DOSIMETRY METHOD BASED ON A TWO-PARAMETRIC MODEL OF ELECTRONS BEAM FOR RADIATION PROCESSING

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The work is devoted to development of electron dosimetry methods for radiation technologies. In authors previous work it was shown that use of two parametric models of electron beam makes it possible to correctly approximate the measurements results of depth dose distributions. In this paper, we describe the method of electron radiation based on a two-parameter electron beam model and basic semiempirical relations of this method. Approbation of proposed methods of radiation dosimetry based on measurements was performed in the sterilization center of the Institute of Nuclear Chemistry and Technology, Warsaw, Poland.

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INTRODUCTION

One of the problems of electron radiation dosimetry in radiation technologies is determination of electrons energy in the process of radiation treatment. The problem is that when implementing optimal irradiation regimes, it is necessary to control the electron energy with high accuracy. In international standards [1, 2], formal procedures for monitoring the electrons energy in process irradiation are determined on basis of use a dosimetric wedge or stack. However, when performing these procedures, it is necessary to obtain solutions incorrect mathematical problems. Quasi-solutions of these tasks are obtained by approximating results of measurements using various mathematical methods and types of functions [3, 4].

In the authors papers [5, 6] it was showen that two-parameters model of electron beam makes it possible correctly approximate the results of measurements of depth dose distributions obtained with use of dosimetric wedge or stack.

Therefore, it is of interest of relations, connecting parameters (E_0, X_0) of the electron beam model with standard characteristics (E_P, E_{Av}) of electrons radiation energy. Since these relationships will allow us to realize the computer dosimetry method, that does not contain errors in traditionally used empirical formulas, which are given, for example, in the standard [2].

1. METHODS OF PROCESSING MEASUREMENTS

1.1. RESULTS OF MEASUREMENTS

The results of measurements of depth dose distribution performed using an aluminum dosimetric wedge from RISO [4] are shown in Fig. 1. The results of measurements are a set of discrete data (l_i, D_i), where l_i is distance from a certain initial point of reference (marked by a marker) to first point i of dose measurement D_i on the dosimetric film. In this dataset, you should select four areas, which are separated in the Fig. 1 by vertical dashed curves.

The results of measurements of depth dose distribution, performed using an aluminum dosimetric wedge from RISO [4], are shown in Fig. 1. The measurement results are a set of discrete data, where is the distance from a certain initial point of reference (marked by a marker) to the dots of the dose measurement point on the dosimetric film. In this data set, four areas should be selected, which are separated in the Fig. 1 by vertical dashed curves.

The measurement results are a set of discrete data (l_i, D_i), where l_i – is the distance from a certain initial point of reference (marked by a marker) to i – dots of the dose measurement point D_i on the dosimetric film. In this data set, four areas should be selected, which are separated in Fig. 1 by vertical dashed curves.

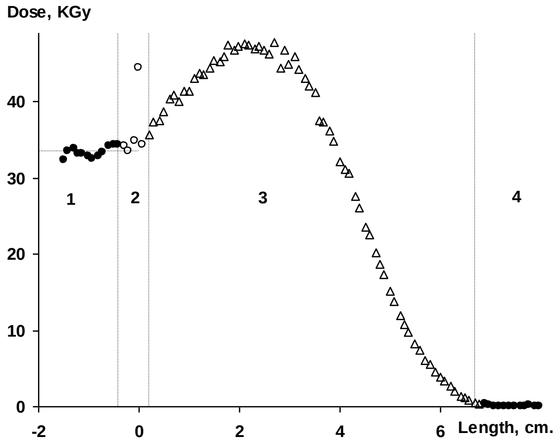

Fig. 1. Results of measurements performed by the method of dosimetric wedge

Area 1 – the dose value in dosimetric film located on entrance surface of dosimetric wedge.

Area 2 – the results of measurements in area where dosimetric film enters into dosimetric wedge. The area contains a marker – a point at which dose value is substantially larger than in neighboring ones. Data in this area are distorted by design of device and application of a marker on film.

Area 3 – the results of measurements of electron radiation dose D_i, depending on spatial position of measurement point in dosimetric wedge.

Area 4 – the dose values in dosimetric film, located on exit surface of dosimetric wedge. The data can significantly depend on design elements, on which the dosimetric wedge is located.

1.2. STANDARD PROCESSING OF MEASUREMENT RESULTS

In the first stage, characteristics of depth dose distribution of electron dose, such as practical range of electrons R_p and depth of half the maximum dose reduction R_{50}, were determined. To do this, it was determine the maximum value of dose distribution D_{max} based on the least-squares fit using a polynomial of third degree. The data, chosen for approximation, are marked in Fig. 2 by filled triangular markers.

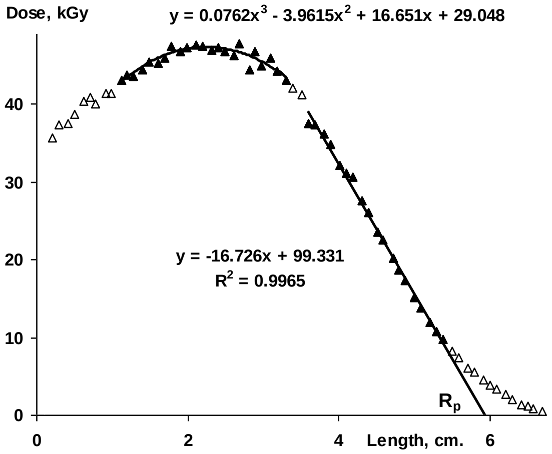

Fig. 2. Standard procedures for processing the depth dose distribution of electron radiation, measured with dosimetric wedge method

To determine value of the practical range of electrons *Rp*, it was selected data on decline of depth dose distribution, where a dose-to-depth curve is observed that is close to linear. In practice, a range of dose values from 0.8 to 0.2 of maximum dose value D_{max} is used. The data on decline in depth dose distribution are chosen to determine the practical range of electrons *Rp*, are marked in Fig. 2 by filled triangular markers.

The value of practical range of electrons R_p is determined based on approximation of selected data using a linear function as shown in Fig. 2. The third-degree polynomial and linear function, which approximate the measurement results are shown in Fig. 2.

The depth of half-reduction of maximum dose value R_{50}, is calculated from value of the maximum dose distribution D_{max} based on linear function, that is used to determine value of *Rp*.

In the second stage, empirical formulas connecting characteristics of depth dose distribution (R_p, R_{50},) with characteristics of electron energy are used to determine characteristics of the electron energy, such as most probable energy E_P and average energy E_{Av} of the electrons source [1]. According to standard [2], empirical formulas for values of E_P, E_{Av} (expressed in MeV) and R_p, R_{50} (expressed in centimeters in an aluminum target) are the following:

$$E_p = 0.423 + 4.69 * R_p + 0.0532 * R^2_p,$$
$$E_{Av} = 0.734 + 5.78 * R_{50} + 0.0504 * R^2_{50}. \quad (1)$$

1.3. MEASUREMENT PROCESSING IN TWO-PARAMETER ELECTRON BEAM MODEL

A parametric adjustment of the semiempirical electron energy absorption model (PFSEM method [7]) to measurements of depth dose distribution of electron radiation performed by the dosimeter wedge method. Solid curve shown in Fig. 3 – calculation according to the semiempirical model of electron energy absorption [8, 9].

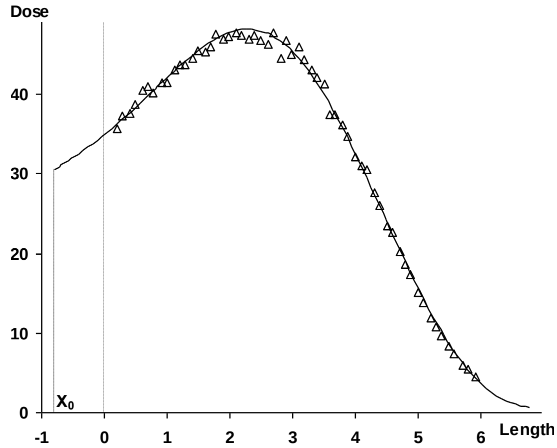

Fig. 3. Parametric adjustment of semi-empirical model to measurements the depth dose distribution of electron radiation

Model parameters are as follows: electron energy E_0 = 9.37 MeV, displacement of dose distribution in the film, X_0 = 0.8 cm. The dose distribution characteristics (R_p, R_{50}) are connected to parameters of electron beam model (E_0, X_0)) with the following relations [6]:

$$R^*_p(E_0) = R_p + X_0, \quad (2)$$
$$R^*_{50}(E_0) = R_{50} + X_0, \quad (3)$$

where $R^*_p(E_0)$ means practical penetration range and $R^*_{50}(E_0)$ range for which the deposited dose is twice smaller than the max value for electron energy level marked as E_0. Those parameters must be calculated on the base of semi-empirical model for depth dose distribution of mono-energetic electron beam.

Linear approximation of calculated data leads to formulas for $R^*_p(E)$ and $R^*_{50}(E)$ as electron energy function:

$$R^*_p(E) = 0.2092 * E - 0.0687, \quad (4)$$
$$R^*_{50}(E) = 0.1691 * E - 0.0965. \quad (5)$$

From the above relations (2) - (5) it follows that:

$$R_p = 0.2092 * E_0 - 0.0687 - X_0 * K_w, \quad (6)$$
$$R_{50} = 0.1691 * E_0 - 0.0965 - X_0 * K_w, \quad (7)$$

here X_0 – displacement of depth dose distribution relative to position of marker on the film. K_w – ratio of film distance to depth in dosimeter wedge substance. For standard aluminum dosimetric wedge, this ratio is K_w = 0.28 [4].

In this method, determination of the energy characteristics of source electrons, such as E_P and E_{Av}, can be performed in accordance with second stage of standard measurement processing.

Empirical formulas, presented in the reports and standards, do not have descriptions of methods for processing depth dose distributions on basis of which these formulas were obtained. Therefore, an estimation of accuracy of the electron radiation dosimetry performed on basis of standard methods of processing measurements is not possible.

In this connection, it is of interest, within the framework of a two-parameter electron beam model, to derive relationships for calculating characteristics of the electron energy of a source directly from parameters of electron beam model: E_0 and X_0.

To obtain the relations, we take into account the following:

- empirical relations $R^*_p(E)$ and $R^*_{50}(E)$ (see (2) and (3)), are the dependences of practical range of electrons R_p and the depth of a half dose reduction R_{50} on energy E for a monoenergetic electron beam;

- the empirical dependencies of most probable energy $E_P(R_p)$ and average energy $E_{Av}(R_{50})$ of the source electrons on the values of R_p and R_{50} (see (1)) are obtained on basis of the depth dose distribution of monoenergetic electron beams;

- in case of monoenergetic beams, values E_P and E_{Av} are equal to electron energy E.

It follows from above facts, that in case when two-parameter electron beam model satisfactorily describes the depth dose distribution, functions $E_P(R_p)$ and $E_{Av}(R_{50})$ can be assumed to be inverse functions to $R^*_p(E)$ and $R^*_{50}(E)$, respectively.

On the basis of this assumption, from relations (6) - (7) we obtain:

$$E_p(E_0,X_0) = E_0 - K_w*X_0/0.2092, \quad (8)$$

$$E_{Av}(E_0,X_0) = E_0 - K_w*X_0/0.1691. \quad (9)$$

Table shows the calculation results, which were performed by the standard method (column *M0*), using two-parameter electron beam model, using the values of R_p,, and R_{50} (column *M1*) and by direct calculation using parameters E_0 and X_0 of the model electron beam (column *M2*)). Calculations of values of E_p and E_{Av} are performed on basis of measurement results shown in Fig. 1.

The values of most probable energy E_p and average energy E_{Av} of electrons, calculated using various computational methods

Electrons energy	*M0*	*M1*	*M2*
E_P, MeV	8.37	8.40	8.30
E_{Av}, MeV	8.15	8.10	8.05

As can be seen from comparison of presented data, results calculations of standard energy characteristics of the electron source have a small spread of values (less than 1%) and are in good agreement with each other.

2. MODIFIED METHOD OF ELECTRON RADIATION DOSIMETRY

The methods of processing the measurement results considered in previous sections are essentially based on fact, that boundary of dosimetric device, as point of the depth dose distribution, is strictly defined on dosimetric film. However, when measuring by the dosimeter wedge method, this point is located in area 2 (see Fig. 1), where the data can be significantly distorted due to construction heterogeneity and the marker application on the film. In this connection, it is of interest to refine the point coordinate, which corresponds to the boundary of dosimetric device.

The procedure for specifying coordinate of dosimetric device boundary was developed on the basis of a two-parameter model of electron beam. According to this model, the depth dose distribution $D(E_0, X_0 + x)$ well approximates the measurement results in the data area 3, presented in Fig. 1.

At the border of dosimetric device, dose value should be equal to dose value on surface of device $\boldsymbol{D_B}$,, i.e. coincide with average value of the dose in region 1 (see Fig. 1). This condition can be represented as an equation and allows you to determine the X_B coordinate of the device boundary.

$$D_B = D(E_0, X_0 + X_B). \quad (10)$$

The procedure for specifying coordinate of dosimetric device boundary is illustrated in Fig. 4.

Triangular markers marked the measurement results, which are used to parametrically fit the semi-empirical model. The solid curve is the depth dose distribution $D(E_0, X_0 + x)$ calculated in a semiempirical model. The horizontal dashed curve is the dose value on the surface of the D_B device.

As can be seen from Fig. 4, position X_B, determined according to described procedure, can significantly differ from marker point, whose position is shown by a vertical dashed curve. Calculation of the most probable energy E_p and the average energy E_{Av} of the source electrons relative to boundary of dosimetric device X_B can be performed using equations (8) and (9) according to the expressions:

$$E_p = E_p(E_0, X_0 + X_B), \quad (11)$$

$$E_{Av} = E_{Av}(E_0, X_0 + X_B). \quad (12)$$

From the formulas (11) and (12) we obtain E_P = 8.64 MeV and E_{Av} = 8.46 MeV. Comparison of these values with given in the Table shows, that change in values of electron energy characteristics, due to refinement of the dosimeter device boundary, significantly exceeds differences in results of calculations, obtained using various methods of processing measurements (see Table).

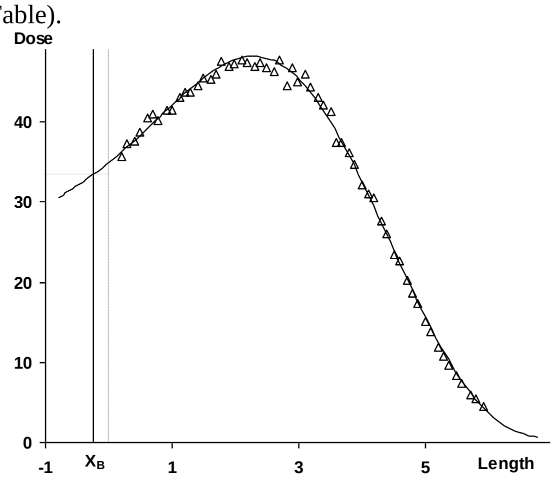

Fig. 4. Modified method for processing the depth dose distribution of electron radiation, measured using a standard dosimeter wedge

The described procedure for processing measurements and presented relations (8) - (12) allow us to calculate characteristics of the electron energy source, taking into account refined coordinate of dosimeter wedge boundary.

When determining the coordinate of boundary of a dosimetry device, using modified method of processing the measurements, the value of X_B is significantly dependent on the dose value on surface of device D_B.

It is well known, that results of dose measurements at the interfaces of dissimilar media can contain significant errors due to the boundary effects that arise when ionizing radiation passes through heterogeneous structures.

In this regard, one of the significant sources of error a modified method for processing measurements is determination of the dose value at boundaries of a dosimetric device.

To eliminate this component of error in method of dosimetry of electron radiation, it is proposed a modification of a dosimeter device design in which an aluminum plate is placed in front of a wedge. The plate should provide a balance of secondary electron radiation at boundary between plate and construction of the dosimeter wedge, which eliminates "boundary effects" when measuring dose values at this boundary.

To test proposed method of dosimetry, measurements of depth dose distribution were performed using the modified design of dosimetric device. A standard dosimetric wedge was used for measurements [4] on which a 2 mm aluminum plate was placed. A standard dosimetric PVC film was placed in the dosimetric wedge at interface between plate and wedge. The measurement results are represented by triangular markers in Fig. 5.

For processing with PFSEM method, it was selected measurement results marked with filled triangular markers. The solid curves – depth dose distributions calculated in a semi-empirical model on the basis of parameters obtained by the PFSEM method. Horizontal dotted curves – the doses values on surface of dosimetric wedge.

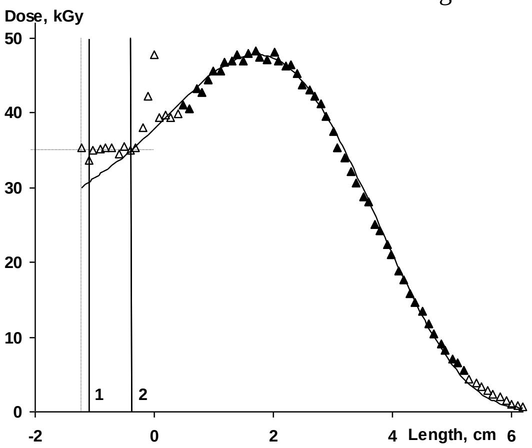

Fig. 5. Processing of depth dose distributions of electron radiation, measured with a modified dosimetric device

The vertical solid straight line 2 – border of dosimetric wedge X_w, which is determined according to equation (10) on basis of dose values on the dosimeter wedge surface. Vertical solid straight line 1 – border of modified structure of dosimeter X_B. Coordinates of this boundary are shifted on plate thickness h and calculated from relation $X_B = X_w + h$.

Calculation of most probable energy E_p and average energy E_{Av} of the source electrons relative to boundary of modified structure of dosimetric device X_B can be performed according to expressions (11) and (12).

Comparison of calculation results of most probable energy E_p and average energy E_{Av} of the source electrons relative to X_B boundary of standard dosimetric wedge and modified dosimetric device allows us to conclude, that dosimetry methods based on two-parameter electron beam model provide determination the standard energy characteristics of electron radiation with an uncertainty not exceeding 2%.

CONCLUSIONS

It was obtained relations, that binding model parameters of the electron beam model directly to the standard electron energy characteristics. This makes it possible to use the dosimetry method on basis of two-parameter electron beam model without calculation stage using standard empirical formulas, that reduces errors of dosimetry method.

It was performed procedure for processing measurements on the basis of a two-parameter electron beam model, and obtained relationships, which allow us to calculate the characteristics of electron energy of the source with allowance for the refined coordinate of dosimetric wedge boundary.

It was proposed modification of the dosimetric wedge construction, in which the equilibrium of the secondary electron radiation at the boundary of the dosimeter wedge is ensured, which eliminates "boundary effects" at measuring the dose value.

It was presented relations that make it possible to calculate characteristics the energy of electrons source on basis of processing the measurements results performed using modified construction of the dosimetric wedge.

It was carried out approbation of the proposed methods of electron radiation dosimetry on the basis of measurements, performed in the sterilization center of Institute of Nuclear Chemistry and Technology, Warsaw, Poland.

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МЕТОД ДОЗИМЕТРИИ НА ОСНОВЕ ДВУХПАРАМЕТРИЧЕСКОЙ МОДЕЛИ ЭЛЕКТРОННОГО ПУЧКА ДЛЯ РАДИАЦИОННЫХ ТЕХНОЛОГИЙ

В.Т. Лазурик, В.М. Лазурик, Г.Ф. Попов, З. Зимек

Работа посвящена разработке методов дозиметрии электронов для радиационных технологий. В предыдущей работе авторов показано, что использование двухпараметрических моделей электронного пучка позволяет правильно аппроксимировать результаты измерений распределений глубинных доз. В настоящей работе описывается метод электронного излучения на основе двухпараметрической модели электронного пучка и основных полуэмпирических соотношений этого метода. Проведена апробация предложенных методов дозиметрии электронного излучения на основании измерений, проведенных в центре стерилизации Института Ядерной Химии и Технологий, Варшава, Польша.

МЕТОД ДОЗИМЕТРІЇ НА ОСНОВІ ДВОПАРАМЕТРИЧНОЇ МОДЕЛІ ЕЛЕКТРОННОГО ПУЧКА ДЛЯ РАДІАЦІЙНИХ ТЕХНОЛОГІЙ

В.Т. Лазурик, В.М. Лазурик, Г.Ф. Попов, З. Зімек

Робота присвячена розробці методів дозиметрії електронів для радіаційних технологій. У попередній роботі авторів показано, що використання двопараметричних моделей електронного пучка дозволяє правильно аппроксимірувати результати вимірів розподілів глибинних доз. В даній роботі описується метод електронного випромінювання на основі двопараметричної моделі електронного пучка та основних напівемпіричних співвідношень цього методу. Проведена апробація запропонованих методів дозиметрії електронного випромінювання на основі вимірювань, проведених у центрі стерилізації Інституту ядерної хімії та технологій, Варшава, Польща.