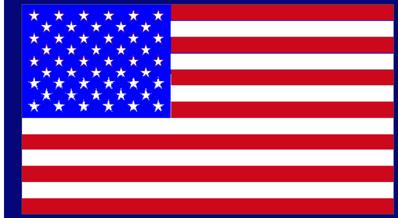
NCRP-151 is wrong for skyshine: new solid angle equation provided



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ABSTRACT

We correct the technical use of the solid angle variable identified in formal guidance that relates skyshine calculations to dose-equivalent rate. We further recommend it for use with all National Council on Radiation Protection and Measurements (NCRP), Institute of Physics and Engineering in Medicine (IPEM) and similar reports documented for any type of radiation emission. In general, for beams of identical width which have different resulting areas, within ± 1.0 % maximum deviation the analytical pyramidal solution is 1.27 times greater than a misapplied analytical conical solution through all field sizes up to 40x40 cm^2. Therefore, we recommend determining the exact results with the analytical pyramidal solution for square beams and the analytical conical solution for circular beams, as the equation provided by NCRP-151 is wrong for linacs.

INTRODUCTION

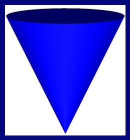
As provided in NCRP-151, the dose-equivalent rate $\dot{H}$ (nSv/h) to be measured for skyshine is directly dependent on the transmission through the barrier. The calculation required is in the form

$$\dot{H} = \frac{2.5\times10^{7}\left(B_{xs}\,\dot{D}_{o}\,\Omega^{1.3}\right)}{\left(d_i d_s\right)^{2}}$$

where $\dot{D}_o$ (Gy/h) represents the x-ray absorbed dose output at a distance of 1m from the target, vertical distance di (m) from the target to a point 2 m above the roof, and lateral distance ds (m) from the isocenter to a point outside the barrier where measurements are taken. The variable Ω (steradians) defines the solid angle formed by the radiation beam. In NCRP-151, this is given as

$$\Omega_{Circle} = 2\pi(1-\cos\theta)$$

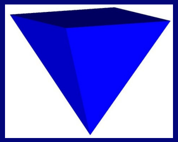
In this equation, the angle θ (degrees) is the angle subtended between the central axis and the edge of the beam as radiation projects away from the source. Thus, the equation represents the analytical conical expression, where the beam pointing upward resembles an inverted cone as in the figure below.



This equation then represents a correct form of the solid angle equation, but only for circular fields such as from those formed by cerrobend blocks. It is rarely considered how the effect of cerrobend blocking with circular apertures affects radiation levels outside the vault. Most accelerators include moving jaw systems or even multileaf collimators, which may be completely opened to square dimensions as large as 40 x 40 cm^2, defined at 1 m from the machine isocenter. Although some Elekta linacs offer rectangular open apertures to maximally 16x21 cm^2, it is these square or rectangular fully opened apertures that are used for radiation protection purposes. For discussion here, we define the distance *h* (cm) as the height of the beam for which the solid angle is determined, commonly used as the 100 cm source-axis-distance (SAD) for accelerators, where the field size a x b (cm^2) is defined.

RESULTS

Given this geometry, the radiation beam will no longer resemble a cone, but rather an inverted pyramid, as in the illustration below.



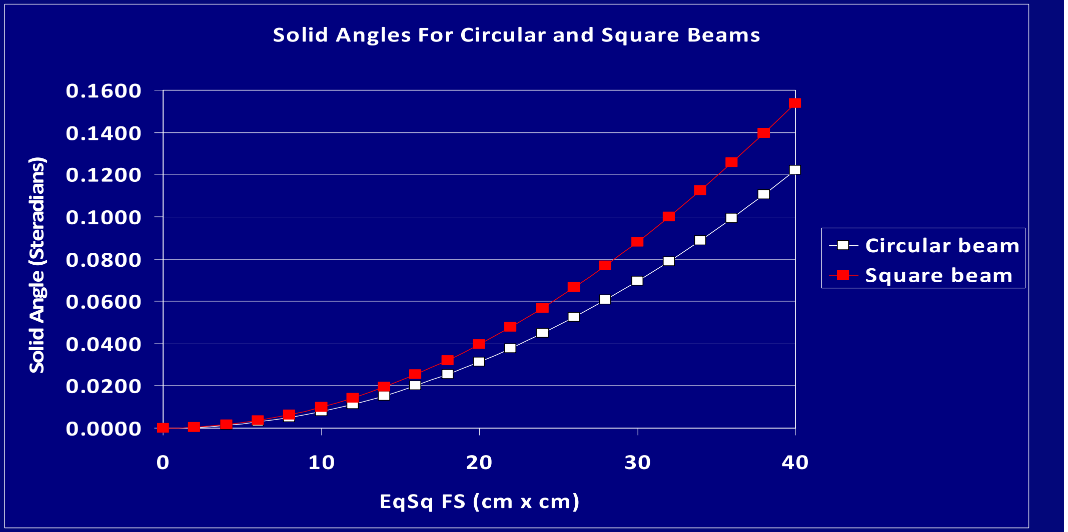
The form of the equation for the solid angle, which should be used for all medical accelerator skyshine calculations, is not the NCRP-151 expressed cone-based equation, which is more appropriate for circular collimation. Rather, an analytical pyramidal equation should be used when medical accelerators are involved, since square-shaped apertures result in an inverted pyramid shaped beam. We have detailed, derived and corrected the technical use of the solid angle variable identified in formal guidance that relates skyshine calculations to dose-equivalent rate. This equation is now provided as

$$\Omega_{Rectangle} = 4\arcsin\frac{ab}{\sqrt{\left(a^2+4h^2\right)\left(b^2+4h^2\right)}}$$

With the solid angle dependence varying as $\Omega^{1.3}$, skyshine dose-equivalent rate error increases dramatically when equations are misused. Thus, it is very important to simplify calculations whenever possible. One cannot assume the same base width (diameter) for the circular beam as for the square beam. In general, for beams of identical width which have different resulting areas, within ± 1.0% maximum deviation the analytical pyramidal solution is 1.27 times greater than the analytical conical solution through all field sizes up to 40 x 40 cm^2. This is proven in the plot shown.

CONCLUSIONS

Therefore, we recommend determining the exact results with the analytical pyramidal solution for rectangular beams and the analytical conical solution for circular beams. These equations may be used for machines other than the Elekta model stated here or within the referenced research. Also, the equations are not limited to skyshine for bremsstrahlung photon irradiations. These should also be used when dealing with gamma producing brachytherapy (i.e., ^{192}Ir) and teletherapy (i.e., ^{60}Co) radiation sources, as well as for neutron skyshine calculations.



REFERENCES

1. **Gossman MS**, Pahikkala AJ, Rising MB and McGinley PH. *Letter To The Editor*. Journal of Applied Clinical Medical Physics. 2011; 12(1): 242-243.
2. **Gossman MS**, Pahikkala AJ, Rising MB and McGinley PH. *Providing Solid Angle Formalism For Skyshine Calculations*. Journal of Applied Clinical Medical Physics. 2010; 11(4): 278-282.
3. **Gossman MS**, McGinley PH, Rising MB and Pahikkala AJ. *Radiation Skyshine From A 6 MeV Medical Accelerator*. Journal of Applied Clinical Medical Physics. 2010; 11(3): 259-264.
4. National Council on Radiation Protection and Measurements. Structural shielding design and evaluation for megavoltage x- and gamma-ray radiotherapy facilities. Report No. 151. Bethesda, MD: NCRP; 2005.