AbstractID: 8063 Title: Opening Comments and Uniform Beam Scanning Systems

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With the expansion of proton therapy has come the desire to update the beam generation and delivery technology for the goal of increasing the conformality of the technique while minimizing risks to the patient such as from out of field dose, mainly from neutrons. The efforts stem from the fact that the vast majority of proton therapy centers rely on the historic passive double foil spreading beam production with fixed range modulators[i,ii]. Although the passive beam spreading technology is capable of delivering highly conformal fields, improvement can be realized by active beam scanning[iii,iv] whilst also reducing out of field dose, mainly from neutrons[v]. The maximum field size for passive spreading systems also becomes practically limited due to the increased thickness of scattering material required for larger field sizes. Magnetic scanning has the potential to outperform scattering in this regard, although is expected also to be practically limited by scanning magnet strength.

Beam scanning can result in uniform or non-uniform delivery (intensity modulation). This presentation describes the common methods of uniform field delivery and specifically the design and characterization of the uniform scanning system developed at the Indiana University Cyclotron Facility (IUCF) and Midwest Proton Radiotherapy Institute (MPRI)[vi]. The uniform scanning nozzle design overview is shown in Figure I.

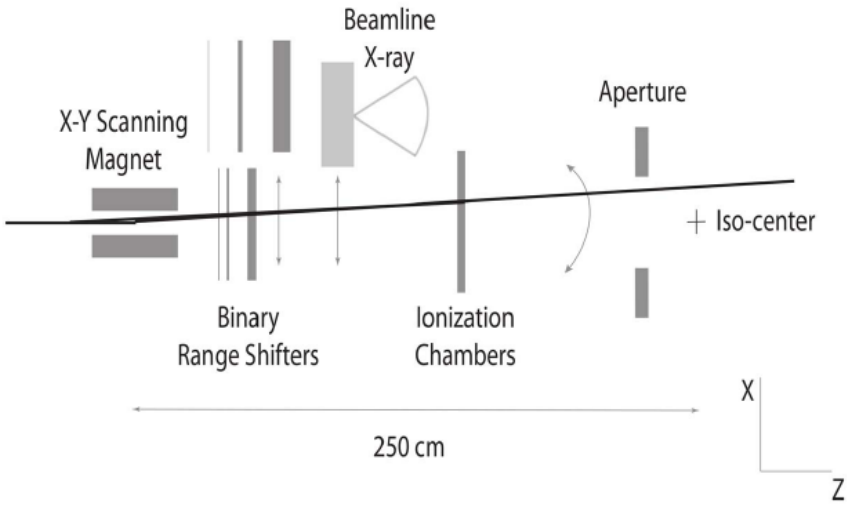

Figure I: Schematic (not to scale) of the uniform scanning nozzle. The proton beam is magnetically scanned by the X-Y electro-magnet. Spread out Bragg peak (SOBP) generation is by a binary range shifter. An aperture is required to reduce the transverse penumbra.

In specific for this system the main characteristics of dose fields produced by the system including transverse, longitudinal, penumbra and absolute dosimetry commissioning results are presented. Using a 208 MeV cyclotron's proton beam, the system provides field sizes up to 20 cm and 30 cm in diameter for proton ranges in water up to 27 cm and 20 cm, respectively. The dose

layer stacking method allows for the flexible construction of spread-out Bragg peaks with uniform modulation of up to 15 cm in water, at typical dose rates 1 - 3 Gy/min. For relative field characterization, multi-element ion chamber arrays, small-volume ion chambers, and radiographic films were employed. Absolute dose measurements were done using calibrated ion chambers, thermoluminescent and alanine detectors. Clinical commissioning of the system has shown that the lateral and longitudinal uniformity of 2.5% or better can be achieved for all clinically important field sizes and ranges. These properties were confirmed within the definition of applied dose reference volumes (Figure II).

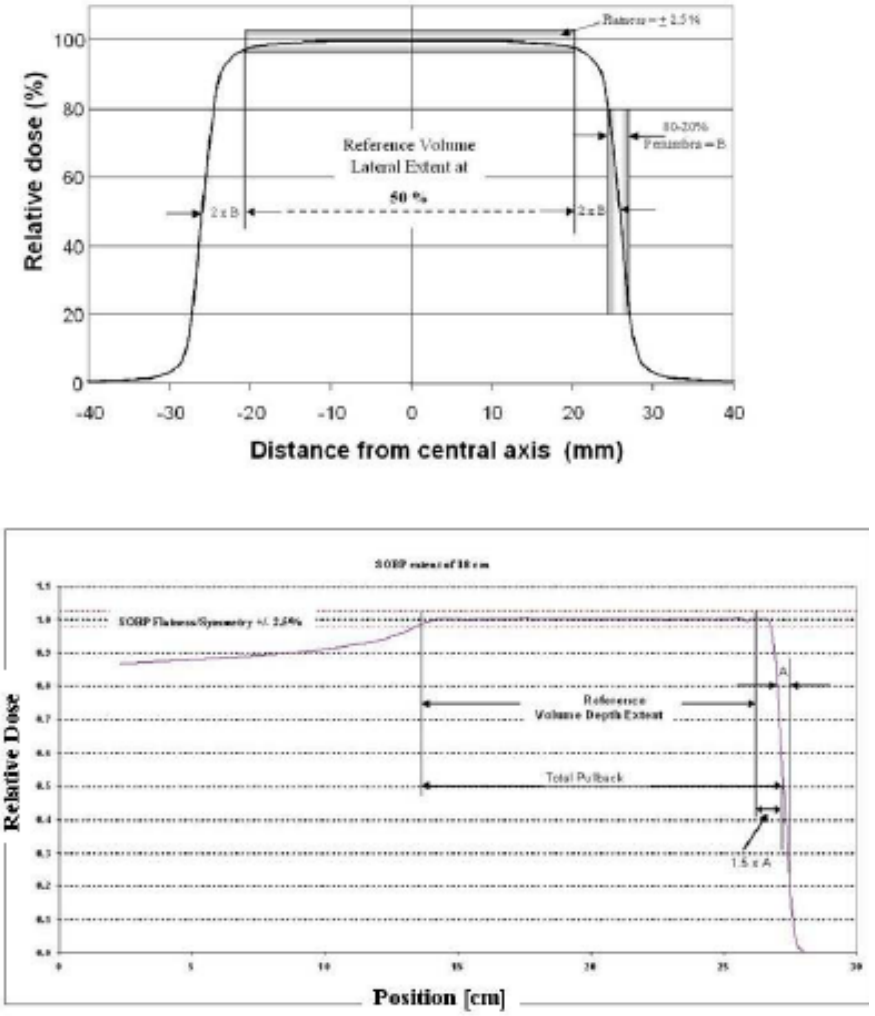

Figure II: Dose reference volume (DRV) definitions. The DRV is defined as 2 penumbra widths 80% - 20% inside the 50% isodose laterally, 1.5 distal fall-off widths (80% - 20%) inside the 50% isodose distally and 1 total pullback water-equivalent thickness inside the (distal) 50% isodose proximally. The design goal for dose uniformity (flatness and symmetry) over the dose reference volume was specified at 2.5%[vii].

Representative longitudinal and transverse results are shown in Figures III and IV, respectively. Absolute dose comparisons conducted using various types of detectors traceable to a national standards laboratory indicate that dosimetry results agree within 3%. The uniform scanning and dose layer stacking system has been commissioned, received the United States Food and Drug Administration 510(k) clearance, and put into clinical practice. The uniform scanning and dose layer stacking system on a gantry, the first of its kind in proton therapy. The versatility of the system allows one to regard it as an intermediate step toward the implementation of pencil beam scanning.

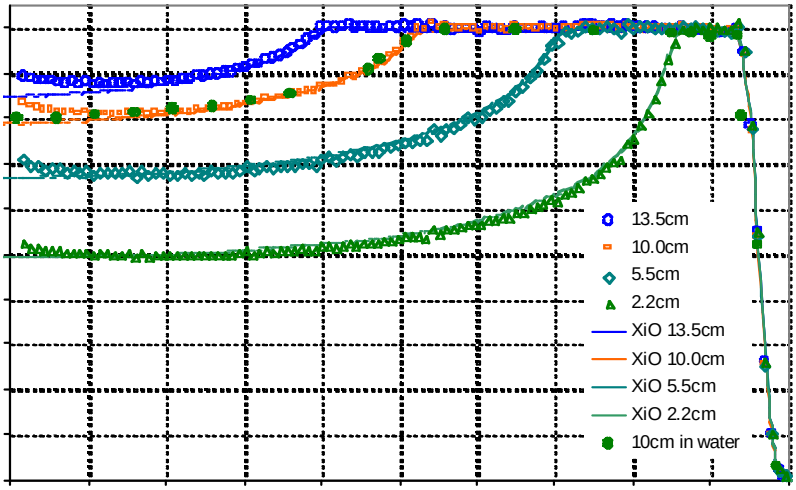

Figure III: Representative spread out Bragg peaks for the high energy regime. The SOBPs were designed in part by adjusting the individual layer weights to produce the nominally flat longitudinal distributions validated in the figure at a chosen energy. In this case the chosen energy was 208 MeV (range of 27 cm in water). A comparison to the longitudinal dose calculation the treatment planning system (XiO) is also validated.

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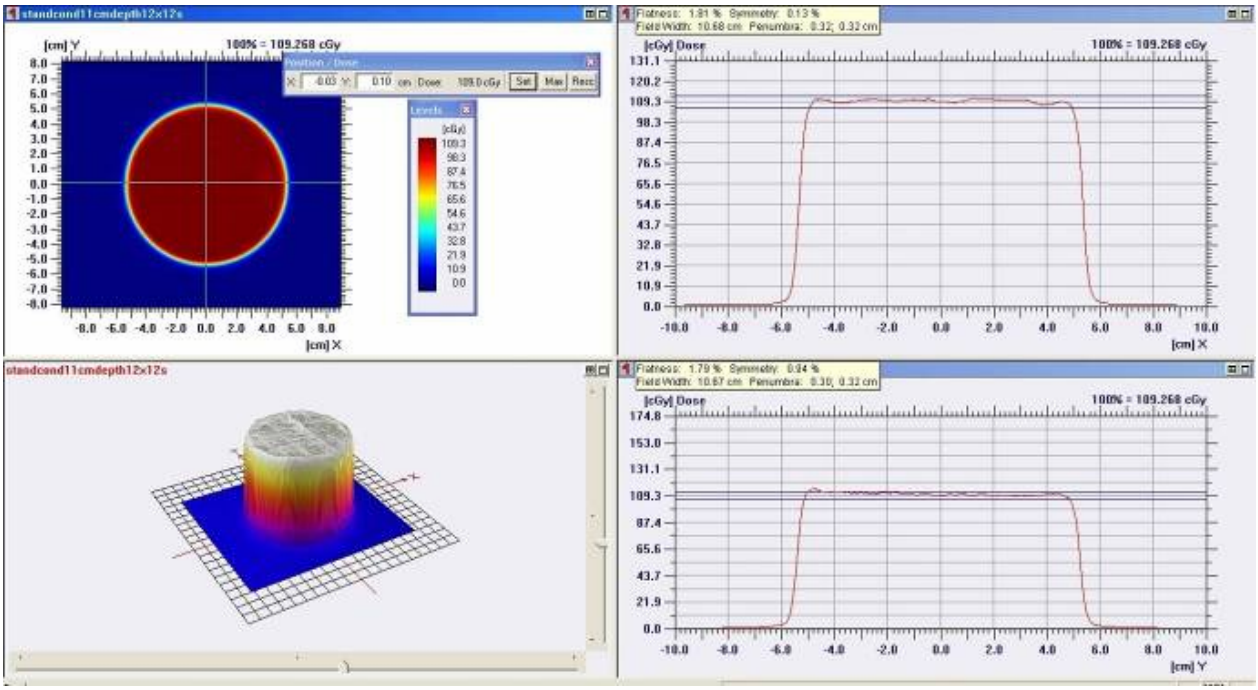

Figure IV: Representative X-Y beam profile characterized with radiographic film at center of DRV for 26 cm water range, 10 cm SOBP.

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[vii] S. Klein, "Clinical performance requirements," Indiana University Cyclotron Facility Report No. 100041 (2003) with modification by D. Nichiporov of DRV definition.