Purpose: Cylindrical ion chambers are known to overestimate the dose in the buildup region, where gradients are high. The potential for MCNP5 to produce accurate calculations in this region, even when benchmarked with a large volume chamber, was tested.

Methods: MCNP5 was used to model 6 and 18 MV photon beams for a Varian accelerator using vendor geometry with the collimator corrections of Chibani and Ma. Modeling was benchmarked by adjusting electron beam energy and diameter to match calculations with ionization chamber (with 0.125 cm$^3$ sensitive volume) measurements of percent depth doses (PDDs) beyond dmax and cross dose profiles for 5$\times$5, 10$\times$10 and 30$\times$30 cm$^2$ field sizes. For comparison in the buildup region, the MCNP5 voxel was reduced to 1 mm, with extrapolation to find surface dose. In this region a plane parallel chamber (with 0.055 cm$^3$ sensitive volume) was used to measure PDDs at 0, 2 and 4 mm depths for the three field sizes, using the Khan over-response correction.

Results: Calculations and cylindrical chamber measurements for PDDs beyond dmax agree within 2% for all field sizes and energies. Dose profiles at dmax (1.5 cm and 3.3 cm for 6 and 18 MV) and at 10 cm agree within 2% in the flat region and within 10% in the penumbra. In the buildup region, the MCNP5 calculations agree with plane parallel PDD measurements within 3% at 2 and 4 mm depths. The extrapolation of the MCNP5 PDD overestimates the surface dose for the 18 MV beam for the 30$\times$30 cm$^2$ field, and is within 4.2% for the smaller fields and for all field sizes at 6 MV. Improved extrapolation techniques may yield better surface dose agreement.

Conclusions: Accurate dose in the buildup region can be calculated by MCNP5