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Assessment of skyshine photon dose rates from 9 and 18 MV medical linear accelerators

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ABSTRACT

► ***Technical note***

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Background: Skyshine describes the radiation scattered by the atmosphere above a LINAC facility to a point on the ground. The aim of this study was to measure the skyshine photon dose rates from two different (9 MV and 18 MV) medical linear accelerators. ***Materials and Methods:*** The photon beam was directed upward (180° gantry position), with a maximum photon field size (40 × 40 cm2) at the isocenter. Measurements were obtained around the external points selected outside the room facilities at a horizontal distance from the target by the calibrated RDS-110 survey meter at four points around the isocenter. ***Results:*** The measured values of the skyshine photon exposure rates at four points for 9 MV and 18 MV were 0.6, 0.5, 0.5, and 0.4 µSv/h, and 0.6, 0.4, 0.4, and 0.5 µSv/h, respectively. All the measured skyshine photon exposure rates were lower than the values recommended by NCRP 147. ***Conclusion:*** There is a poor agreement between the measured and the calculated values; therefore it seems that caution is needed while using the equations available in NCRP 147 or 151.

Keywords: *Skyshine, shielding, radiation measurement, radiation protection, radiotherapy, scattering, medical accelerator.*

INTRODUCTION

Skyshine radiation is a phenomenon that consists of radiation scattered by the atmosphere above the roof of a medical linear accelerator facility to point at the ground level outside the treatment room [1,2]. This generates an additional dose at ground level in the vicinity of the treatment room. Skyshine plays an important role when little or no shielding is provided on the facility roof and in particular, if there are people in the adjacent rooms [2].

Photon skyshine can expose public in regions beyond the boundary of the radiation production center, even in regions that are not in the line of sight of the source. Therefore, photon radiation can contribute a radiation dose to employees and if there is an alley, parking, or sidewalk in the vicinity of the facility, members of the public may be exposed to scattered radiation of skyshine [2].

There are a few studies about skyshine measurement [3-6]. From outside a shielded room McGinley measured photon and neutron levels produced by an 18 MV accelerator for a 40 cm × 40 cm field size in one direction [3]. Gossman *et al.* evaluated the dose level from skyshine produced by a 6 MV medical accelerator for various field sizes and in one direction [4]. de Paiva *et al.* measured skyshine photon exposure rates produced by 6 MV and 10 MV medical accelerators at a horizontal distance from the target and for a 40 cm × 40 cm maximum photon field size at the accelerator isocenter (6). There are a few studies about 9 MV skyshine photon exposure rates and skyshine measurement in four directions around isocenter. In this work, we measured skyshine photon dose rates produced by two different 9 MV and 18 MV medical LINACs, and then compared them to the calculated values.

MATERIALS AND METHODS

Dose measurement

To measure the skyshine photon dose rates, a cross-sectional study was performed in one radiotherapy center equipped with two medical LINACs (Nepton 10PC, ZDAJ, Poland and Saturn 20, CGR, France). The measurements were obtained for 9 MV and 18 MV photon energies.

For this aim, a multi-purpose survey meter, RDS-110 (RADOS Inc., Finland) was used as the detector for exposure rate measurements. The RDS-110 can measure radiation exposure in the range of 0.001–999.9 mSv, and the exposure rate of 0.05 μSv h^{-1} to 99.99 mSv h^{-1}. The detector consists of one halogen quenched energy-compensated GM-tube. It was calibrated for X and gamma rays by the Iran Secondary Standard Dosimetry Laboratory (ISSDL). The calibration accuracy is, at 300 μSv h^{-1} and 20 ºC, ± 5% of the reading with a ^{137}Cs gamma source, the dose linearity is ±15 % from 0.1 μSv h^{-1} to 100 mSv h^{-1} and the energy response is ±30 % from 50 keV to 1.3 MeV (7).

The measurements were taken in the area next to the physics room, the control room, the simulator room, and the corridor, immediately lateral to the position of the isocenter. These vault walls form a primary barrier for the facility. Each measurement was performed around the external points selected outside the room facility at a horizontal distance from the target, 1.5 m above the floor, and for a 40 × 40 cm^2 maximum photon field size so that the beam positioned in the upward direction. The geometry used in measurements is shown in figure 1 according to the previous works (2,6). Equation 1 defines a solid angle Ω formed by the photon beam (5):

$$\Omega = 4 \arcsin \frac{a^2}{a^2 + 4h^2} \quad (1)$$

where a and h are the field size side (40 cm) and the source-axis distance (100 cm), respectively. Gossman *et al*. pointed out that equation 1 is an appropriate way to determine solid angle Ω (5).

In figure 1, d_i is the vertical distance from the target to a point 2 m above the roof and d_s is the horizontal distance from the isocenter to the point M in terms of meters where the exposure rate is measured. Measurements were performed at certain points which had been located 1.5 m above the floor for each facility. Point M is the nearest point located outside the treatment room that an observer *hypothetically* located two meters above the roof in the central axis of the beam can see. Figures 2 and 3 illustrate the schematic illustration of the two treatment rooms equipped with 9 MV and 18 MV LINACs, respectively.

For each measurement, the leakage dose rates arising from the lateral wall of the treatment room were subtracted from the total dose rates at the point M. The leakage was determined in 0 × 0 cm^2 field size so that there was no radiation scattered above the roof. The authors ignored the primary radiation scattered on the inside walls of the room which may be contributing to the exposure rate at point M. All the measurements were repeated for three times.

Dose calculation

To calculate the dose-equivalent rate [$\dot{H}$ (nSv h^{-1})] at a horizontal distance d_s (meters) from the isocenter, the following equation was used (2-4):

$$\dot{H} = \frac{2.5 \times 10^7 (B_{xs}\, \dot{D}_0\, \Omega^{1.3})}{(d_i d_s)^2} \quad (2)$$

where B_{xs} is the roof shielding transmission factor for photons, $\dot{D}_0$ represents the x-ray absorbed-dose output rate at 1 m from the target (Gy h^{-1}), and the constant 2.5 × 10^7 is a conversion factor of gray to nano-sievert (nSv).

B_{xs} is also the transmission factor through the roof and can be calculated by equation 3.

$$B_{xs} = 10^{-\left\{1+\left[\frac{(t-\mathrm{TVL}_1)}{\mathrm{TVL}_e}\right]\right\}} \quad (3)$$

where TVL_1 and TVL_e are the first and second tenth-value layers of concrete, respectively [2]. The ceiling thickness is also shown by *t*.

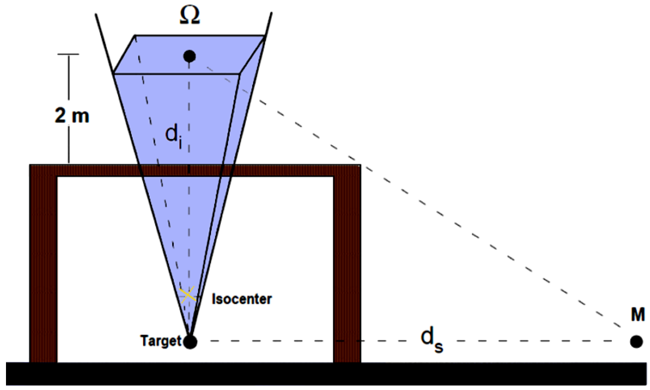

Figure 1. The geometry used in skyshine measurements adjacent to the therapy facility.

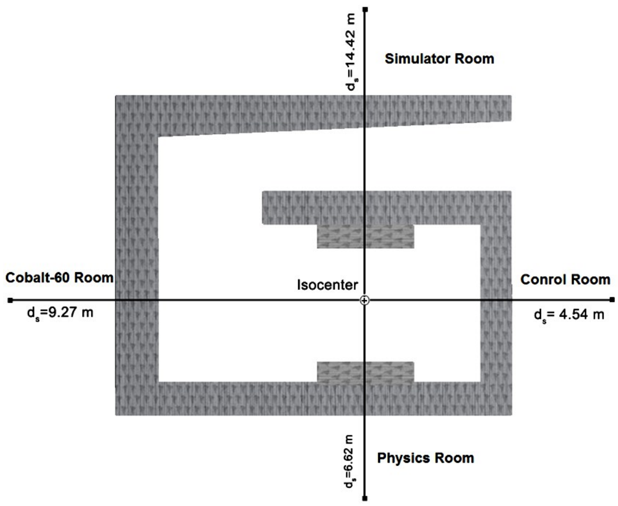

Figure 2. The schematic illustration of treatment room equipped with 9 MV. ds distances in four directions are shown.

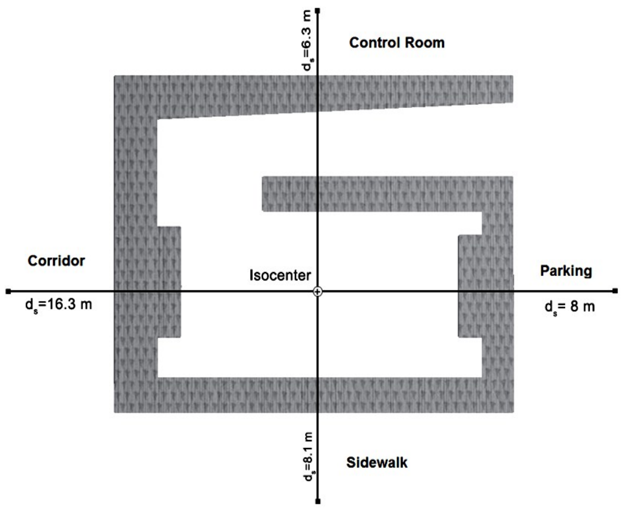

Figure 3. The schematic illustration of treatment room equipped with 18 MV. ds distances in four directions are shown.

RESULTS

Results of measurements

According to figures 2 and 3, the measurements were obtained at 4 points at a distance d_s (meters) from the isocenter in four directions around the isocenter. Therefore, 4 points (M) were selected for each treatment room. Table 1 shows the measured dose rates ($\dot{H}$) for 4 points in comparison to the calculated dose rate by equtation 2 for the facilities equipped with 9 MV and 18 MV machines, respectively.

Results of calculations

According to the equation 3, TVL_1 and TVL_e are the first and second tenth-value layers of concrete which were 0.41 m and 0.37 m for 9 MV, and 0.45 m and 0.43 m for 18 MV, respectively [2]. The ceiling thickness for both of the treatment rooms was 0.6 m of concrete (2.3 g/cm^3). Using these information, the B_{xs} was calculated to be 0.0306 and 0.044 for 9 MV and 18 MV, respectively. The for $\dot{D}_0$ 9 MV and 18 MV

LINACs were 0.0395 Gy/s (237 cGy/min) and 0.029 Gy/s (174 cGy/min), respectively. The solid angle Ω was equal to the constant value of 0.1539 steradians. The $d_{\text{-i}}$ was approximately 4.73 m and 5.10 m for the 9 MV and 18 MV facilities, respectively. According to the spatial distribution of Ω, the d_s was calculated in four directions around the isocenter for both of the treatment rooms (figures 2 and 3).

DISCUSSION

Roofs of the treatment room may be considered as controlled or uncontrolled areas. Sometimes, radiation may be detected on the ground due to the scattering of radiation from the air above the roof [8,9]. As shown in table 1, all the measured skyshine photons were lower than the corresponding calculated values because it seems that adequate protection has been made in the studied vault walls. These measurements were also lower than the shielding goal 0.1 and 0.02 mSv/week for controlled and uncontrolled areas, respectively, as suggested by NCRP 147 [10]. Therefore, the concrete thickness used for the ceiling shield is sufficient to attenuate the weekly exposure rate arising from the radiation passing through ceiling to reach values lower than the mentioned values recommended by NCRP 147 [10].

To calculate the thickness of concrete needed for the ceiling in order to reduce the scattered radiation due to skyshine, the maximum measured photon dose rates should be used. Based on these measurements, it can be concluded that there was a poor agreement between the measured and the calculated skyshine photon dose rates for the two studied treatment rooms. This difference has been found in other studies, despite the different geometries and photon energies among them [3,4,6].

Some studies have been conducted in this regard including Gossman *et al.*'s on measuring of radiation skyshine from a 6 MeV medical accelerator, which reported that the calculations was also found to underestimate the dose rate from skyshine at nearly all distances for field sizes of 20 × 20 cm^2, 30 × 30 cm^2 and 40 × 40 cm^2, the ratio resulted in a dose rate three times different in magnitude [4]. A study by de Paiva *et al.* on the measurement of the skyshine photon doses from 6 and 10 MV medical linear accelerators showed a poor agreement between measured skyshine photon dose rates and empirical estimations [6]. Another study by McGinley which compared measured neutron and photon skyshine levels at an 18 MeV medical accelerator with values calculated by use of the information presented in NCRP Report No. 51. showed that calculations yielded dose levels less than those obtained by direct measurements [3]. The difference between the results of the present study and the results of the previous studies may be related to the different used field sizes, energies and distances of measurement; because different field sizes can affect on skyshine maximum observed at the same distances. Therefore, caution is needed while using equtation 2, which is available in NCRP 151, for the skyshine photon exposure calculation rate.

Table 1. Measured and calculated skyshine at horizontal distances from isocenter (ds) for 9 and 18 MV facilities and 40 × 40 cm2 field size.

d_s (m)		Measured skyshine photon dose rate (µSv/h)		Calculated skyshine photon dose rate (µSv/h)		Ratio Measured/ Calculated	
9 MV	18 MV	9 MV	18 MV	9 MV	18 MV	9 MV	18 MV
4.54	6.3	0.6	0.6	20.711	9.767	0.029	0.061
9.27	8.1	0.5	0.4	4.967	5.908	0.101	0.068
6.62	8.0	0.5	0.4	9.741	6.075	0.051	0.066
14.42	16.3	0.4	0.5	2.053	1.459	0.195	0.343

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Conflicts of interest: *Declared none.*

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