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A comparison of the basic photon and electron dosimetry data for Neptun 10PC linear accelerators

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Abstract. In recent years the similarity of dosimetric characteristics of modern linear accelerators with the same make, model and nominal energy, has become more common. The goal of this study was to quantitatively investigate the reproducibility of the basic photon and electron dosimetry data from Neptun 10PC accelerators across the institutions. In the current study, the photon and electron dosimetry data collected during acceptance and initial commissioning of six Neptun 10PC linear accelerators are analyzed. The dates of original installations of these six machines were evenly spread out over a 5 year period and the series of measurements were conducted during an average of 1–2 months after original installations. All units had identical energies and beam modifiers. For photon beams, the collected data include depth dose data, output factors and beam profile data in water. For electron beams, in addition to depth dose data and output factors, the effective source skin distance for 10 × 10 cm field size is also presented. For most beam parameters the variation (one standard deviation), was less than 1.0% (less than 2% for 2 parameters). A variation of this magnitude is expected to be observed during annual calibration of well-maintained accelerators. In conclusion, this study is presenting a consistent set of data for Neptun 10PC linear accelerators. This consistency implies that for this model, a standard data set of basic photon and electron dosimetry could be established, as a guide for future commissioning, beam modeling and quality assurance purposes.

Key words: dosimetry • photon beam • electron beam • linear electron accelerator

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Introduction

Establishing standard dosimetry data for medical linear accelerators of the same make and model and nominal energy has been recommended by Cho *et al.* [1, 2]. It has been suggested that a photon reference data set can be used commonly as a guide for commissioning, beam modeling and quality assurance (within a clinically acceptable tolerance), as long as the following conditions are met:

a) make, model, and nominal energy of the machines are identical and have not been altered from the manufacturer's original specifications;
b) the data are accumulated through consistent measurements [1, 2].

There have been several investigations on common applicability of dosimetry data for Philips/Elekta, Siemens and Varian linear accelerators of the same make and model [1, 2, 5, 7]. In this work, a similar investigation is carried out for Neptun 10PC linear accelerators (manufactured in Poland by IPJ-ZdAJ Świerk). This unit and older version, Neptun 10P, are a Polish version of the French accelerator Neptune, manufactured under license from the French designer and manufacturer. The data presented here was accumulated during commissioning of six Neptun 10PC linear accelerators, by one physics team. The dates of original installation and commissioning for these six machines were evenly spread out over a 5 year period. Therefore, there was very little correlation between these accelerators. All units were commissioned during an average of 1–2 months after original installations and they were not changed from the manufacturer's original specifications. In order to make the measurement technique and data analysis methods consistent, identical dosimetry devices and protocols were used.

Methods and materials

Neptun 10PC is a PC controlled unit with beam generating components unchanged from analog predecessors, Neptun 10P and Neptune. The RF generator is a magnetron, the standing wave structure is one meter long and the X-ray target is fixed. In electron mode, a deviation coil is used to change the electron trajectory in such a way to avoid the target. The accelerator generates a photon beam of 9 MV and 3 electron beams of 6, 8 and 10 MeV nominal energies. Electron beams are scattered by 2 scattering foils, one for 6 and 8 MeV and a separate one for 10 MeV. X-ray jaws are consisted of four pairs of leaves. Each leaf is slightly curved and move in an arc shaped path. Two pairs of variable applicators are used to define the electron beam and create electron field sizes ranging from 3 × 3 cm to 25 × 25 cm. This model is designed to move the X-ray jaws asymmetrically, up to 1.5 cm away from the collimator axis. Electron applicators are attached to the X-ray jaws and move with them in an arc shaped path as well. Therefore, the gap between the applicator edges and the isocenter changes with field size. The source-applicator distance for a 10 × 10 cm field is 99.5 cm.

Acceptance testing procedures and data collections were performed using the ZdAJ supplied acceptance procedures [6]. For photons, the ratio of percentage depth dose (PDD) values, at 10 and 20 cm depth (D_{20}/D_{10}) and for electrons, the practical range, R_p, are the key beam parameters for acceptance. Accordingly, beam quality and symmetry and flatness were set as follows:

a) for 9 MV photon beam a value of 0.62 is specified for D_{20}/D_{10} for a 10 × 10 cm field size at 100 cm source skin distance (SSD);
b) for electron beam, the practical range (R_p) is specified as follows: 2.85 to 2.95 cm for 6 MeV; 3.85 to 3.95 cm for 8 MeV and 4.85 to 4.95 cm for 10 MeV using depth dose curves measured for a 10 × 10 cm field size at 100 SSD;
c) a 3% criterion for flatness and symmetry is specified at the depth of maximum dose ($d_{\max}$) over 80% of a field size of 30 × 30 cm for photon beams, and 25 × 25 cm for electron beams, both at 100 SSD.

For relative dose distribution data collections, Scanditronix water scanning systems, consisting of a 50 × 50 × 50 cm^3 water tank and a 3D scanning mechanism (RF300 software version 5.3) equipped with p-type silicon diodes, were used. The manufacturer's specification of repeatability of positioning the diodes with the scanning system is ± 0.1 mm. Effective points of measurement for photon and electron diodes are 0.5 ± 0.15 mm and 0.45 ± 0.1 mm from the front wall, respectively. For each measurement, the reference diode detector was placed in air at a fixed position relative to the linac head and a second diode was used as the dose detector. The ion chambers used for relative and absolute values of photon beam outputs were Wellhofer FC65G (IC70) farmer type ion chambers with an active volume of 0.65 cm^3. For all units, relative and absolute values of electron beam output were measured using Scanditronix NACP parallel plate chambers with an effective point of measurement at the back of the front entrance wall of 0.6 mm of Mylar (0.1 mm of water). Scanditronix-Wellhofer Dose 1 reference class electrometers were used for all point measurements. Photon beams from all units were normally incident on the phantom surface at 100 cm SSD. The same orientation was used for electron beams as well. Although the acceptance testing procedure for all electron beams were performed at 100 SSD, due to an insufficient gap between the applicator end and patient surface at 100 SSD (0.5 cm for 10 × 10 cm); all data collections were done at the clinically employed SSD of 105 cm. For 9 MV photon beam depth dose distributions along the beam central axis, diode readings at each depth were normalized to the reading at $d_{\max}$. For photon beam output factors, ion chamber readings were obtained at a reference depth (d_{ref}) of 10 cm for the following field sizes: 6 × 6 cm, 10 × 10 cm, 15 × 15 cm, 20 × 20 cm and 30 × 30 cm. The depths of measurements incorporated a shift to the effective point of measurement following the recommendation of IAEA code of practice for dosimetry TRS-398, i.e. 0.6 times the radius of the chamber cavity upstream from the chamber axis [3].

Results and discussions

The relative depth dose distribution curves for photons and electrons are the same as depth ionization curves. The PDD values at 5, 10, 15, and 20 cm depth for 10 × 10 cm field, for six machines, are compared in Table 1. For photon beam, the ratio of PDD values

Table 1. Percentage depth dose for 10 × 10 cm field at 5, 10, 15 and 20 cm depth, 100 cm SSD

Linac#	Depth (cm)			
	5	10	15	20
1	90.10	72.50	56.50	44.90
2	89.45	72.40	57.20	44.60
3	92.00	71.90	56.00	43.90
4	89.90	73.00	56.40	45.20
5	90.30	73.20	57.50	46.00
6	90.10	71.80	56.80	44.50
AVG	90.31	72.47	56.73	44.85
SD(%)	1.0	0.8	1.0	1.6

Table 2. D_{20}/D_{10} for photons, and R_{50} and R_p for electrons (cm), for 10 × 10 cm field at 100 cm SSD

Linac#	9 MV	6 MeV		8 MeV		10 MeV	
	D_{20}/D_{10}	R_{50} (cm)	R_p (cm)	R_{50} (cm)	R_p (cm)	R_{50} (cm)	R_p (cm)
1	0.619	2.26	2.84	3.11	3.85	3.87	4.76
2	0.616	2.27	2.87	3.10	3.82	3.90	4.82
3	0.611	2.25	2.82	3.13	3.87	3.91	4.86
4	0.619	2.26	2.90	3.14	3.90	3.89	4.80
5	0.628	2.26	2.85	3.14	3.85	3.90	4.83
6	0.620	2.27	2.87	3.13	3.84	3.99	4.85
AVG	0.619	2.26	2.86	3.13	3.86	3.91	4.82
SD(%)	0.9	0.3	1.0	0.5	0.7	1.1	0.8

Table 3. Off-axis ratios for 9 MV for 40 × 40 cm field at d_{max} vs. off-axis distance (cm)

Linac#	Field size (cm × cm)						
	4 × 4	6 × 6	10 × 10	15 × 15	20 × 20	30 × 30	40 × 40
1	0.941	0.961	1.000	1.035	1.067	1.119	1.151
2	0.939	0.960	1.000	1.038	1.069	1.120	1.155
3	0.938	0.961	1.000	1.040	1.072	1.120	1.160
4	0.942	0.959	1.000	1.041	1.070	1.118	1.159
5	0.940	0.960	1.000	1.036	1.071	1.119	1.154
6	0.938	0.958	1.000	1.037	1.070	1.121	1.162
AVG	0.940	0.960	1.000	1.038	1.070	1.120	1.157
SD(%)	0.2	0.1	0.0	0.2	0.2	0.1	0.4

at 10 and 20 cm depth is the key beam parameter for acceptance and also, according to TRS-398, the beam quality specifier. For electron beam however, R_p is the key beam parameter for acceptance and the depth of 50% dose (R_{50}) is recommended as the beam quality specifier. Therefore, D_{20}/D_{10} value for photons, and R_{50} and R_p for electrons, measured for 10 × 10 cm field for six accelerators are compared in Table 2. The average value of D_{20}/D_{10} for the six linacs is 0.619 with a relative variation, one standard deviation (1SD), of 0.9%. The observed D_{20}/D_{10} of 0.619 ± 0.9% agrees well with the manufacturer's specification of 0.62 for the Neptun 10PC series. For the same reason, close agreement of measured R_p between the machines is not unexpected either (max standard deviation of 1.0%). The maximum variation of R_{50} values of the 3 electron qualities between the 6 units was 1.1% (1SD).

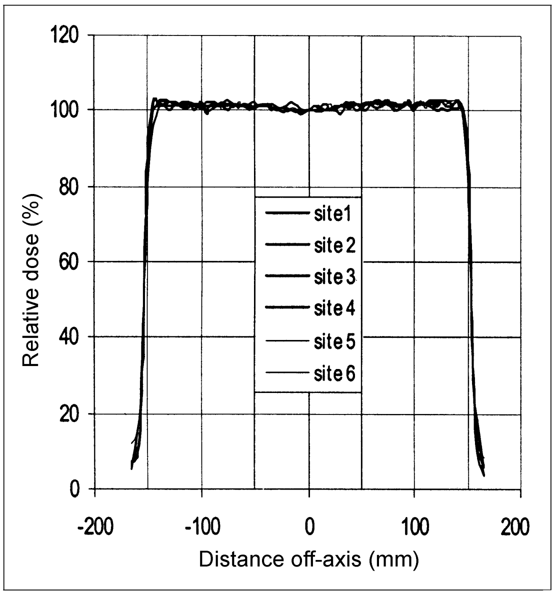

Fig. 1. 9 MV beam profiles at d_{max} for 30 × 30 cm field, 100 cm SSD.

X-ray output of fields of 4 × 4 cm, 6 × 6 cm, 15 × 15 cm, 20 × 20 cm, 30 × 30 cm and 40 × 40 cm relative to that of 10 × 10 cm, i.e. output factors or collimator and phantom scatter factors (S_cS_p), are listed in Table 3 (values measured at depth of 10 cm were converted to values at d_{max} using corresponding PDD's). As it can be seen, the maximum variation is 0.4% (1SD), which is close to the determined precision of measurement (which in most cases was about 0.2%). X-ray profiles for 30 × 30 cm fields measured at d_{max} and 100 cm SSD are compared for the six accelerators in Fig. 1. Off-axis similarities between the machines are readily apparent. The overlay of the profiles for the six machines is close to a single line, with a maximum variation of 0.9% in the central 80% of field, indicating a similar beam quality and consistency in the construction and positioning of the flattening filter and collimators. For more detailed analysis, off-axis ratios of all six machines measured for a 40 × 40 cm field at d_{max} and at distances 5, 10 and 15 cm away from the central axis are listed in Table 4.

Table 4. Off-axis ratios for 9 MV for 40 × 40 cm field at d_{max} vs. off-axis distance (cm)

Linac#	Off-axis distance (cm)		
	5.0	10.0	15.0
1	101.4	103.0	109.3
2	101.2	104.1	110.0
3	100.9	103.5	109.2
4	101.6	103.0	108.8
5	101.1	103.2	109.3
6	101.0	103.9	110.0
AVG	101.2	103.4	109.4
SD(%)	0.3	0.4	0.5

Table 5. Output factors for electron beam (output at d_{max} relative to output for 10 × 10 cm field) vs. field size (cm) made by variable applicators in water at 105 cm SSD for: 6, 8 and 10 MeV

Linac#	Field size (cm × cm)											
	6 × 6	10 × 10	15 × 15	20 × 20	6 × 6	10 × 10	15 × 15	20 × 20	6 × 6	10 × 10	15 × 15	20 × 20
	6 MeV				8 MeV				10 MeV			
1	0.955	1.000	1.018	1.031	0.998	1.000	0.993	0.972	1.018	1.000	0.970	0.947
2	0.962	1.000	1.012	1.027	0.997	1.000	0.990	0.970	1.015	1.000	0.968	0.940
3	0.967	1.000	1.010	1.029	1.002	1.000	0.989	0.974	1.011	1.000	0.961	0.937
4	0.958	1.000	1.015	1.021	1.000	1.000	0.995	0.971	1.014	1.000	0.971	0.949
5	0.966	1.000	1.012	1.025	0.998	1.000	0.990	0.968	1.019	1.000	0.960	0.942
6	0.968	1.000	1.009	1.020	1.001	1.000	0.991	0.970	1.012	1.000	0.966	0.939
AVG	0.963	1.000	1.013	1.026	0.999	1.000	0.991	0.971	1.015	1.000	0.966	0.942
SD(%)	0.5	0.0	0.3	0.4	0.2	0.0	0.2	0.2	0.3	0.0	0.5	0.5

Table 6. Electron effective source distances (cm) for 10 × 10 cm fields

Linac#	6 MeV	8 MeV	10 MeV
1	85.0	90.0	91.0
2	84.6	89.4	90.2
3	85.7	90.2	91.3
4	84.9	90.1	90.6
5	85.2	90.5	91.1
6	84.5	89.7	90.9
AVG	84.9	89.9	90.8
SD(%)	0.5	0.4	0.4

The maximum variation between off-axis ratios within the central 80% of the beam is 0.5% (1SD).

Output of 6, 8, and 10 MeV electron beams, relative to that for 10 × 10 cm, i.e. output factors, for 6 × 6 cm, 15 × 15 cm and 20 × 20 cm field sizes, made by variable applicators, and measured in water at d_{max}, at 105 cm SSD, are compared for all six accelerators in Table 5. A common reference depth was used for all energies, regardless of the field size. In another words, since d_{max} peaks are broad enough to find a common reference depth for all energies, an adjustment for a "shift" in d_{max} was not necessary. The maximum variation in output factors observed was 0.5% (1SD).

Electron effective source position for each energy and field size of 10 × 10 cm is shown for the six accelerators in Table 6. Ionization measurements for electron beams were recorded from 100 to 120 cm nominal SSD in the following increments: 1.0 cm for 100 to 105 cm SSD, 2 cm for 105 to 110 cm and 5 cm for 110 to 120 cm, using NACP chambers, at d_{max}. The effective source-surface distances, SSD_{eff}, were calculated from the ionization chamber measurements using the method of Khan *et al.* [4]. The variation in SSD_{eff} was less than or equal to 0.4% (1SD). This would indicate not only the consistency in beam energy, but also in the applicator design and construction as well as X-ray jaw position.

Conclusions

Beam parameter values obtained for 6 Neptun 10PC units were presented. For photon beams, the absolute differences between the maximum and minimum of PDD values at 5, 10, 15 and 20 cm depth were 2.6, 1.4, 1.5 and 2.1%, respectively. The maximum variation of PDD values for 6 units was 1.6% (1SD). For each field size, the variation of output factors was less than or equal to 0.4% (1SD). The absolute differences between maximum and minimum values of OAR for a 40 × 40 cm field measured in water were no more than 1.2%, at all off-axis distances considered in this study.

For electron beams, the largest difference between maximum and minimum of R_{50} and R_p values was observed as 0.1 and 0.12 cm, respectively, for 10 MeV electron beams. The maximum variation observed for output factors was 0.5% (1SD), for each quality and each field size. The maximum difference between the maximum and minimum of SSD_{eff} values for 10 × 10 cm fields was 1.1 cm. In general, it can be seen that for most beam parameters the variation was less than 1.0% (1SD) (less than 2% for 2 parameters). This variation is of the magnitude one expects to observe during annual calibration of well-maintained accelerators.

This study presented a consistent set of data for the Neptun 10PC linear accelerators. It is evident that for this model, a standard data set could be established. The standard data set could facilitate future commissioning of new Neptun 10PC units as well as entering and modeling the radiation beams in the treatment planning system, by serving as a beam data guide. It can also be used for benchmarking purposes in Monte Carlo studies that utilize this unit as the radiation source.

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