SCATTERED FRACTIONS OF DOSE FROM 18 AND 25 MV X-RAY RADIOTHERAPY LINEAR ACCELERATORS

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INTRODUCTION

Over the years, measurements have been made at a few energies[1,2] to estimate the scattered fraction of dose from the patient in medical radiotherapy operations. This information has been a useful aid in the determination of shielding requirements for these facilities. With these measurements, known characteristics of photons, and various other known parameters, Monte Carlo codes are being used to calculate the scattered fractions and hence the shielding requirements for the photons of other energies commonly used in radiotherapeutic applications.

The National Institute of Standards and Technology (NIST) acquired a Sagittaire medical linear accelerator (linac) which was previously located at the Yale-New Haven Hospital. This linac provides an x-ray beam of 25 MV photons and electron beams with energies up to 32 MeV. The housing on the gantry was permanently removed from the accelerator during installation. A Varian Clinac® 1800 linear accelerator was used to produce the 18 MV photons at the Frederick Memorial Hospital Regional Cancer Therapy Center in Frederick, MD.

This paper represents a study of the photon dose scattered from a patient in typical radiation treatment situations as it relates to the dose delivered at the isocenter in water. The results of these measurements will be compared to Monte Carlo calculations. Photon spectral measurements were not made at this time. Neutron spectral measurements were made on this Sagittaire machine in its previous location[3] and that work was not repeated here, although a brief study of the neutron component of the 18 and 25 MV linacs was performed utilizing thermoluminescent dosimetry (TLD) to determine the isotropy of the neutron dose.

MATERIALS AND METHODS

A commercial drinking fountain water-bottle with a radius of 12.8 cm was used as the patient phantom for this work. A Capintec 0.076 cc chamber complete with its ^{60}Co buildup cap was inserted in a sleeve and placed at the isocenter within the phantom. The phantom was filled with water to the edge of the neck and placed at the isocenter of the accelerators (100 cm from the targets) to provide the scattered radiation. The beam for each accelerator was set to a 20 cm x 20 cm field at the isocenter.

A Victoreen model 550-3 (330cc) chamber with its ^{60}Co buildup cap was placed in front of a 26 mm sheet (25 cm x 25 cm) of polystyrene at two meters from the isocenter. An appropriate amount of buildup material was then placed in front of the chamber. The chamber was connected to a Victoreen model 500 electrometer. Approximately 30 cm in front but out of the direct path of the Victoreen chamber, a 12.7 cm diameter polyethylene moderating sphere containing TLD-600 (neutron and gamma sensitive) and TLD-700

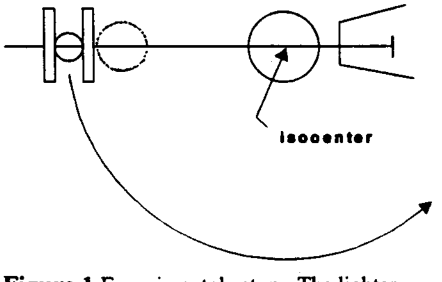

Figure 1 Experimental setup. The lighter circle indicates the location of the TLDs though they actually sat below the level of the chamber.

(gamma sensitive) chips was placed to measure the neutron component of dose equivalent throughout the angles of interest. The sphere remained in the same place for all measurements on a given accelerator, but was not necessarily in the same place from accelerator to accelerator. A top view of this setup can be seen in Figure 1.

Because there was a shift in the predominant energy of scattered photons as the chamber was moved through the angles, various thicknesses of polystyrene were placed in front of the Victoreen chamber to determine the appropriate thickness of buildup material to obtain a good photon signal reading yet exclude noise from secondary electrons. This was performed at each measurement angle. A preliminary investigation in the forward direction had shown that the effect of buildup material both in front and behind the chamber had nearly the same effect as standard build-up caps. The difference did appear to be somewhat energy dependent; however, it was consistent throughout the work on each accelerator, so was ignored.

Numerous measurements were made at angles from 0° to 140° for the 18 MeV photon beam. Because of the nature of the setup for the Sagittaire linac however, measurements were made only at a few select angles from 0° to 140° and the variation with angle was assumed to be smooth as found for the other accelerator. Repeated measurements were made on each accelerator with no phantom in the beam to check for air and wall scatter, and with the jaws in the closed position to get an assessment of head leakage contributions at each measurement location.

TLD measurements were made every 20° from 0° to 140° about the isocenter on the linear accelerators. Five chips of ^{7}LiF enriched LiF (TLD-700) and five chips of ^{6}LiF enriched LiF (TLD-600) were placed at each measurement location. Control TLDs were maintained throughout to account for any transit or extraneous exposures that may have occured. The TLDs were calibrated to ^{252}Cf for the neutron dose-equivalent calibration factor.

RESULTS AND DISCUSSION

Note that only the results from the 18 MV accelerator are presented below.

Neutron Dose Equivalent

We were interested in the neutron isotropy about the target, not the isocenter. The distance from the target along a 170 cm arc about the isocenter is:

$$R = a\sqrt{(5 + 4 \cos \varphi)}$$

where R is the distance from the target, a = 1 meter, and ϕ is the angle about the isocenter from the central beam axis. The measured dose equivalent (DE) was then corrected by $1/r^2$ to get the DE at 270 cm from the target.

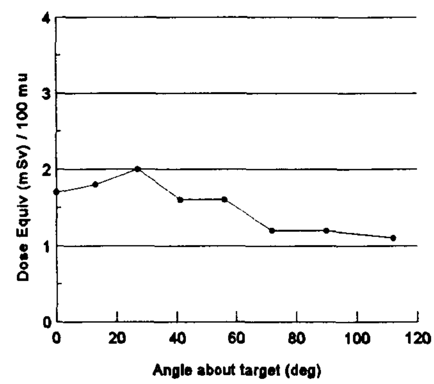

Figure 2 Neutron doses corrected to 270 cm from the target vs. angle about the target from the central beam axis

The TLDs gave expected results, namely, that the dose from neutons is relatively isotropic about the target with somewhat higher readings in the forward direction, see Figure 2. The energies of neutrons from this type of accelerator have been shown to fall predominately fall between 0.01 and 1 MeV[4], much lower than the calibration energy, so an exact determination of dose equivalent was not possible.

Photon Scattered Fractions

Figure 3 shows the scattered fractions of dose about the isocenter at 2 meters for 18 MV x-rays. The ordinate represents the ratio of the dose measured 2 m from the isocenter per unit dose at the center of the phantom. Measurements were made in the horizontal plane at angles of 10, 15, 20, 25, 30, 40, 50, 60, 75, 90, 105 and 120° from the central beam axis. The ratio is seen to drop off sharply with increasing angle which is as expected. Table 1 compares our values with those from an earlier report. Our values are smaller than those from Abrath, et al[2] by about 50% at the smaller angles to 150% at the larger angles.

Further work showed that a $1/r^2$ approximation does not hold for scattered radiation. Our measurements indicate that the ratios of dose at 1 m to that at 2 m varies from 2.5 to 3.8 and appeaıs to be somewhat machine dependent. These measurements were made at both 30 an 90° for 6, 10 and 18 MV beams, but neither energy nor angle seemed to play a predominant role. Another finding of interest concerns the field size dependence of the scatter fraction. It is a common practice to take results from a 10 cm x 10 cm field and multiply by 4 to obtain an estimate for the result of a 20 cm x 20 cm field. Our investigation has shown that this is not the case: the result is acutally less than 4, and that the multiplicative factor is more a function of angle than of energy. Further work is being done to address this issue.

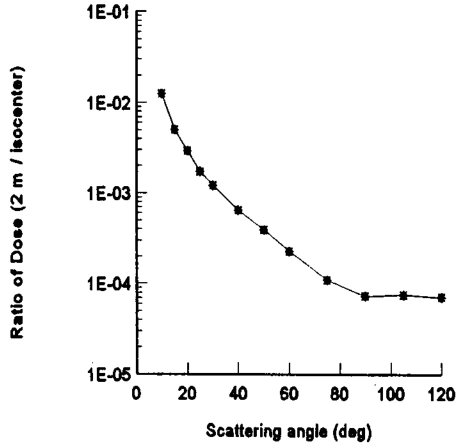

Figure 3 Ratio of radiation scattered at 2 m to that at isocenter vs. angle of scatter from central beam axis.

Differences in measurement technique lead to the inconsistencies in reported scattered fraction values found in the literature. The numerator can be affected by such variables as primary beam quality vs. scattered beam quality, distance of measurement from the isocenter, build-up thickness used, etc. The denominator can be affected by whether the value at the isocenter is recorded as measured at depth in the phantom or as computed to d_{max} for the energy of interest. Monte Carlo codes in progress should help resolve some of these issues.

Table 1 Comparison of our work with previous work. The values for Abrath *et al.* were read from their graph.

Angle	20°	30°	40°	60°	90°	120°
Our work	2.9 E-03	1.2 E-03	6.4 E-04	2.3 E-04	7.3 E-05	7.1 E-05
Abrath *et al*	5.2 E-03	2.2 E-03	9.2 E-04	3.5 E-04	1.8 E-04	1.6 E-04

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