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DOSE FIELD SIMULATION FOR PRODUCTS IRRADIATED BY ELECTRON BEAMS: FORMULATION OF THE PROBLEM AND ITS STEP BY STEP SOLUTION WITH EGS4 COMPUTER CODE

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Abstract

When performing radiation treatment of products using an electron beam much time and money should be spent for numerous measurements to make optimal choice of treatment mode. Direct radiation treatment simulation by means of the EGS4 computer code fails to describe such measurement results correctly. In the paper a multi-step radiation treatment planning procedure is suggested which consists in fitting the EGS4 simulation results to reference measurement results, and using the fitted electron beam parameters and other ones in subsequent computer simulations. It is shown that the fitting procedure should be performed separately for each material or product type. The procedure suggested allows to replace measurements by computer simulations and therefore reduces significantly time and money required for such measurements.

1. INTRODUCTION

At present the computer code EGS4 is one of the most popular tools for performing coupled electron-photon transport simulation [1]. For radiation treatment planning the most important consequence of such computer simulation is the calculated absorbed dose distribution. However in Figs 1 and 2 one can observe significant differences between measured and calculated dose distributions even for simple homogeneous well-studied medium like aluminium. The differences are systematic ones and reveal themselves as increased slopes (both left and right) of dose-depth curve as well as some shift of the curve maximum to deeper layers. When considering realistic heterogeneous objects like a box with syringes the problem becomes more complicated. The differences between measurement and calculation can be attributed partially to incorrect knowledge of energy distribution in the incident electron beam.

2. THE PROBLEM FORMULATION

For more correct calculation of absorbed dose distribution inside objects irradiated using electron accelerators it is very important to single out the most important parameters which influence the distribution. The knowledge can help to choose optimal radiation treatment mode. To our mind the parameters are the following:

(1) Dependence of average absorbed dose in a layer on its depth, i.e. distance from the surface (curve dose-depth)
(2) Statistical deviation from the average value for each of the layers (variance)
(3) Depth range significant in practice.

To achieve uniform object irradiation the entrance dose should approximately be equal to double exit dose. Relevant object thickness corresponds to almost total (80-90%) deposition of energy delivered to the object. Then using two-sided treatment gives rise to almost uniform irradiation.

3. THE STAGES OF THE PROBLEM SOLUTION

As far as direct radiation treatment simulation fails to describe correctly the measured dose distribution, one should perform some fitting to a reference measurement. We suggest to use the following multi-step procedure:

(1) Approximate choosing of an irradiation mode for product to be irradiated;
(2) Performing a 'reference' measurement for the same mode with fixed electron beam current, electron energy, scanning length and conveyor velocity. The measurement includes:
   - experimental determination of electron beam parameters with a standard spectrometer like a set of aluminium or polyethylene plates, and
   - experimental determination of the dose field inside treated product with a large set of thin dosimetry films which are distributed uniformly over the box volume without distorting the dose field significantly;
(3) Fitting of electron beam parameters with the modified EGS4 computer code to achieve reasonable coincidence between calculated and measured dose distributions for aluminium and/or polyethylene
(4) Calculation of dose distributions for realistically treated product for two extreme types of description, i.e. homogeneous and heterogeneous;
(5) Determination of appropriate homogenization degree and fitting of calculated average dose distribution to experimental one preserving realistic deviations from the average values at different depths;
(6) Additional calculations for another treatment modes (using fitted parameters) to achieve minimal dose non-uniformity factor. For the mode found averaged over volume absorbed dose should be calculated as well as averaged over surface absorbed dose to compare the value with a reference dose value obtained using a surface dosimeter.

4. MEASUREMENT RESULTS AND DISCUSSION

Previously we have modified the well-known EGS4 computer code [1, 2] to take into account 3D structure of irradiated objects as well as developed some tallying routines to make it more suitable for serial calculations. Since then it have been successfully used for resolving different problems [3-5]. Therefore it has been used in present work also.

Irradiation treatment has been performed using electron accelerator UELV-10-10 installed at RPCPI. Available electron energies extend up to 10 MeV with electron beam power up to 10 kW. Dosimetry studies have been performed using films SOPD(F)5/150 tested metrologically at VNIIFTRI (Mendeleevo, Russia). Absorbed dose has been determined using a spectrophotometer SF-26 comparing optical density of the films to that of the reference specimen at wavelength equal to 512 nm.

When fitting calculated distributions to measured ones some shift of maximum for the calculated curves can be achieved by a small variation in the incident electron energy (±0.5 MeV). The sharp maximum can be smeared out using a Gaussian energy distribution instead of δ-function. Absorbed dose at entrance in a treated object can be increased if one allows existence of a low energy (1-5 MeV) tail in the primary electron beam. Slope of a dose-depth curve in its right part increases with energy decreasing and is one of the most difficult values for fitting. The calculated dose-depth distributions were normalized in area to the measured ones using the thickness where the absorbed dose is equal approximately to one half of the dose at the entrance. Accelerator outlet window was supposed to be titanium plate 50 μm thick. Variations of this value did not influence the calculated dose distributions noticeably.

In Figs 1 and 2 measured absorbed dose distributions are represented for homogeneous aluminium and polyethylene slabs. They were obtained in one irradiation run at 6.9 MeV. The energy was determined from the extrapolated range in alumunium according to formulae and recommendations of ASTM. Direct simulation fails to describe measured dose distribution. Fitted dose-depth curve for

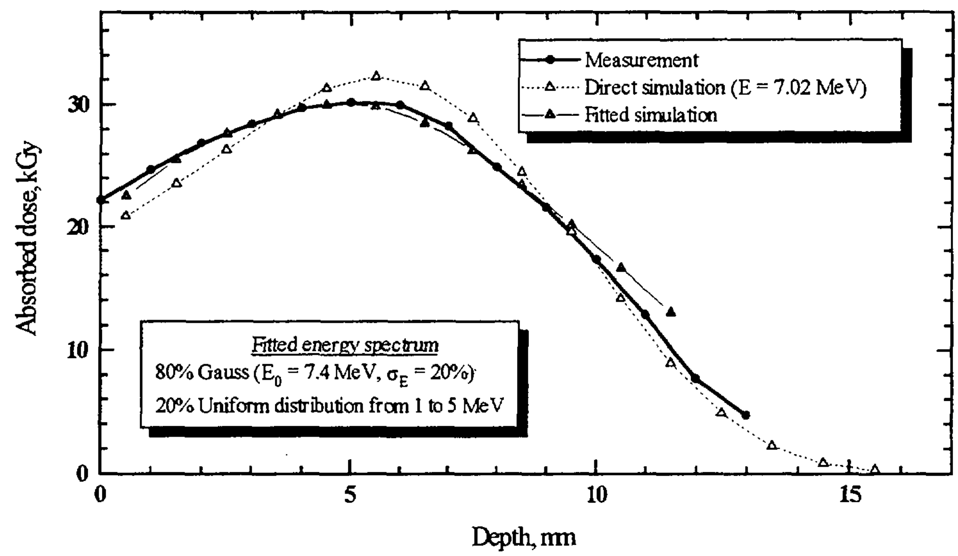

FIG.1. Measured and calculated absorbed dose distributions in an aluminium layer irradiated by an electron beam. The calculations were performed by the EGS4 computer code [1,2].

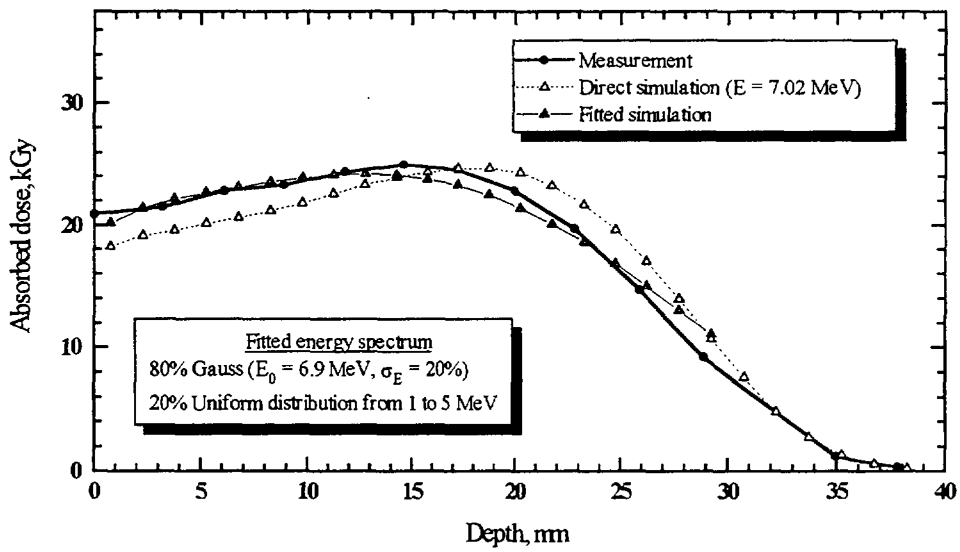

FIG.2. Measured and calculated absorbed dose distributions in a polyethylene layer irradiated by an electron beam. The calculations were performed by the EGS4 computer code [1,2].

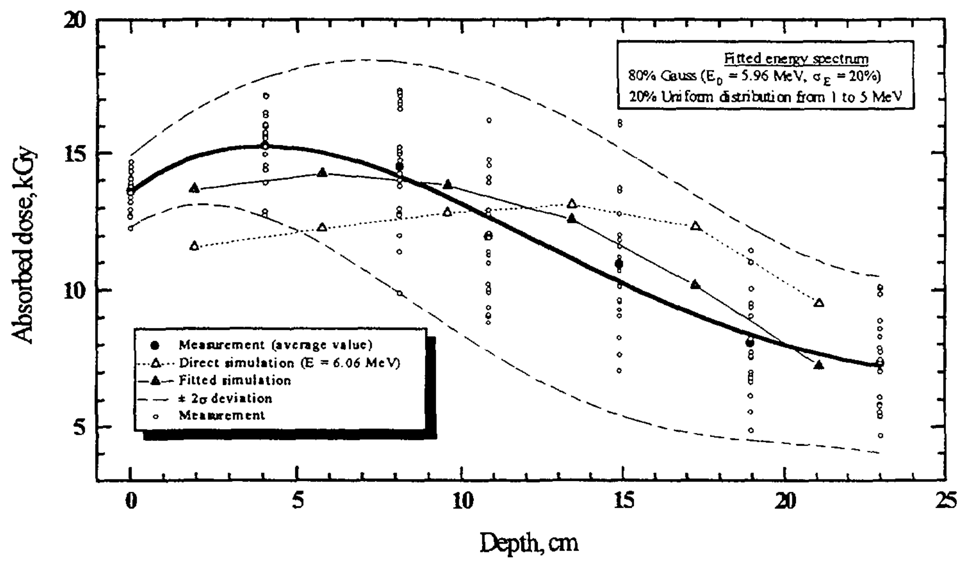

FIG. 3. Measured and calculated absorbed dose distributions inside a box with 'Polmed' syringes irradiated by an electron beam. The calculations were performed by the EGS4 computer code [1,2].

aluminium did not fit measured distribution for polyethylene. Thus one should perform individual fitting for each material under investigation.

In Fig. 3 measured and calculated dose distributions for a box with syringes ('Polmed', Poland) are represented. The box (600x400x250 mm^3) contained 1400 syringes each with capacity equal to 2 ml. Inside the box 140 dosimetry films were situated at 7 different depths, i.e. 20 films at each depth. One can observe from the figure that calculated curve obtained for homogenized model of the box fits to measured one reasonably good. The calculated curve was obtained using beam parameters fitted to measurement in the case of the polyethylene slab (Fig. 2).

5. CONCLUSION

It is shown that direct radiation treatment simulation with EGS4 computer code fails to describe correctly absorbed dose distributions inside a box with realistic objects irradiated by an electron beam. The suggested procedure which consists in fitting to a reference measurement enables to describe the measured dose distributions more correctly. Therefore one can perform minimal number of measurements with less labour, time and money consumption preserving reasonably high accuracy in description of dose fields. Thus one can state that the approach can be very useful in practice. In future we shall continue the work for more detailed description of dose fields using more realistic (heterogeneous) calculation models.

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