The "MULTICOUNTER" for Radioactive Iodine Distribution Studies on Human Beings, and Other Uses

presented by

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Mathematical and experimental studies indicate that it is possible to achieve, with several counters, appreciably greater sensitivity and resultant higher accuracy than can be obtained with a single counter. These results are obtained independent of geometry, sample size, or relative position of the source, and to some degree independent of internal absorption.

MULTIPLE G. M. COUNTER TECHNIQUE FOR PRECISE MEASUREMENT OF RADIOACTIVE SOURCES INDEPENDENT OF GEOMETRY AND SAMPLE SIZE (for use in medical and biological isotope applications, (e.g.) studies and therapeutic applications of I^{131}).

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INTRODUCTION

In the biological and medical uses of radioactive isotopes and particularly in the study and treatment of goiter patients with I^{131}, numerous requirements for a precise measurement of the radio isotopes administered and of their distribution in the body exist. One of the authors (S.H.) (1), has treated patients with toxic goiter by means of radioactive isotopes of Iodine since March 1941. In this work reliance upon externally placed single geiger counters over the thyroid gland has allowed a qualitative, but not entirely satisfactory quantitative, estimation of the radiation dosage (2). Clinical experience during this interval has indicated that a more precise measurement of radiation dosage might help in avoiding the one undesirable sequel of such therapy (i.e., the development of hypothyroidism from the administration of excessive dosage of I^{131}). It is therefore, suggested that a method of measurement which might be generally applied for the purpose of radiation measurements and which might be independent of geometry, sample size, and slight movement of the patient would be of considerable clinical value.

In the earliest publications from the Massachusetts General Hospital and the Massachusetts Institute of Technology (2), (3), it was clearly appreciated that the usual practice of radiation measurement of a single source by means of a single geiger counter has an accuracy highly dependent upon geometry. A geometrically less critical measuring arrangement was sought by using several counters in a pragmatic manner.

It was found that six counters of matched type yielded data which encouraged the further study of this problem from the theoretical point of view looking toward the designing of a device which could be relied upon to accomplish the desiderata. It was found that not less than three counters must be used, and it was reasoned that four geiger counters would simplify the geometric conditions in a highly satisfactory manner. In preliminary studies it was found that for four counters, arranged around a circle, a considerable area existed within which a radioactive sample can be placed and from which the radiation as averaged over the four counters will be uniform within 5%.

It was also found that this area is contained by a figure approximating a circle, (Fig. 1), with center at the center of the circle passing through the four counters, and with radius not greater than about one-fifth the radius of the circle passing through the counters. The method was limited to measurement of isotopes which emit gamma-radiation.

APPARATUS AND ANALYSIS

A sketch and picture of the apparatus are given in Figs. 4 - 5.

For the purpose of analysis the following assumptions are made regarding the geometry, source, and counters.

1. The radiation is emitted uniformly in all directions about the source. There is no absorption in the medium between the source and counters; or the absorption is uniform

in all directions. There is no appreciable decay or build-up of source activity during the course of a measurement.

2. The efficiency of the counter is proportional to the solid angle subtended at the source by the geiger counter cathode.

3. The efficiency of the counter is inversely proportional to R^2. R being the distance from the source to the center of the counter cathode.

4. The efficiency of the counter is independent of angle θ between the normal to the counter cathode and the line from the source to the center of the cathode.

5. All of the counters have identical counting characteristics (plateau and efficiency).

6. The source is a point.

7. The region of interest is limited to the plane containing the centers of the four counters.

Under the above assumptions the analysis reduces to evaluating the sum of the $1/R^2$ factors over all four counters for a source position within the circle passing through the four counters. This yields the following expression for the counting efficiency ϵ^*:

$$\epsilon^* = \frac{K\,(x^2+1)\,(x^4+1)}{(x^4-1)^2 + 4\,x^4\,\text{Sin}^2\,(2\theta)} \qquad (1)$$

where $x = \dfrac{r}{A} = \dfrac{\text{distance of source from center of counter circle}}{\text{radius of counter circle}}$

and K = a constant of proportionality containing such factors as the solid angle subtended at the source by the counters, the number of counters used, and the energies of the gamma-radiation emitted by the isotopes being measured. By considering the relative efficiency ϵ (compared to the efficiency ϵ_0 at the center of the counter circle), the constant K can be eliminated and the following expression results:

$$\epsilon = \frac{\epsilon *}{\epsilon_0} = \frac{(x^2+1)\ (x^4+1)}{(x^4-1)^2 \quad 4\,x^4\ \mathrm{Sin}^2\ (2\Theta)} \qquad (2)$$

Solution of equation (2) for X as a function of Θ at constant values of ϵ yields the curves shown in Fig. 1. For ϵ = 1.05 (i.e. for an efficiency 5% greater than the efficiency at the center of the counter circle) the curve is approximately a circle of radius very nearly one-fifth the radius of the counter circle (x = 0.2). Curves for higher efficiency are also given and are seen to lie outside the curve for ϵ = 1.05. Thus, within this latter curve the efficiency is nowhere greater than 5% higher than the efficiency at the center.

In Fig. 2 are shown curves of ϵ as a function of X at two values of Θ (0 and 45 degrees). The curve for Θ = 0 degrees (directly at one of the counters) is seen to rise much more rapidly than the curve for Θ = 45 degrees (half-way between two counters).

In Fig. 3 are shown curves of ϵ as a function of Θ for several values of X.

These curves quite describe the apparatus as defined or limited by the assumptions made above.

With regard to the variations of ϵ, it is of value to note that these are all positive and that the variation from a distributed source is therefore generally less than that indicated by the smallest curve of Fig. 2 or Fig. 3 that fully contains the source.

Also, one should note that assumption 4 listed above is probably not fully justified when accurate measurements are being made. Consideration of the variation of ϵ with Θ indicates that considerably smaller variations of ϵ may be expected than those indicated by the above analysis.

For the accuracy desired (better than 5%) it is also essential to make corrections for the counting losses incurred by the "dead time" of the geiger counters when the counting rates are greater than a few thousand per minute. Note, however, that these losses are smaller by a factor of four at any given counting rate because of the use of four geiger counters.

SOME MEASUREMENTS

An apparatus as shown in Fig. 4 and described by the analysis above was assembled and a series of measurements made to determine its usefulness. A Radium source was used and the counting rate (i.e., the efficiency in arbitrary units) was measured at the center of the counter circle and at several values of Θ for each of two values of X and the results are shown plotted in Fig. 6. The circle drawn in indicates the value of ϵ_0 at the center of the counter circle, and it is seen that no value of ϵ differs from this center value by as much as 5% indicating the validity of the analysis. Also, the average value of ϵ over all the measurements taken at the greatest value of X (0.2) is less than 2% greater than the center value, and the average value of ϵ over the smaller value of X (0.1) is practically the same as the center value (i.e., within the probable statistical error of the measurements). These averages are more significantly related to the measurements of distributed sources than are the single measurements made at particular values of θ . That these averages are appreciably smaller than the 5% which might have been expected is probably due to the variation of ϵ with α which by assumption 4 above is assumed to be insignificant. At large values of X this variation is further increased by the thick lead shield whose slit exposes the counter to the source in a variable manner as x varies.

The statistical probable error of the measurements is considerably smaller than the observed variations. The asymmetry observed in Fig. 6 is almost certainly due to one of the counters in this run of measurements not having the same characteristic as the other three and therefore counting at a higher rate. In Fig. 7 is shown the summary of a statistical analysis of the data, and it is seen that the distribution of the measurements is in reasonable agreement with a "normal error curve."

It is expected that with this apparatus measurements of radiation dosage can be made to an accuracy approaching a few per cent, subject to variations of absorption that may occur from one (human) sample to the next. We are investigating the magnitude of the variation of ϵ with height of source above or below the plane of the four counters.

In a subsequent communication we plan to report upon this aspect and upon current clinical appraisals of the apparatus herein described.

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ACKNOWLEDGMENTS

The authors wish to acknowledge the advice and counsel of Dr. A. K. Solomon of the Biophysics Laboratory of the Medical School of Harvard University whose original suggestions to the senior author stimulated this study. They also wish to thank Mr. L. W. Cronkhite of the Atomic Instrument Company for cooperation in making the resources of his company available to us. The authors wish also to acknowledge the work of Mr. P. J. Edwards who performed the computations.

Note:

A Multiple Geiger-Meuller counter device is now commercially available at reasonable cost from the Atomic Instrument Company, Charles Street, Boston, Massachusetts, for use with the usual types of scaling units currently present in most biophysics and physics laboratories.

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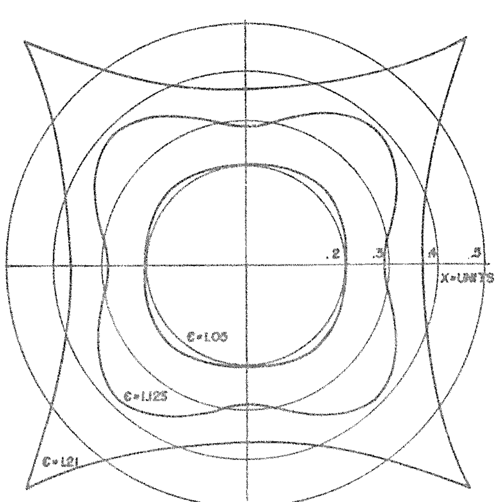


$$\epsilon = \frac{(X^2+1)(X^4+1)}{(X^4-1)^2 + 4X^4 \sin^2 2\theta}$$

$$X = r/a$$

FIGURE 1 EFFICIENCY CONTOURS
X VS θ FOR CONSTANT ε (THEORETICAL)

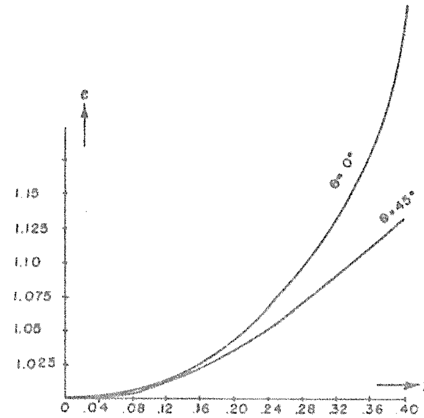


FIGURE 2 ε VS X (THEORETICAL)

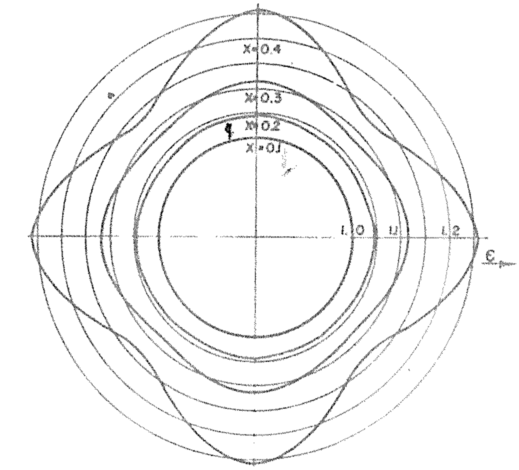
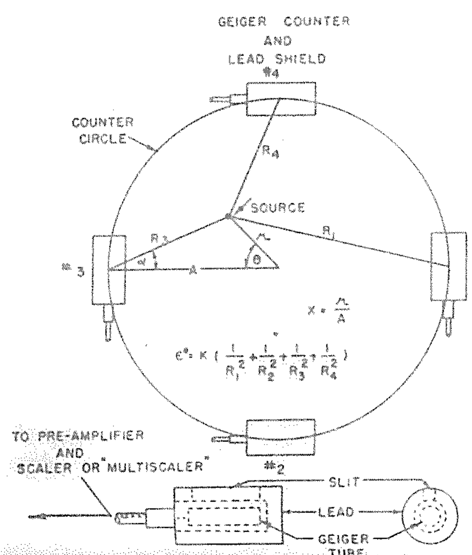


FIGURE 3 ε VS θ (THEORETICAL)

ε = RELATIVE EFFICIENCY (COMPARED TO EFFICIENCY AT CENTER)



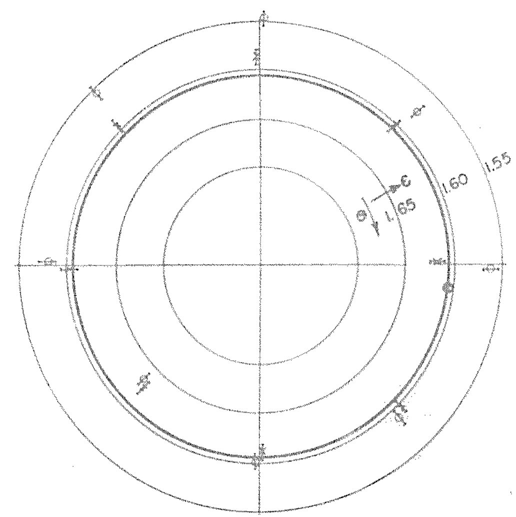


FIGURE 6 ε VS θ (EXPERIMENTAL)

⊕ - ϵ_0 - CENTER EFFICIENCY = 1.606, ± 0.003,

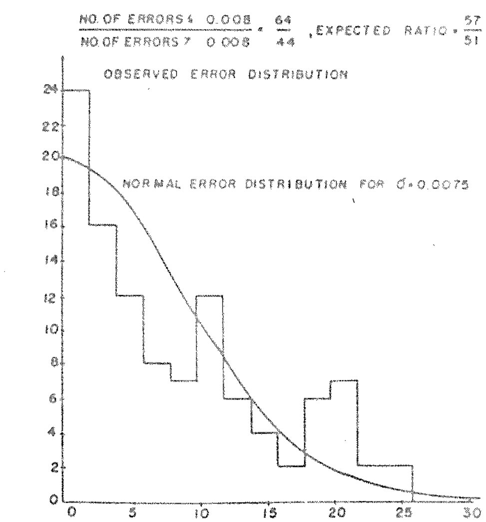


FIGURE 7 STATISTICAL SUMMARY OF DATA