FILTER TO CORRECT FOR INVERSE SQUARE LAW NONUNIFORMITY IN THE PINHOLE COLLIMATOR

A letter from Donald W. Fink and F. Wes Wilcox in a recent issue of the *Journal* (*1*) raises the problem of field nonuniformity due to operation of the inverse square law when using a pinhole collimator with an Anger camera. They suggest two solutions to this problem: with the use of a computer nonuniformity correction, and their own solution, use of a rectilinear scanner instead of the camera.

This letter proposes a third solution which is much simpler than their first and not as drastic as their second. That is, to use an absorbing filter constructed so as to absorb gamma radiation in a pattern complementary to the nonuniform pattern obtained. The filter, of course, is placed in close proximity to the crystal of the camera.

The geometry of interest is shown in Fig. 1. Note that in the Nuclear-Chicago gamma camera, the normal value of the pinhole-to-crystal distance, a, is 7.5 in., while with the pinhole reversed to give a larger image as described by Quinlan, et al (*2*), a is 5.5 in. (I have not calculated filter parameters for other gamma cameras.) The active radius of the crystal is $r_0 = 4.875$ in. The nonuniformity in radiation flux arriving at the crystal from a uniform flat source is proportional to the difference between the squares of the distances to the crystal at the center and edge, and is 44 and 30% for a = 5.5 and 7.5 in., respectively.

There is, however, a partial correction to this nonuniformity, particularly for high-energy gamma radiation. Due to the fact that radiation reaching the crystal edge passes through the crystal at an angle, its path in the crystal is longer than that of radiation passing through perpendicularly at the center. For gamma radiation above about 300 keV the one-half value layer for sodium iodide is greater than the thickness of the crystal (½ in. or 1.25 cm) and thus the percentage of radiation absorbed is greater at the edge than at the center (although the net amount absorbed remains greater at the center). Table 1 shows the nonuniformity expressed as percentage drop-off at the crystal edge compared to the center, for various isotopes. (The first values are the pure inverse-square effect, which would hold for very low energy radiation whose half-value layer in sodium iodide is zero.)

TABLE 1. SENSITIVITY VARIATION, CRYSTAL EDGE TO CRYSTAL CENTER

Isotope	a (in.)	$\frac{S_c - S_e}{S_e} \times 100\%$
0 keV	5.5	44
	7.5	30
^{99m}Tc	5.5	42
	7.5	28
^{131}I	5.5	32
	7.5	20
^{18}Fl	5.5	30
	7.5	20

TABLE 2. HALF-VALUE LAYER FOR SODIUM IODIDE AND SEVERAL FILTER MATERIALS

Material	140 keV	364 keV	511 keV
NaI	0.28 cm	1.5 cm	2.1 cm
Pb	0.025	0.24	0.41
Cu	0.35	0.80	0.95
Fe	0.45	0.92	1.02
Al	1.9	2.7	3.0

By elementary mathematical methods we find the thickness of the desired correction filter as a function of its radius to be

$$t = \frac{1.44}{\left(\frac{a^2 + r^2}{a^2}\right)^{1/2}} \ln \left[\frac{a^2 + r_o^2}{a^2 + r^2} \, \frac{1 - e^{-\frac{0.693 \times 1.25}{X_{1/2}}\left(\frac{a^2 + r^2}{a^2}\right)^{1/2}}}{1 - e^{-\frac{0.693 \times 1.25}{X_{1/2}}\left(\frac{a^2 + r_0^2}{a^2}\right)^{1/2}}} \right] t_{1/2}$$

where t is the filter thickness in centimeters, $t_{1/2}$ the half-value layer for the filter material (Table 2), $x_{1/2}$ the half-value layer for sodium iodide, a the pinhole-to-crystal distance in inches, r_0 the crystal radium, 4.875 in., r the radius at which measurement is made, and ln the natural logarithm.

Table 3 gives the values of $t/t_{1/2}$ for values of r from r = 0 (at center of filter) to $r = r_0$ (at edge) in steps of one-tenth.

Typical half-value layers are given for the read-

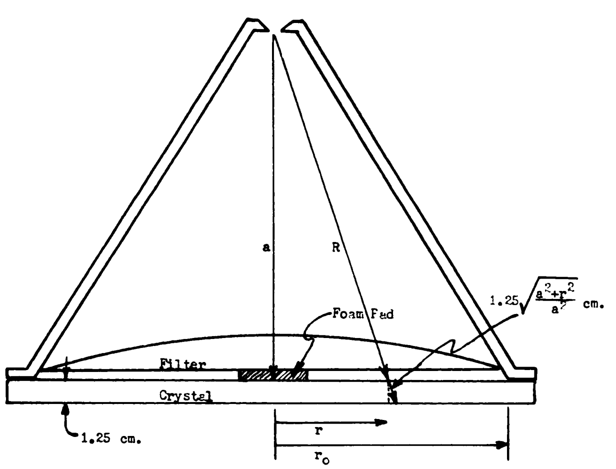

FIG. 1. Geometry of pinhole collimator and correction filter.

TABLE 3. VALUES OF FILTER THICKNESS AS A FUNCTION OF r, FOR VARIOUS ISOTOPES AND TWO PINHOLE CONFIGURATIONS

	$t/t_{1/2}$					
	a = 5.5 in.			a = 7.5 in.		
r/r_0	^{99m}Tc	^{131}I	^{18}Fl	^{99m}Tc	^{131}I	^{18}Fl
0.0	0.79	0.54	0.51	0.48	0.33	0.31
0.1	0.78	0.53	0.50	0.47	0.32	0.30
0.2	0.74	0.51	0.48	0.45	0.31	0.29
0.3	0.68	0.46	0.44	0.42	0.29	0.27
0.4	0.60	0.41	0.38	0.38	0.26	0.24
0.5	0.50	0.35	0.32	0.33	0.22	0.21
0.6	0.40	0.28	0.26	0.27	0.18	0.17
0.7	0.30	0.21	0.19	0.20	0.14	0.13
0.8	0.19	0.13	0.13	0.14	0.09	0.09
0.9	0.09	0.07	0.06	0.07	0.05	0.04
1.0	0.00	0.00	0.00	0.00	0.00	0.00

er's convenience in Table 2. Aluminum is the preferred material if the filters are to be machined on a lathe, since it will be thick enough to be easily shaped. However, iron or copper foil of appropriate thickness can be cut into disks and cemented together to form an excellent filter. If, for example, ten disks are used, the nonuniformity at each disk edge (a sudden change of thickness of one-tenth the total filter thickness) will be about 5½% for the worst case. Since the manufacturers of Anger cameras promise a field uniformity of no worse than ±15% or so, we see that this discontinuity is negligible.

If this disk construction is used, it is suggested that a cross-section drawing to scale be made of the filter to be constructed from the data in Table 3. The foil thickness available is then found and the maximum number of layers decided on. The vertical scale of the drawing is then divided into a similar number of "slices" and the diameter of each measured, the disks then being cut out and cemented together.

Note that Table 3 gives values of $t/t_{1/2}$. If we calculate for each energy radiation, the thickness at, for example, r = 0 (center), we find a pleasant surprise. For example, using aluminum and a = 5.5 in., we find that $t = 0.79 \times 1.9 = 1.5$ cm for radiation from technetium, $t = 0.54 \times 2.7 = 1.46$ cm for iodine, and $t = 0.51 \times 3.0 = 1.53$ cm for fluorine. If we constructed a filter having a center thickness of 1.5 cm, that is to say, designed for technetium, it would result in an error in sensitivity of 1.5% when used with iodine, and 0.7% with fluorine.

Similarly, a single filter designed for technetium, having a center thickness of 0.91 cm for use with a = 7.5, would give equally small errors for the higher energy radiations. Thus, only two filters need be made.

Simple calculations show that the loss in total sensitivity due to these filters is minimal, being about 15% for the filter for a = 7.5 in. and about 20% for the a = 5.5 in. filter.

Any convenient method may be used for mounting the filter, including simply adhesive tape. I suggest, however, that the center diameter of the filter disk be made so as to drop the filter into the pinhole collimator cone about ¼ in. A piece of sponge rubber is cemented to the filter disk to press lightly on the crystal face when mounted in place and keep the filter in position.

A pair of these filters, prepared as described, are easily interchangeable for use with the two different pinhole configurations.

I wish to thank Lester M. Levy* for helpful discussions.

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