A NEW INSTRUMENT FOR DETERMINING THE INTENSITY OF γ-RADIATION—A GAUSS QUANTOMETER

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A NEW INSTRUMENT FOR DETERMINING THE INTENSITY OF γ-RADIATION–A GAUSS QUANTOMETER

When a beam of γ-radiation is completely absorbed in a substance, all of its energy U is, practically speaking, ultimately expended on the ionization and excitation of the atoms of the material. This fact underlies the method of transition curves ([1]). Thus, if, with the aid of an infinitely narrow slit, one measures the ionization at various depths t of the irradiated substance, then the area S under the resulting curve, called the transition curve (t.c.) (total ionization), will be proportional to the incident energy U:

$$U = \frac{W}{e}\frac{\delta_z}{\delta_g}\rho\int_0^\infty i(t)\,dt = \frac{W}{e}\frac{\delta_z}{\delta_g}\rho S. \tag{1}$$

In this formula $i(t)$ is the magnitude of the ionization charge collected in a gas gap of unit width located at depth t; W is the work required to form one ion pair in the gas; e is the electron charge; ρ is the ratio of the mass stopping powers of the solid substance and the gas, averaged over the effective electron spectrum; δ_z and δ_g are the densities of the solid substance and the gas.

The area to be integrated under the t.c. may be divided into two parts: 1) the area under the exponentially decreasing "tail"–its magnitude, beginning from a certain thickness L, can be determined analytically; 2) the area under the main part of the t.c. (whose analytical form exists but is unknown)–its magnitude must be determined by integration with the aid of a selected quadrature formula ([2,3]).

To apply a quadrature formula it is necessary to know the values of the function at several points–the nodes; as applied to the t.c., such a formula has the form

$$S = \int_0^L i(t)\,dt = \sum_{k=1}^{n} B_k^{(n)} i(t_k), \tag{2}$$

where $B_k^{(n)}$ are interpolation coefficients; t_k are the integration nodes.

Fig. 1. Design of the new quantometer.

Figure 1: Fig. 1. Design of the new quantometer.

It becomes clear from this what design the instrument must have in order for automatic integration of the area of the t.c. to be carried out in it: it must be a multichannel ionization chamber, the arrangement of whose gaps corresponds to the nodes of the quadrature formula. The magnitude of the gaps must be chosen so that the total ionization is proportional to the area under the t.c.

If the magnitude of the k-th gap is denoted by a_k, then the ionization in this gap is equal to $a_k i(t_k)$, and the total collected charge is determined as

$$Q = \sum_{k=1}^{n} a_k i(t_k). \tag{3}$$

Comparison of expressions (2) and (3) shows that, in order to achieve proportionality between Q and S, it is necessary that the magnitudes of the gaps satisfy the relations

$$Q/S = a_1/B_1^{(n)} = a_2/B_2^{(n)} = ... = a_k/B_k^{(n)} = ... = a_n/B_n^{(n)}. \tag{4}$$

If the value of one of the gaps (for example, the minimum one) is specified, then all the others are determined uniquely by the chosen integration formula through relation (4).

Thus, the use of the quadrature formula makes it possible, in a single measurement act, to determine the area under the p.c. up to the thickness L. To determine the total area, the remaining area under the "tail" of the p.c. must be added to it.

Fig. 1. Design of the new quantometer. B –high-voltage electrodes; C –collecting electrodes; BT –separating bushings; I –insulators; K –outer casing; P_1, P_2 –front and rear panels of the quantometer

$$S_L = \int_L^{\infty} i_L e^{-t\tau}\, dt = i_L/\tau, \tag{5}$$

where i_L is the ionization charge collected in a gas gap of unit width at depth L.

This is accomplished by placing, at depth L, an additional gap a_L, in which the charge $Q = a_L i_L$ is collected. To preserve proportionality between the collected charge and the area under the p.c., the following relation must be satisfied:

$$Q_L/S_L = a_L\tau = a_k/B_k^{(n)}. \tag{6}$$

An analogous expression determines the width of the concentric gap a_k, by which the instrument must be surrounded in order to compensate energy leakage to the sides through the edges of the plates ([4,5]). Various instrument designs are possible, depending on which quadrature formula is used.

Wilson' s quantometer ([4]) is constructed so that the quadrature of the first section of the area is performed by means of Simpson' s formula at several equidistant coordinates.

In our laboratory it was shown ([6]) that at energies $E_{\gamma\,\max} < 100$ MeV the sensitivity of Wilson' s quantometer decreases. This result was confirmed in ([7]). The nonconstancy of the sensitivity is due, to a considerable extent, to—

considerable inaccuracy in integrating the area under the first segment of the depth-dose curve.

It is possible, however, to increase the accuracy of integration and at the same time simplify the design of the instrument by using the Gaussian quadrature formula. In Simpson' s formula the intervals between the nodes are identical. According to Gauss' s idea, the nodal points, and consequently the intervals between them, are not fixed in advance, but are chosen so as to obtain the most accurate results. In the Gaussian quadrature process, the zeros of Legendre polynomials, i.e., the zeros of an orthogonal

Table 1

Plate thicknesses and gap widths in the new quantometer*

Gap width, cm	Gap width, cm	Plate thickness, cm	Plate thickness, cm
a_1 0.104	a_4 0.284	X_0 0.405	X_4 2.536
a_2 0.219	a_5 0.219	X_1 1.628	X_5 1.628
a_3 0.284	a_6 0.104	X_2 2.536	X_6 0.800
		X_3 2.863	

* When assembling the instrument, all gaps are maintained with an accuracy of ± 0.001 cm.

set of polynomials. The convergence of this interpolation process is guaranteed by the general properties of orthogonal expansions. Even with rounding of the numerical values of the abscissas of the nodal points, Gaussian quadrature gives practically acceptable accuracy.

Guided by practical considerations, we settled on the Gaussian formula containing 6 nodes. A new quantometer based on this formula was constructed and tested. The design of the quantometer is shown in Fig. 1. The nodes for integrating the first segment of the area under the depth-dose curve were chosen for an absorber length of 12 cm of copper. The size of the first gap was chosen equal

Fig. 2. Dependence of the sensitivity of the new quantometer on the limiting energy of the bremsstrahlung spectrum $E_{\gamma\,\max}$. The data are reduced to an air pressure in the instrument of 760 mm Hg and $T = 20°$.

Figure 2: Fig. 2. Dependence of the sensitivity of the new quantometer on the limiting energy of the bremsstrahlung spectrum $E_{\gamma\,\max}$. The data are reduced to an air pressure in the instrument of 760 mm Hg and $T = 20°$.

to 0.104 cm; the remaining gaps were determined according to the weights of the ordinates at the nodes using relation (4). The coordinates of the nodes and the weights of the ordinates were calculated using tables of normalized values of the indicated quantities for the interval $(-1, +1)$ (3).

The resulting calculated values of the gap widths and plate thicknesses of the quantometer are given in Table 1. The additional gap a_L, serving to integrate the "tail" of the depth-dose curve, must be located at a depth of 12 cm and be equal to $a_L = a_k/B_k^{(n)} = 0.405$ cm. The plate following it—the backscatterer—will in this case serve as the collecting electrode, and special measures must be taken to prevent ions from the space outside the quantometer from being collected by it. This difficulty can be avoided if the gaps a_L and a_6 are combined, taking advantage of the fact that they are located close to one another, and that the law of variation of ionization with depth for the depth-dose curve in copper is known—it is an exponential with exponent $\tau = 0.25\ \text{cm}^{-1}$.

If we transfer the additional gap to the smaller depth L_1, then the requirement of proportionality between Q_L and S_L gives us, instead of (6),

$$Q_{L_1}/S_L = i_{L_1} a_{L_1}/i_L \tau = a_L \tau = a_k/B_k^{(n)}, \qquad (7)$$

since $i_{L_1}/i_L = e^{\tau(L-L_1)}$,

$$a_{L_1} = \frac{a_k}{B_k^{(n)}\tau} e^{-\tau(L-L_1)}. \qquad (8)$$

The calculation carried out showed that, when the gap is placed at a depth of 11.595 cm ($L - L_1 = 0.405$ cm), its size will be $a_{L_1} = 0.366$ cm. The sum $a_6 + a_{L_1} = 0.470$ cm.

The experimental results of determining the sensitivity of the new quantometer, obtained by comparing its readings with data from the calorimetric method in the range $E_{\gamma\,\max} = 15 \div 80$ MeV and at 650 MeV, are shown in Fig. 2. The quantometer was filled with dry air. It can be seen that the overall change in sensitivity does not exceed $2 \div 3\%$. The calculated value of the sensitivity in the limiting case of very high energies (indicated by the arrow) agrees with the experimental values with an accuracy no worse than 2%.

Fig. 2. Dependence of the sensitivity of the new quantometer on the limiting energy of the bremsstrahlung spectrum $E_{\gamma\,\max}$. The data are reduced to an air pressure in the instrument of 760 mm Hg and $T = 20°$.

Thus, the use of Gauss' s quadrature formula made it possible to create a quantometer with a small number of plates, whose sensitivity is constant within $\pm(1 \div 1.5\%)$ for all limiting energies of bremsstrahlung radiation greater than 15 MeV. This accuracy is quite sufficient for solving most dosimetric and physical problems.

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Note: Figure translations are in progress. See original paper for figures.