Verification Measurements on Single Section or in Air on ICRU/AAPM Long CT Phantom: Application of AAPM Report 200

D. BAKALYAR , J STEINER[1] Henry Ford Health System, Detroit, Michigan ([1]Now with the Maine Medical Center in Portland, Maine.)

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INTRODUCTION

AAPM Report 200 describes the implementation of ideas put forth in Report 111, written to address some of the limitations of the CTDI phantom and to extend the method to provide a more complete portrayal of radiation dose behavior in a simple geometry. The resultant ICRU/AAPM phantom, displayed in Figure 1, is a polyethylene cylinder 60 cm long and 30 cm in diameter, constructed in three 20 cm long sections. It is long enough to capture essentially the entire dose profile (including the extensive scatter), and to foster the determination of the rise to equilibrium function $h(L)$ along the central axis (z axis), and in a parallel channel near the edge at a 13.37 cm radius. (A third intermediate radius channel is available as well.) However, the large size of the phantom makes it impractical for routine QC and so, following the suggestions in Report 200, we have made measurements in air and in a single section to see if such measurements could serve to verify measurements made in the entire phantom.

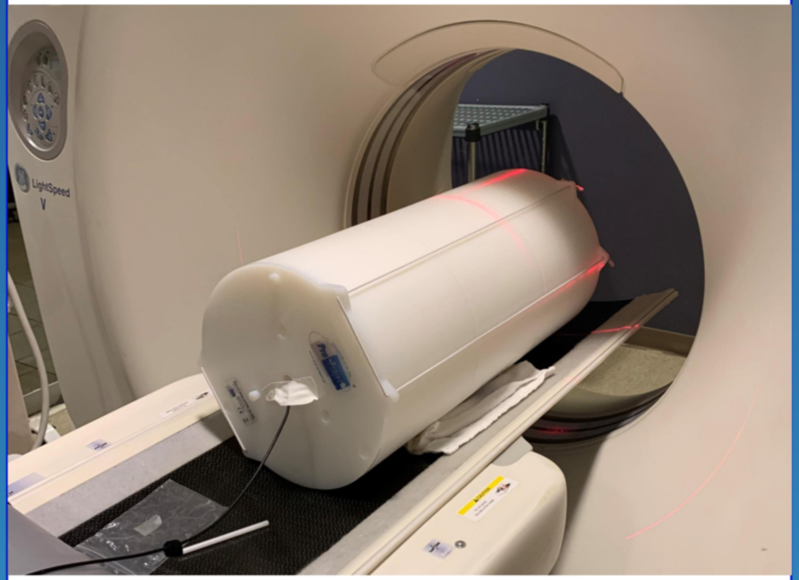

Fig. 1: The ICRU/AAPM phantom fully assembled and positioned.

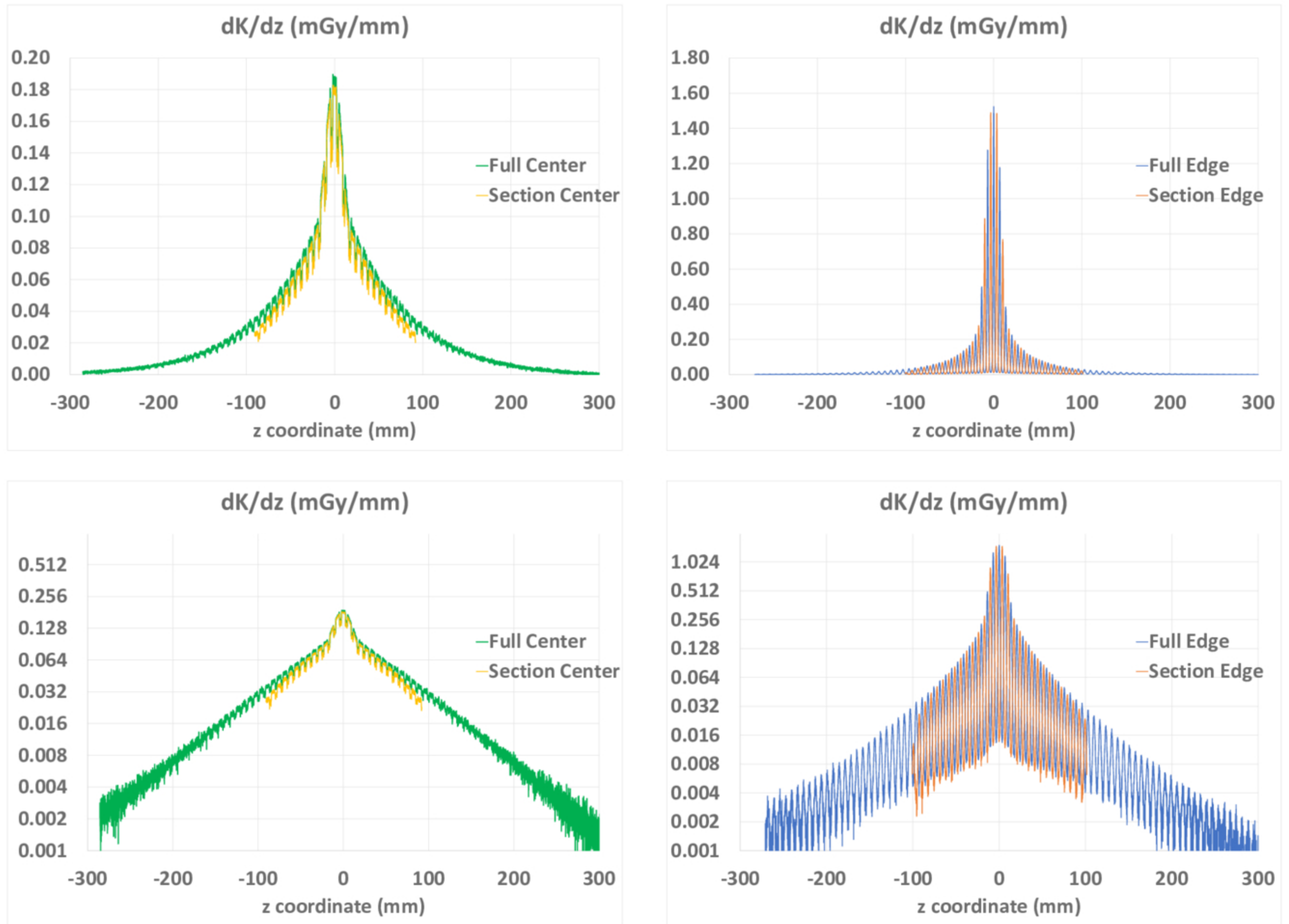

Fig. 2: dK/dz for scans of full 600 mm phantom and 200 mm sections with the thimble dosimeter at 120 kV. On the left are the linear and logarithmic (base 2) plots for the scan along the center; on the right are the corresponding plots for the scan along the edge. Note the large difference in scale between edge and center plots; yet the integrals D_{eq} between center and edge are comparable. The scans depicted were performed on a Philips Brilliance 64, 16 x 0.625 mm collimation, 0.685 pitch, 0.4 s rotation time, 163 mA (CTDI 8 mGy).

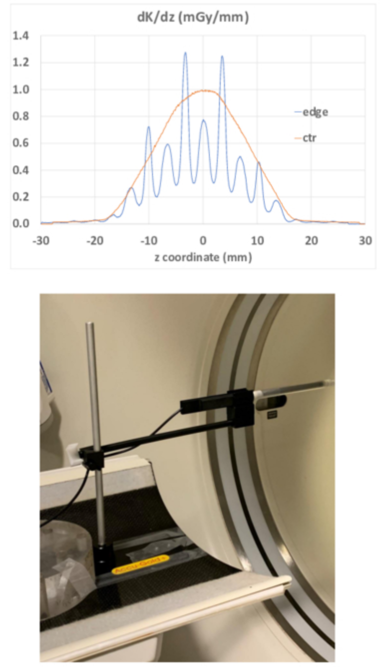

Fig. 3: Scans in Air at the center and off center (edge) positions (with the table outside of the beam).

radius	# sec-tions	VCT 80 kV	Br64 80 kV	VCT 100 kV	Br64 100 kV	VCT 120 kV	Br64 120 kV	VCT 140 kV	Br64 140 kV
ctr	1	49	38	98	80	159	133	228	195
ctr	3	64	51	132	109	216	187	315	273
ctr	air	102	68	182	130	278	211	391	299
edge	1	58	43	109	87	173	142	246	204
edge	3	66	50	128	102	201	166	289	245
edge	air	59	42	111	83	173	135	248	198

The table shows the integrated dose over the length of the scan. All values are normalized by the effective tube current-time product expressed in Ampere seconds. Thus all values are in mGy/As or mGy/C. The effective tube current-time products were 128 mAs for the GE VCT and 95.2 mAs for the Philips Brilliance 64.

METHOD

A small thimble chamber, 0.6cc in volume and 19.7 mm in length (Radcal 10X6-0.6CT) was positioned in the central plane of the phantom, either at the center or at the edge position. Scans over the full 60 cm length of the ICRU/AAPM phantom were performed along the central axis and along the edge for multiple tube potentials for both a GE VCT and a Philips Brilliance 64 CT machine. The process was repeated on a single 20 cm length section of the phantom and again in air where the air scans were performed without the table in the beam both at isocenter and at the edge position 13.37 cm above isocenter. During the scans, the instantaneous air kerma rate, dK/dt, was measured and recorded as a function of time. Dividing by the table speed, dz/dt, then yielded dK/dz, the differential air Kerma absorbed per unit distance as a function of position along the length of the phantom. Air scans and other selected scans were also performed with a standard CTDI pencil chamber (Radcal10X6-3CT) and $CTDI_{vol}$ was measured for reference.

In accordance with the recommendations of AAPM Report 200, scans were performed at the narrowest beamwidth and lowest pitch available. This was to keep b, the table movement per rotation as small as possible in order to adequately sample the dK/dz waveform. Because of near cylindrical symmetry, the waveform is insensitive to b along the central axis; however, large table excursions per rotation can introduce significant error at the edge[tg200]. The Philips scanning parameters are given in the caption for Figure 2. For the VCT, the scans were performed with 32 x 0.625 mm collimation, 0.531 pitch, 0.8 s rotation time, 100 mA (CTDI 12.77 mGy).

Air scans on the Philips scanner at 120 kV are shown in Figure 3. The plots were acquired using the 0.6 cc thimble chamber. (Scans were also performed using the standard CTDI pencil chamber. In air, the measured values between the two chambers were virtually identical.)

RESULTS

Figure 2 demonstrates that the scan through the single section by itself is only slightly depressed from that of the center section when the full phantom is being scanned on the Philips Brilliance 64. Similar results hold for the GE VCT. Fine tuning D_{eq} as discussed in Appendix 5 of AAPM Report 200 worked very well for the full phantom. The method described therein, adjusting D* in the equation

$$g(L, D^*) = \log\left[1 - \frac{h(L)}{D^*}\right]$$

until the plot becomes a straight line, worked well for the three sections as expected and as might be anticipated from the log plots of the three section data shown in Figure 2. Using the same method on a single section did not find the same value for D_{eq} as for three sections, falling short by as much as 23%. Nonetheless, it is expected that single section measurements could be used successfully to verify full phantom measurements.

The table shows the integrated dose for the scan through the phantom or single section. All values are normalized by the tube current-time produce expressed in Ampere-seconds. Note that the corresponding values between the two scanners are comparable and all follow the same trends.

RESULTS (CONTINUED)

The results in air were very encouraging. The trends between air and the full and short phantoms were similar. The central values for air were always higher than the corresponding edge values; they were always lower for the 1 section measurements. For the three section measurements the center and edge measurements were comparable.

Air scans at the edges were very reproducible despite the scan angle dependent structure shown in Figure 3 with the standard deviation on the order of 1% or less.

CONCLUSIONS

Scanning a single section would readily serve as a verification for scanning the entire ICRU/AAPM phantom. Even better, we are quite confident that scanning in air may serve the same purpose, especially if scanning both at the axis of rotation and off axis at a fixed amount (easily accomplished by simply raising the table and re-scanning). Note that the off-axis measurements are important; the central axis measurement samples only the central beam and does not test the bowtie filter.

Our previous measurements demonstrated that the approach to equilibrium function $h(L)$ is very similar for different scanners and even at different tube potentials and varies predictably with detector position. Our current measurements hold the promise that the ICRU/AAPM phantom performance can be verified with a single section or even with measurements in air alone.

REFERENCES

- AAPM Report 111: Comprehensive Methodology for the Evaluation of Radiation Dose in X-Ray CT (2010)
- AAPM Report 200: CT Dosimetry Phantoms and the implementation of AAPM Report 111 (2020)
- Steiner J, and Bakalyar D. A Comparison of the Approach-To-Equilibrium Function Measured on CT Scanners from Four Different Manufacturers Using the ICRU/AAPM CT Radiation Dosimetry Phantom. J Med Phys 2019; 46(6):e519-e520.

CONTACT INFORMATION

Donovan M. Bakalyar, Ph.D. donovanb@rad.hfh.edu.