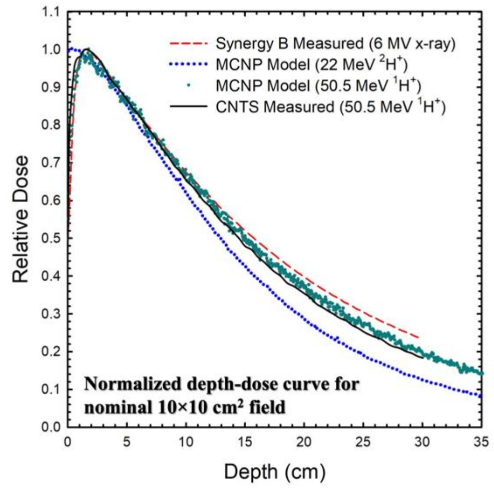
- The Clinical Neutron Therapy System (CNTS) used for treatment of cancers resistant to low LET x-rays and protons
- The CNTS has treated over 3,500 patients since 1984 and is especially effective against salivary gland and other photon-resistant tumors
- Implemented intensity modulated neutron therapy (IMNT) in Oct 2022, which improves off-target dosing compared to prior 3D conformal treatment techniques
- 90-95% of our patients are now IMNT

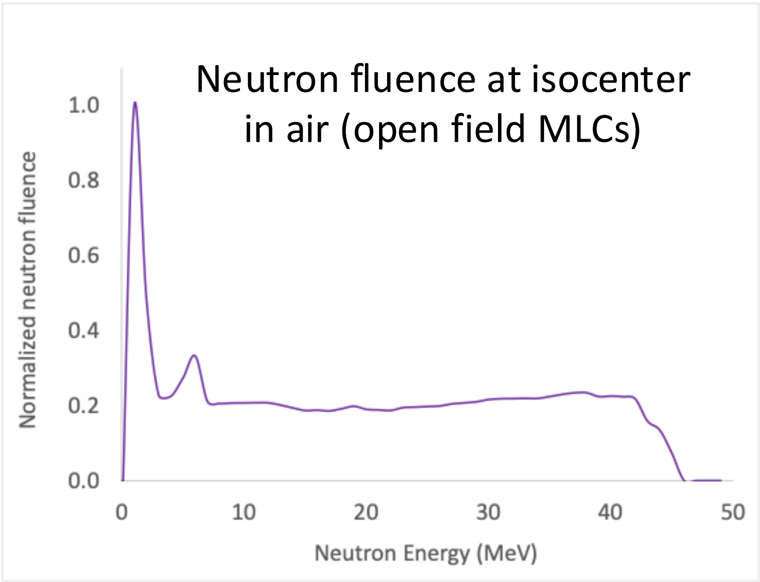


Isocentric fast neutron treatment gantry

Characteristics of neutron beam

- 50.5 MeV protons incident on Be target
- Average energy of 15-30 MeV depending on field size and shape
- 1.7×10^8 neutrons cm^{-2} s^{-1} at isocenter in air with 10 x 10 cm^2 MLC opening
- Depth dose profile similar to 6 MV x-rays
- Absolute calibration using NIST-calibrated IC-17 in water tank several times per year



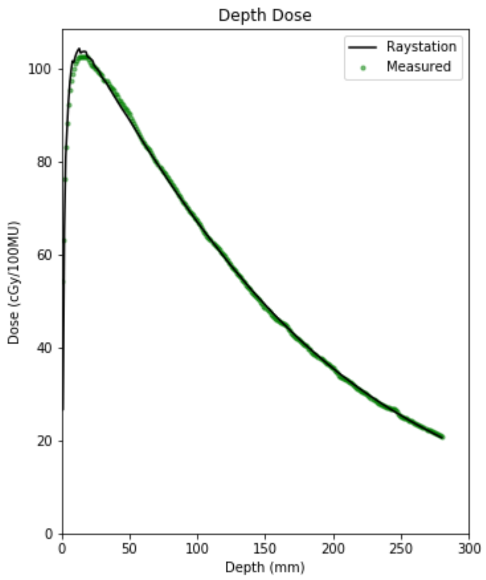


Beam Modulation and Patient Treatment

- Isocentric gantry with 360-degree collimator and table rotation
- Multi-Leaf Collimator (MLC)
  - Capable of delivering fields from $2.8 \times 2.8\ cm^2$ to $28.8 \times 28.8\ cm^2$
  - 40 leaves, entirely analog operation
- Wedges
  - 30- and 60-degree wedges available to create a dose gradient
  - Recently decommissioned in favor of Field-in-Field treatment plans using the MLC
- Typical treatment is (16 x 1.15 Gy = 18.4 Gy) compared to 70-80 Gy x-rays (**effective RBE $\geq$ 3.8-4.3**)
- Upgrades to MLC, control system, treatment planning, and patient-specific QA led to intensity modulated fast neutron treatment (IMNT)

Treatment planning and dosimetry

- Custom research build of RayStation
- Inverse planning for intensity modulated neutron therapy
- Neutron-specific dose collapsed cone and singular value decomposition kernels
- Validated against output factors, Percent Depth Dose, and lateral profile measurements using IC-17 chamber in water tank



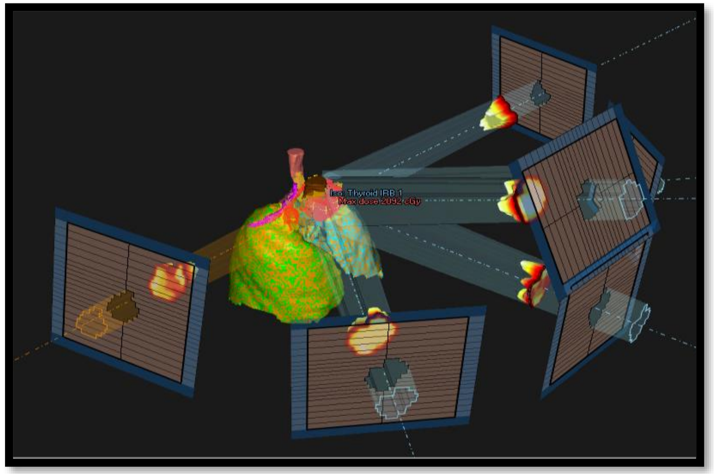
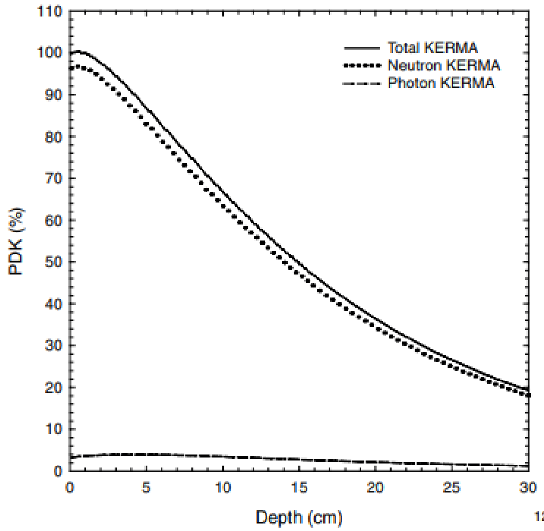


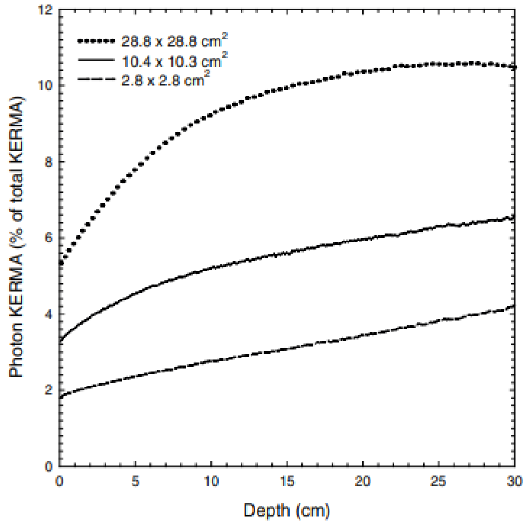
Illustration of IMNT 6 field plan

Dose Contribution from Photons

- Fast neutrons and related secondary charged particles deposit 90-95% of dose
  - $^{1}H^{+}$, $^{4}He^{2+}$, and a few higher Z ions)
- Photons contribute ~5-10% of dose
  - Depends on field size, depth and lateral location
  - Mainly from (n,γ) reactions with H_2O



Percent dose kerma (PDK) for neutrons and photons as a function of depth along central axis

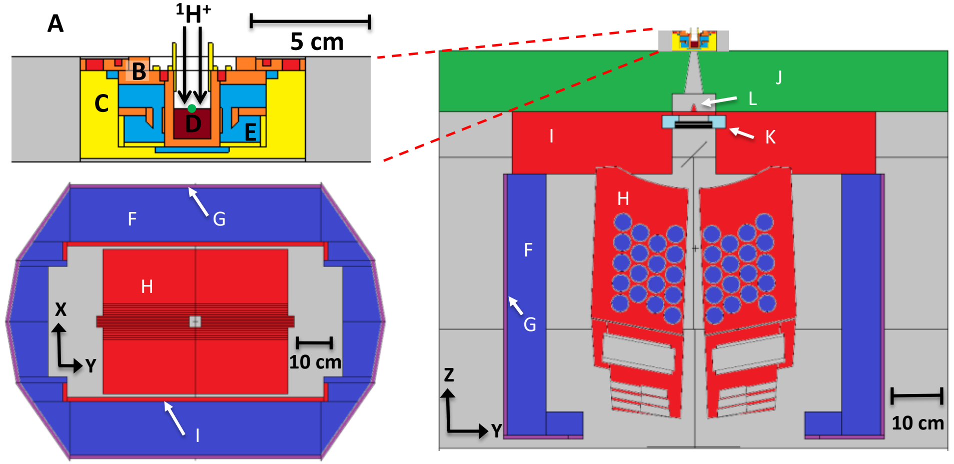


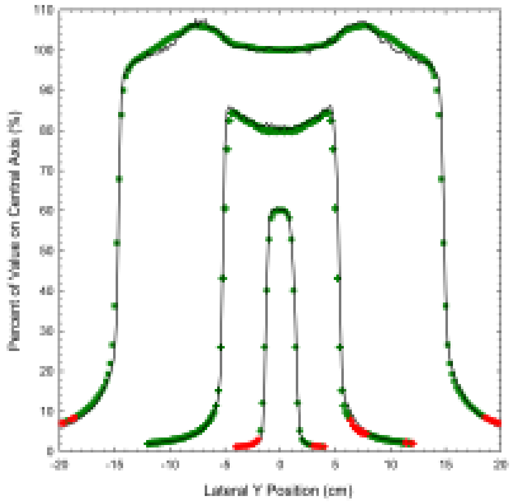
Photon percentage total dose as a function of depth for 3 sizes of square fields

Moffitt et al. 2016

Monte Carlo model of CNTS

- Used in Patient Specific Quality Assurance (PSQA)
- Research applications
- Validated with extensive IC-17 measurements
- Active area of development





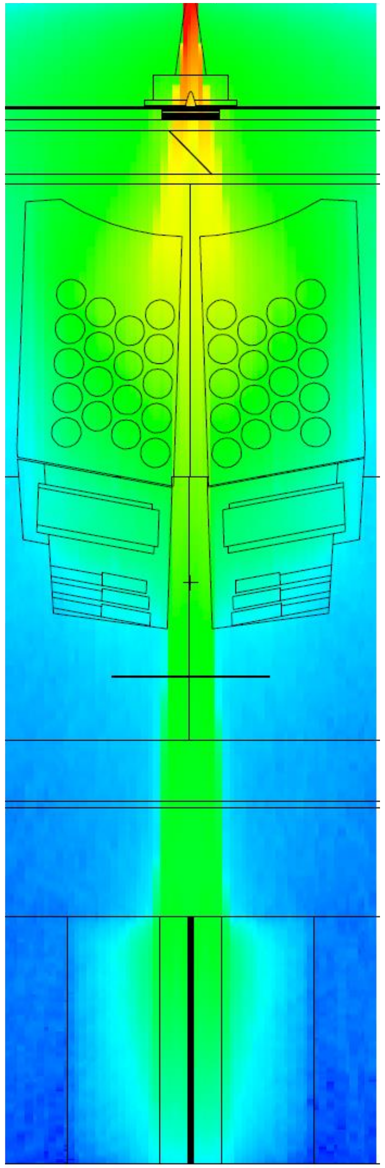
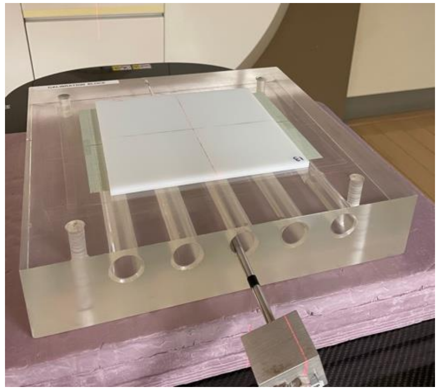


Illustration of MCNP simulation with shaded neutron intensity

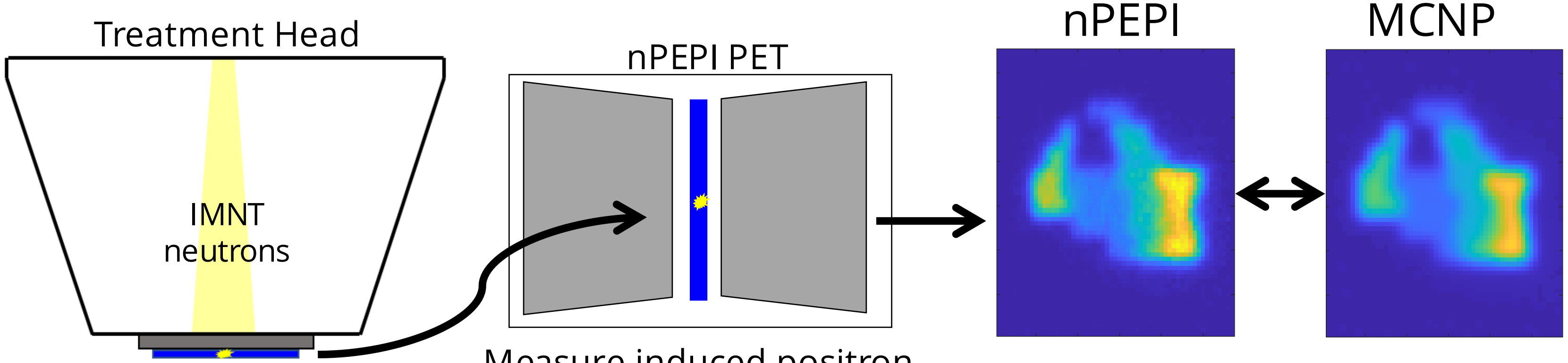
doi: 10.1088/1361-6560/aabd52. PMID: 29637903

Patient-Specific Quality Assurance (PSQA)

- High LET neutrons are <u>highly damaging </u>to electronics, so IMNT PSQA requires novel technologies and workflows
- Use a two-pronged approach to measuring PSQA
  - Measurements at isocenter with tissue-equivalent ionization chamber as a redundant confirmation of absolute dose
  - Measure induced ^{11}C activity using custom 2D PET scanner and compare ($\boldsymbol{\gamma}$-analysis) with Monte Carlo (MCNP) simulated activity maps



nPEPI plate on calibration block with IC-17 probe



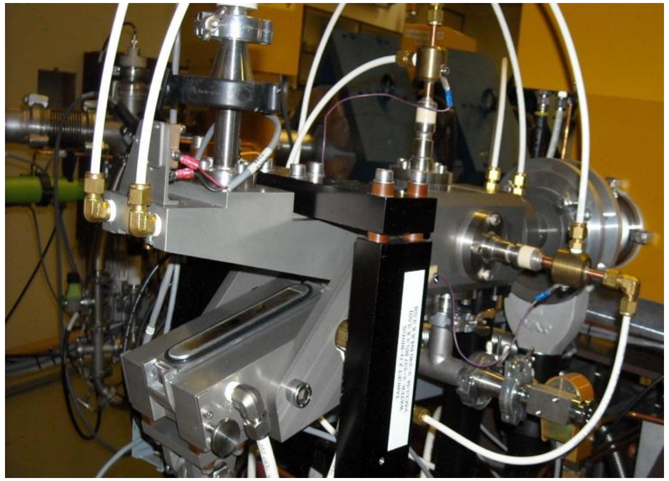
Irradiate polyethene plate

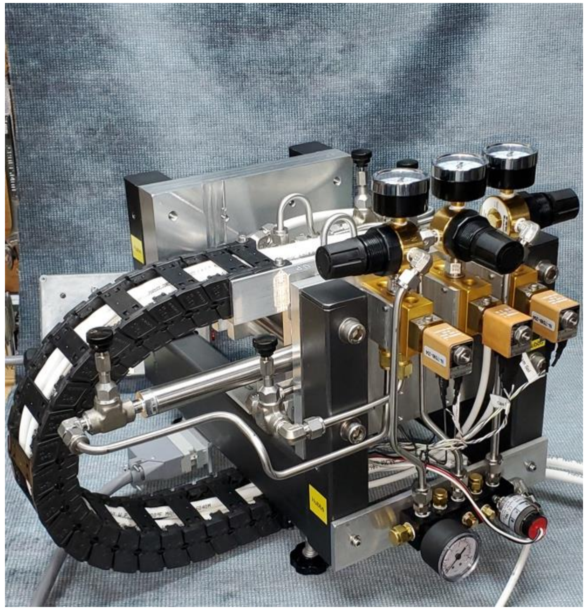
Measure induced positron activity with nPEPI

Gamma analysis of measured and simulated activity maps

Radioisotope Production

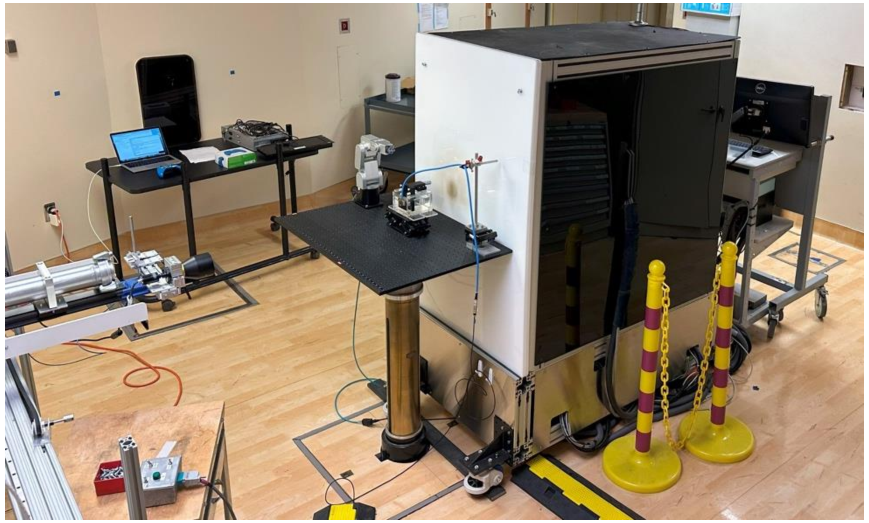
- Historical: ^{11}C, ^{18}F, ^{99m}Tc, ^{85}Sr
- Current: ^{117m}Sn, ^{155}Tb, ^{205}Bi, $\mathbf{^{211}At}$
- In development: $^{72}Se/^{72}As$, ^{155}Dy, ^{186}Re
- Two target stations
  - TRIUMF
  - In-house
- Hot cell with pneumatic tube transfer system
- Part of US Dept of Energy National Isotope Development Center (NIDC)

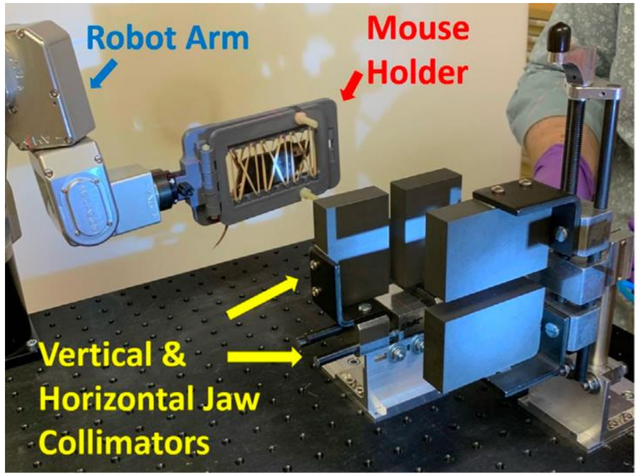




Proton beam in R&D

- 50.5 MeV native beam
- Graphite degraders
- MCNP models of native and degraded beam in laboratory space
- Preclinical proton FLASH
  - 50-80 Gy/s FLASH vs. 0.6-1 Gy/s conventional
- Radiation Effects Testing
  - Space/satellite component testing
  - Sometimes uses neutrons or alpha beam





Facility QA and maintenance

- Very low downtime: 52 weeks per year, delivering more than 98% of scheduled beams
- Full time engineering team (no field engineer support!)
- Comprehensive weekly/monthly/annual preventative maintenance schedule
- Full documentation and knowledgeable team has kept us going for 40 years!

Opportunities and Challenges

- We are a small interdisciplinary team. As such we each wear many different "hats", and the team is very agile.
- We love collaborating with other groups, and have an extensive network of academic and industrial partners
- Our 40-year-old facility must be kept running smoothly
  - Patient treatment necessitates very low downtime
  - It can be challenging to get parts
- Patient treatment always takes priority. This both limits time spent on research, but provides our guiding star: **we care for and advance our machine so we can help change lives**

Future Directions

- Academic and Industrial collaborations
- Improvements to treatment head Monte Carlo model
  - Moving to sdef model of neutron source
- Improvements to patient treatment
  - Looking into removal of flattening filter to speed treatment
- Other applications of the alpha beam (rad effects)
- Further characterization of beams for rad effects testing
- Cyclotron operator training program

Acknowledgements

Cyclotron team:
Marissa Kranz
Devin Short
Bob Smith
Geoff Avila
Al Mullen
Zack Lindbloom-Brown

Medical Physics team:
Robert Stewart
Jie Fu

Alumni:
Greg Moffit
David Argento

The UW Medical Cyclotron Facility and its research is supported in part by the US Department of Energy Isotope Research and Production, managed by the Office of Science for Isotope R&D and Production (DE-SC0019197)

Thank you!