AbstractID: 2798 Title: Effect of Range Modulation on Neutron Dose Equivalent Exposures Around a Passive Scattering Proton Therapy Treatment Nozzle

Purpose: The purpose of our study was to examine the influence of range modulation on the neutron dose equivalent exposures outside the treatment volume around a large-field passively scattered proton therapy treatment nozzle.

Method and Materials: In this study, the neutron dose equivalent spectra per proton ($H(E/p)$) and total neutron dose equivalent per therapeutic absorbed dose (H/D) were calculated using Monte Carlo simulations of the neutron fluence and the energy dependent neutron fluence-to-dose equivalent conversion factor for NCRP 38. ($H(E)/p$) and H/D were calculated at 54 locations around a passively scattered proton therapy treatment nozzle for varying amounts of range modulation.

Results: As the step thickness of the range modulator wheel increased from 1.0 to 12.0 cm, the peak values of $H(E)/p$ increased from $1 \cdot 10^{-17}$ to $2 \cdot 10^{-17}$ mSv/Gy at 50 cm from isocenter along the beam's central axis. In general, H/D increased with increasing range modulation at all locations studied, and the maximum H/D exposures shifted upstream of isocenter and away from the end of the nozzle.

Conclusion: Several important findings can be summarized from the presented work. First, with increasing thickness of the RMW step, the high-energy peak in the $H(E)/p$ spectra shifted to higher energies. Second, at 90^{o} with respect to the proton beam axis, the high-energy peak occurs at substantially lower neutron energies. Also, the H/D values around the treatment nozzle increased as the modulation of the beam increased. Finally, the H/D values change significantly with distance from isocenter and angle with respect to the incident beam axis, due in part to the effects of the nozzle components on the neutron fluence downstream of the end of the nozzle.