INTEGRATION OF COMPUTATION METHODS IN DOSIMETRY OF RADIATION PROCESSING

V.T. Lazurik, V.M. Lazurik, G.F. Popov, Y.V. Rogov
Kharkiv National University
Kharkiv, Ukraine
E-mail:lazurik@hotmail.com

Software for modelling by Monte Carlo (MC) method the dosimetric devices such as dosimetric wedge (ModeDW) and stack (ModeStEB) irradiated with scanned electron beam on moving conveyer was developed by authors. Integration of computer modelling of a dose distribution in films located in a wedge and stack made of arbitrary materials expands the procedure opportunities of the dosimetric devices in the dosimetry of radiation processing.

PACS*:* 29.17.+w

1. INTRODUCTION

Radiation processing dosimetry is vitally important for all radiation-technological processes based on electron beam (EB) irradiators. Control method of EB characteristics in radiation processing by the wedge and stack in conjunction with dosimetric films is well-known and widely used in practice [1-3].

The idea of usage of a procedure of the dosimetric wedge and stack in radiation processing is related with determination of the depth-dose distribution of electrons in an irradiated target for a flat one-dimensional case and obtaining an information about characteristics of EB on the basis of the solution of an inverse problem.

International standards determine the measurings procedure for the depth-dose distributions with usage of the dosimetric wedge and stack, experimental data treatment and an interpretation of observed results [4,5]. Practical use of a procedure of the dosimetric wedge and stack is related with utilization of a standard construction of the devices that ensures only determination and control of the most probable energy, E_p, and the average energy, E_a, of an EB. These information in some cases testifies only about a level of stability of a radiation processing.

Dosimetric devices of the reference sizes, made of reference homogeneous materials, such as aluminum, polyethylene, polystyrene, graphite, traditionally are used in radiation processing. Empirical formulas defining values of electron energy for a monoenergetic beam on value of the practical range R_p and half value depth R_{50} of electrons in an irradiated material are known for the reference materials.

The R_p and R_{50} values for electrons in the reference materials are obtained on the basis of analytical approximation of the depth-dose distribution in a spatial field of the strong decreasing of a dose in a dosimetric film located between plates of the reference materials. In this case the choice of a spatial field for analytical approximation is not formalized. It is obvious, that results of such treatment of experimental data depend on spectrum and angular distribution of electrons in an EB.

Derivable at such mathematical treatment of observed data, the integral characteristics for passage of electrons in substance is poorly suitable for prediction of a spatial dose distribution in an irradiated objects. For example, at radiation sterilization a density and effective atomic number of irradiated materials in some times is less than for aluminum wedge, on the basis of which a value of the E_p and E_a for an EB are obtained.

Essential expansion of procedure opportunities of the dosimetric wedge and the stack can be established due to integration of computer modeling of a dose distribution in a film located in a wedge and stack made of an arbitrary materials, processing methods and the comparative analysis of calculated with experimental results.

The software ModeDW (Modelling of Dosimetric Wedge) and ModeStEB (Modelling of Dosimetric Stack) are the special modules of information system RT-Office 3 which are used for computer modeling of dosimetric devices [6,7]. Software ModeDW is intended for modeling an EB dose distribution in dosimetric film placed along the sloping surface between the two wedges made of an arbitrary materials. Software ModeStEB is intended for modeling an EB dose distribution in a stack of plates of an arbitrary materials interleaved with dosimetric films or a stack of dosimetric films alone. The dosimetric wedge and stack irradiate with scanned EB on industrial radiation facility that is based on the pulsed or continuous type of electron accelerators in the electron energy range from 0.1 to 25 MeV.

2. GEOMETRICAL MODEL OF EB FACILITY AND IRRADIATED PRODUCT

Schematic representation of the EB facility used for simulation of the electron depth-dose distributions in the dosimetric stack with dosimetric films irradiated with scanned EB and on moving conveyor is shown in Fig.1.

Dosimetric stack consists of a set of plates made of an arbitrary materials interleaved with dosimetric films or a stack of dosimetric films alone. The number of plates with dosimetric films in the stack are in the range from 1 to 60. The plates of stack with dosimetric films should be located on the conveyer platform perpendicular relatively incident EB axis.

Fig.2 demonstrates the geometrical model of dosimetric wedge irradiated with non-diverging EB on moving conveyor.

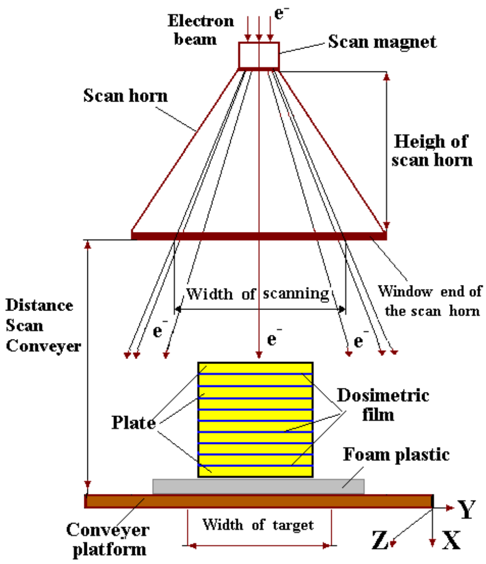

Fig.1. Electron beam and irradiated dosimetric stack geometry. Arrangement of a stack plates interleaved with dosimetric films on moving conveyor irradiated with triangular scanned EB. Axis X - direction of EB incidence, axis Y - direction of EB scanning, axis Z - direction of conveyer motion

In the Fig.2 two wedges are stacking together to form a rectangular block. Dosimetric film is inserted along the sloping surface between the two wedges made of an arbitrary materials. The rectangular block can be located under arbitrary angles relatively incident electron beam axis.

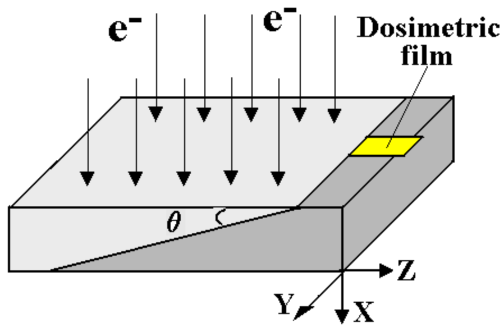

Fig.2. Model of the dosimetric wedge with dosimetric film irradiated by scanned EB. Axis X - direction of EB incidence, axis Y - direction of EB scanning, axis Z - direction of conveyer motion

Simulation of EB dose distributions in an irradiated films located in the wedge and stack was accomplished by the MC method in a tree-dimensional (3-D) geometrical model by the programs ModeDW and ModeStEB. In accordance with the schematic representation of electron beam facility and heterogeneous target presented in Figs.1,2 a source of electron beam including spectral characteristics, a scanner, a conveyor line, an irradiated target are considered as uniform self-consistent geometrical and physical models.

3. PHYSICAL AND SIMULATION MODEL

3.1. PHYSICAL MODEL OF AN IRRADIATION PROCESS

The physical model of an irradiation process for EB radiation technologies includes the following principal elements: EB irradiator characteristics, the systems parameters which provide the necessary spatial characteristics in radiation processing, radiation and physical characteristics of irradiated product. Besides, the set of processes of interaction of ionizing radiation with product which are necessary for description of results with the established accuracy are included in physical model at the theoretical analysis and/or computer modeling of ionizing radiation expose on product.

In the physical model the parameters of an EB irradiator, an irradiation system, and an irradiated object as *Input data* for the programs ModeDW and ModeStEB are the following: *Parameters of electron beam*: average beam current, or pulse duration and repetition frequency in pulsed accelerators, electron spectrum, beam diameter and spatial distribution of the beam intensity, angular distribution of electron beam at the outlet of a scanning system. *Parameters of scanning system*: modes of operation, the triangular or non-diverging irradiation of target; form of current in magnet of scanning system; repetition frequency of scanning; parameters of the exit window for electron beam. *Parameters of conveyor line*: speed and geometrical characteristics of the line. *Parameters of irradiated product*: geometrical characteristics of the irradiated product; elemental composition of the target; material and size of the covering for irradiated product. *Regimes of target irradiation*: one-, two-sided irradiation.

The following processes of interaction of an EB with material and their modeling conceptions were included in the physical model:

- electrons lost energy by two basic processing: inelastic collisions with atomic electrons and bremsstrahlung;
- inelastic electron collisions with atomic electrons lead to excitation and ionization of the atoms along the path of the particles (model of grouping of the transferred energy);
- emission of the secondary electrons (model of the threshold energy);
- electrons participated in elastic collisions with atomic nuclear lead to changes in the electron direction (model of grouping of transferred pulse).

In the energy range of incident electrons from 100 keV to 10 MeV and irradiated materials with atomic number $Z \leq 30$, the model uncertainty is less than 5% for calculated dose and charge depositions in the field of the basic EB energy absorption.

3.2. MATHEMATICAL AND COMPUTER METHODS OF CALCULATION

The developed software use a combination of two methods for calculation of an absorbed dose in an object irradiated by electrons: the formulas of semiempirical models and simulation of transport of electron and gamma radiation by a MC method. The features of a program realization are the use of the following methods:

1. Method of a randomization of EB scanning process is used for an effective evaluation of productivity of the calculation scheme at the set parameters of an irradiation process and a choice of statistics for MC simulation which ensure a required statistical error for simu-

lation results.

2. Method of object translation. This new method is intended for the effective solution of non-stationary tasks in which desired quantity is the integral on a process time. The problem of a dose calculation in an irradiated object after its passage through an irradiation zone (travel or crossing through a zone) falls into such class of tasks.

3. Optimization of model parameters of calculation. The uncertainty of modeling results essentially depends on values of the adjusting parameters for used models of interaction processes of radiation with materials. Therefore, in the computation scheme the model parameters of simulation are chosen according with geometrical and physical characteristics of an irradiation process to minimize the run time for obtaining simulation results with the established accuracy. For optimization of model parameters the adaptive algorithm on the basis of semiempirical formulas is used [8].

The 3-D dose distribution in an irradiated dosimetric films located in the wedge and stack is represented as a function of two coordinates: the film width along the scan direction (axis Y), and the film length along conveyer motion (axis Z), the dose value integrated along film thickness (axis X).

Modeling of EB transport from the outlet window of accelerator to the incident surface of the irradiated target takes into account scattering of electrons in an air gap. The requirements for computer modeling were chosen so that in selected range of absorbed doses the relative root-mean-square statistical error was less than 1%.

The software ModeDW and ModeStEB provides the end-user with: data sets in the graphic and tabular form for an absorbed dose and charge depositions within the dosimetric devices irradiated with a scanned EB; comprehensive comparative analysis of output data; cognitive visualization of output data; decision of optimization problems with using dynamic and statistical databases; presentation of physical and operational characteristics for radiation processing.

4. DESCRIPTION OF THE SOFTWARE MODEDW AND MODESTEB

Developed software can be used for the following problem tasks in radiation processing:

1. Determination of dependence of an absorbed dose distribution in a film as function of: density and a chemical composition of film material; width and thickness of a film; geometrical arrangement of a film in a wedge and stack; density and a chemical composition of a wedge and stack materials; geometrical sizes of a wedge and stack; an orientation angle of a wedge and stack relatively to incident electron beam.

2. Examination of dependence of an absorbed dose distribution in a film as function of: an EB current and speed of a conveyer motion; an angular distribution of electrons in a beam; a spatial distribution of electrons in a beam; a width of EB scanning; an angular characteristics of a scan process; a time sweep of the scanner; an air gap between the scanner and a target.

3. The comparative analysis of visual and numerical difference of the depth-dose distributions in a film for: various parameters of calculation; various calculation models; an experimental and calculated depth-dose distributions in a film.

The feature of the software ModeDW and ModeStEB are the following:

1. Built-in tools for statistical analysis.

2. Built-in tools for uncertainties estimation of results simulation due to uncertainties of input data for radiation facility.

3. Estimation of uncertainties for physical models.

4. Comparison Modulus for visual and a numerical analysis of calculated and experimental data and for decision of optimization tasks in radiation processing.

5. Built-in tools for processing of experimental dosimetric data and their comparison with simulation predictions.

The softwares have intuitively clear graphical interface for the end-users with the following features:

1. Detailed decomposition of input data for main elements of source and target (including spectral characteristics for irradiation source).

2. Two levels for entering of input data via configuration files and manually.

3. Expert control for the range of input data and coordination for the set of geometrical and physical input data.

4. Compatibility of export an input data to different modules.

5. RESULTS SIMULATION

Some results of simulation of an EB dose distribution in the PVC (polyvinylchloride) dosimetric films located between stack plates are presented in Figs.3,4.

The comparison results for EB dose distribution in the 1st, 4th and 7th PVC films layers located between PS (polystyrene) plates are shown in Figs.3,a,b, c respectively. Stack consists of 8 packages. Each package includes 2 layers: PS with thickness 1 cm and density 1 g/cm^3, and PVC film with thickness 0.026 cm and density 1.3 g/cm^3. Stack size is 10x10 cm along scan direction and along conveyer movement. Stack is irradiated by a point beam of electrons with energy 10 MeV in the stationary regime.

As it is seen from Figs.3,a,b,c, the form of EB dose distribution has the cone form in each film layers. The passage of the point EB through the multi-layer structure of the stack is characterized by the monotonous decreasing of EB energy and expansion of the cone base diameter with increasing of layers number from an entrance surface of EB.

The comparison results for EB dose distribution in the 1st, 4th and 6th PVC films layers located between PE (polyethylene) plates are shown in Figs.4,a,b,c respectively. The stack consists of 6 packages. Each package includes 3 layers: PE-PVC-PE, PE with thickness 0.5 cm and density 1 g/cm^3, and PVC film with thickness 0.1cm and density 1.3 g/cm^3. Stack size is 20 cm along scan direction and 10 cm along conveyer movement. Stack is irradiated by the scanned non-diverging EB with energy 10 MeV on moving conveyer.

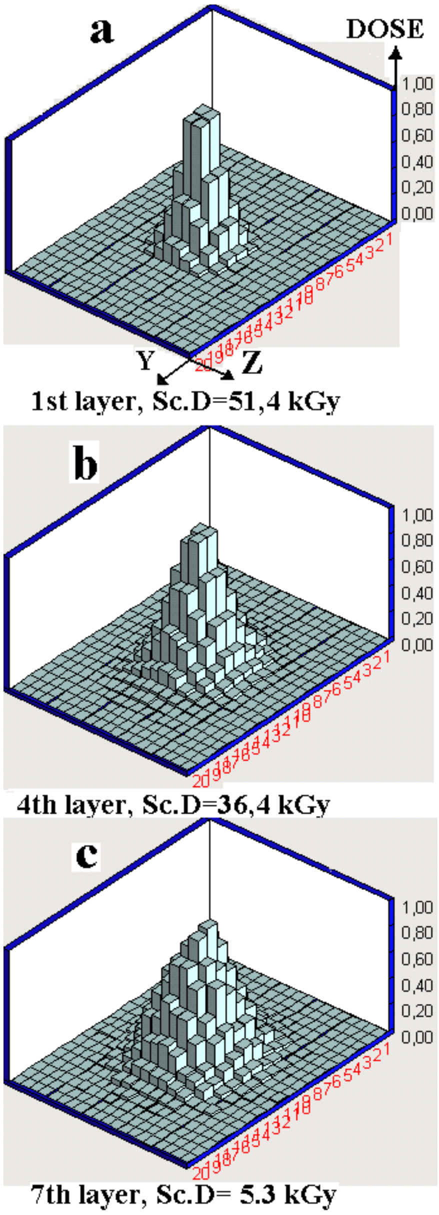

Fig.3. 3-D view of the dose distribution in the PVC dosimetric film in the 1st, 4th and 7th film layers

Analysis of simulation results for the EB absorbed dose field formation in the multi-layer structure of the stack irradiated with the scanned non-diverging EB have shown that beginning with 2nd package, the value of absorbed dose in PVC films near the interface of package with air is reduced about in 20-40 percent on the length from interface up to 4 cm in comparison with the packages center (See Fig.4,a). This effect can be explained by the balance disruption of primary scattered electrons near the interface of stack plates with air.

An appearance in the lowermost (6th) film layer of the local maximum for dose distribution near interface of film with air (See Fig.4,a) can be explained by the lateral highlighting by the flux of primary electrons scattered in air.

Together with dosimetric functions, the developed software allow to investigate the mechanism of absorbed dose field formation in multi-layers targets.

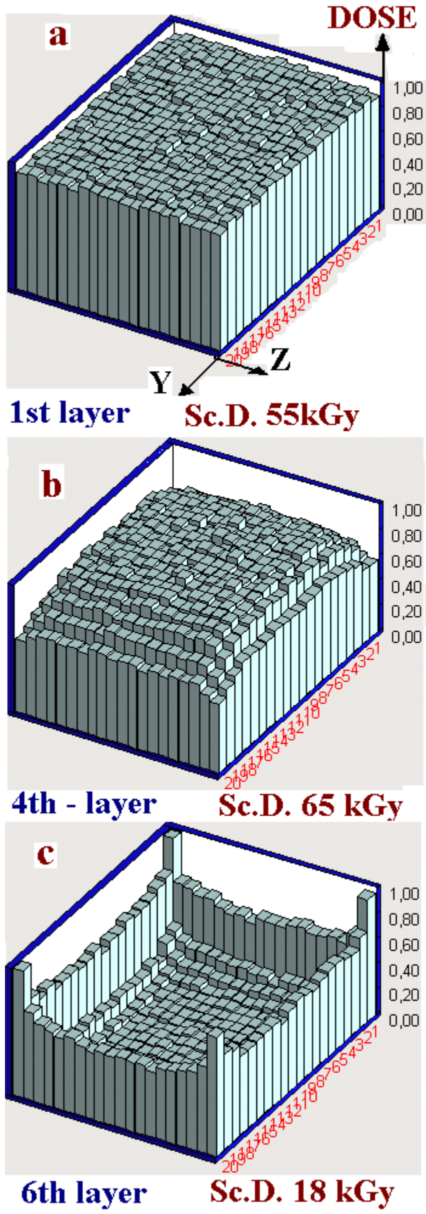

Fig.4. 3-D view of the dose distribution in the PVC dosimetric film in the 1st, 4th and 6th film layers

CONCLUSIONS

The developed software essentially expands opportunities of the further development and usage of a procedure of the dosimetric wedge and the stack, because it remove the restrictions on obtaining of experimental data only in conditions when the flat one-dimensional case of an EB irradiation is realized.

1. Software allows to develop optimum constructions of the dosimetric wedge and stack for monitoring of operational characteristics for EB. (on the basis of the analysis of sensitivity procedure of the dosimetric wedge and stack).

2. Software allows to extract the maximal possible information on characteristics of the irradiation process with scanned EB on the basis of the comparative analysis of calculated and experimental results.

3. Software allows to develop the optimum phantom of an object irradiated with EB for the experimental testing of selected modes of an irradiation.

The softwares allow to determine a dose map in an irradiated materials, a dose uniformity ratio, an energy of incident electrons, an EB ranges, prediction and analysis of the EB absorbed dose characteristics related with parameters of EB radiation facility, as well as an interpretation of experimental dosimetry results. In the field of EB radiation processing the programs can be used for commissioning of EB facility, EB facility qualification, process validation and routine process control.

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ИНТЕГРИРОВАНИЕ ВЫЧИСЛИТЕЛЬНЫХ МЕТОДОВ В ДОЗИМЕТРИЮ РАДИАЦИОННЫХ ТЕХНОЛОГИЙ

В.Т. Лазурик, В.М. Лазурик, Г.Ф. Попов, Ю.В. Рогов

Разработано программное обеспечения для моделирования методом Монте-Карло дозиметрических устройств, таких как дозиметрический клин (ModeDW) и пакет (ModeStEB), облучаемых сканирующим пучком электронов на движущемся конвейере. Интегрирование компьютерного моделирования распределения дозы в пленках, расположенных в клине и пакете, изготовленных из произвольных материалов, расширяет методические возможности этих дозиметрических устройств в дозиметрии радиационных технологий.

ІНТЕГРУВАННЯ РОЗРАХУНКОВИХ МЕТОДІВ В ДОЗИМЕТРІЮ РАДІАЦІЙНИХ ТЕХНОЛОГІЙ

В.Т. Лазурік, В.М. Лазурік, Г.Ф. Попов, Ю. В. Рогов

Розроблено програмне забезпечення для моделювання методом Монте-Карло дозиметричних приладів, таких як дозиметричний клин (ModeDW) та пакет (ModeStEB), які опромінюються скановаmaking пучком електронів на конвеєрі, що рухається. Інтегрування комп'ютерного моделювання розподілу дози в плівках, які розташовані в клині та пакеті з довільного матеріалу розширюють методичні можливості цих дозиметричних приладів в дозиметрії радіаційних технологій.