DISTRIBUTION OF ABSORBED DOSES IN THE MATERIALS IRRADIATED BY "RHODOTRON" ELECTRON ACCELERATOR: EXPERIMENT AND MONTE CARLO SIMULATIONS*

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Abstract

This paper describes the experimental setup and presents studies of absorbed doses in different metals and dielectrics along with corresponding Monte Carlo energy deposition simulations. Experiments were conducted using a 5 MeV electron accelerator. We used several Monte Carlo code systems, namely MARS, MCNP, and GEANT to simulate the absorbed doses under the same conditions as in experiment. We compare calculated and measured high and low absorbed doses (from few kGy to hundreds kGy) and discuss the applicability of these computer codes for applied accelerator dosimetry.

1 INTRODUCTION

The prediction of correct distribution of absorbed doses in the irradiated product is very important for applied radiation technologies. Application of Monte Carlo energy deposition computer simulation allows us to increase the efficiency of the product irradiation. Different materials (from metals to dielectrics), different geometries with variation of density of irradiated product lead to complex problems of measurements and calculations of absorbed doses [1]. Present status of computer simulation for radiation technologies is not quite simple. Two main calculation methods were developed - analytical solutions and statistical simulation also known as Monte Carlo method. Monte Carlo method has been developed quite extensively lately and several large code systems are available for comparison and evaluation. We present an attempt to make comparison of three main computer codes (MCNP, GEANT3 and MARS14) with experimental data taken from industrial electron accelerator "Rhodotron".

2 EXPERIMENTAL SETUP

The experiments were conducted using CW "Rhodotron" Electron Accelerator [3] manufactured by IBA(Belgium) [2] with the main parameters listed in Table 1.

Accelerator is able to operate in either static or scanning mode. The static mode is used only for sample irradiation. The scanning mode of electron beam in the area of irradia-

Table 1: Main Parameters in the experiments

Electron kinetic energy	5 MeV;
Beam current	2-16 mA;
RF operating frequency	107.5 MHz;
Beam repetition rate	100 Hz.

tion leads to pulsed regime of accumulation of the absorbed doses under the adiabatic conditions [4].

Electron beam propagates in air over the 70 cm distance on its way from accelerator foil window to the sample position. Time of irradiation determined the different level of absorbed doses, and by increasing irradiation time from 5 sec to 1 min or more we covered all interesting doses from several kGy to hundreds kGy.

Samples were made from plates of particular material with film dosimeters placed in between. The plates had varying thickness for different materials but with constant dimensions $2 \star 2$ cm^2 in the direction transversal to the beam propagation.

Dielectrics such as Teflon and glass, and metal (Aluminum) were used as materials for samples. The standard Cellulose TriAcetate (CTA) film dosimeters (FTR-125) were used for the dose measurements. We employed "Beckman DU640" spectrophotometer with the wavelength of 280 nm in order to get dose readings from CTA films.

3 COMPUTER CODES AND NORMALIZATION PROCEDURE

Three popular computer codes: MCNP v.4C [5], GEANT3 v.3.21 [6] and MARS v.14 [7] were used in this study. These codes have long history and are applicable in different research areas. MCNP was started as pure neutron transport code and only lately the electron, positron and gamma transport were added from Integrated Tiger Series developed by M. Berger and S. Seltzer. MCNP team concentrated on low energy transport above 1 keV but below 20 MeV. MCNP has highly advanced biasing technique which allows for optimization of data scoring and efficiency. Another MCNP advantage is the ability to use PVM with multiple processors or network of workstations to speed-up the calculations. GEANT was developed as Monte Carlo tool for high energy physics detectors. Main interest area is high-energy processes, so GEANT can track electrons, positrons, and photons only down to

10keV. 3D geometry block is included but GEANT requires a lot of programming skills in order to set up the calculations. MARS was started as tools for accelerator and shielding studies and from middle 70s has been developed into full scale Monte Carlo code. It got advanced electromagnetic module last year [8]. As in GEANT, programming skills are required to set up the calculations. Particles can be tracked down to 1keV for photons and 10keV for electrons. Electromagnetic module can be used either separately or embedded into software controlling technological process. MARS has biasing technique implemented to increase calculation efficiency.

Monte Carlo accuracy, in general, depends on the number of particles tracked through the setup since the statistical error goes down as inverse square root of number of tracked particles. All codes have systematic errors due to cross-section data uncertainty around few percent. We continued tracking until statistical error was below 1% in all bins. This study considers the electron source with realistic parameters, angular and spatial distribution of beam, sample geometry, and normalization condition for scanning work mode of the accelerator.

Normalization procedure is quite complicated and takes into account beam size, sample size, current, scanner position, speed, and frequency. We also take into account electron struggling through the air and angular and spatial spread due to multiple scattering. For normalization purposes we derived complicated expression which accounts for all above mentioned factors and calculates the number of electrons which actually hit the target. It is available on request and will be published in extended version of this paper.
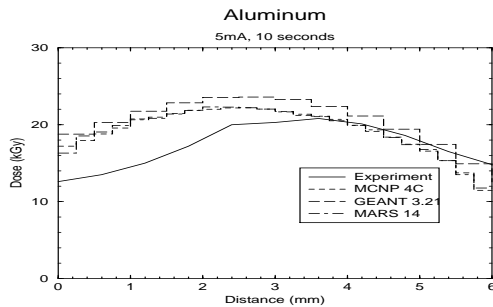
4 RESULTS

Figure 1: Aluminum sample, 5 ma current, 10 sec irradiation

Typical distributions of measured and calculated absorbed doses for different materials and irradiation times for aluminum, Teflon and glass are presented on Figs. 1-6 Variation of irradiation time allows us to generate different levels of accumulated absorbed doses without overheating the samples under our adiabatic conditions. The results of computer simulation and experiments show that for conducting materials such as aluminum (Figs. 1-3) we have almost perfect linear dependence between irradiation time and absorbed dose for all interesting levels starting with
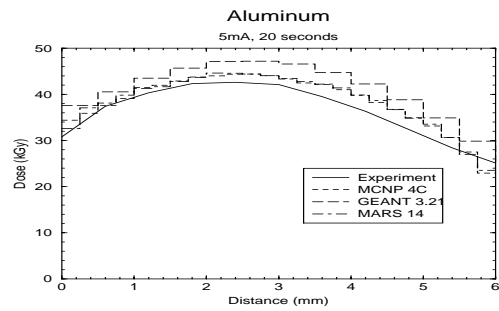

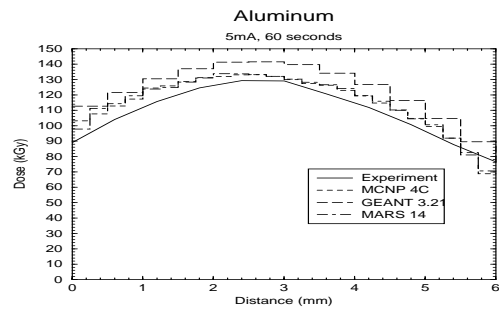Figure 2: Aluminum sample, 5 ma current, 20 sec irradiation

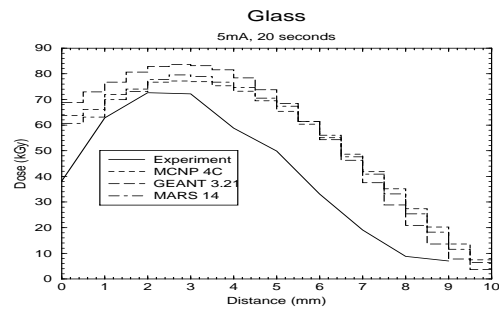Figure 3: Aluminum sample, 5 ma current, 60 sec irradiation

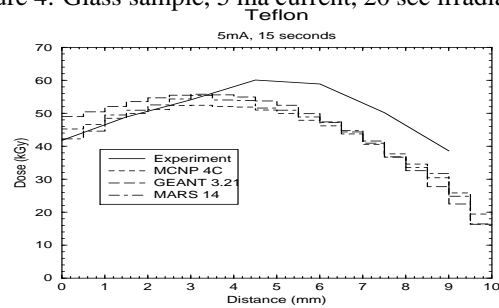Figure 4: Glass sample, 5 ma current, 20 sec irradiation

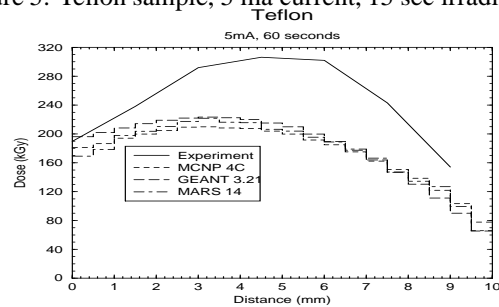Figure 5: Teflon sample, 5 ma current, 15 sec irradiation

Figure 6: Teflon sample, 5 ma current, 60 sec irradiation

low dose (up to 20 kGy) up to high doses (around 150-200 kGy). The results for dielectric materials for these levels of absorbed doses have strong nonlinear behavior. Also we can clearly see the shift of the position of the dose maximum. For the high level of doses in Teflon 6 one can see close to 30-40% difference between experimental data and simulation results. The average error of simulation is below 5% if we take into account statistical and systematic Al errors combined. The total average experimental error for absorbed doses on the level of 15% for both minimum and maximum doses. Monte Carlo calculations for all three codes were done using the same source and geometry terms and were traditionally done per one incident particle. Given the irradiation time and using normalization procedure mentioned above we were able to compare and plot together calculated and experimental data.

5 DISCUSSION

In course of our research we found good correlation for conducting materials such as aluminum for all levels of doses. The results for measured and simulated absorbed doses in Al confirm it. The dose growth has linear dependence versus irradiation time or beam current. We could also see that MCNP and MARS reproduce the dose shape reasonably well with about 20% difference, which we could attribute to possible normalization uncertainties and systematic errors. In the case of dielectric materials (glass and Teflon) we have good correlation with the data up to medium doses. But in the case of high doses which are quite interesting range of doses for radiation technologies, the results of simulation show the difference on the level of 30-40% after the dose maximum. We believe it can be explained by the properties of dielectrics. Effect of dielectric charging by electrons could be responsible for much of the difference, as was clearly demonstrated and summarized earlier in the monograph [9]. The position of dose maximum in dielectric materials relative to the metals can be explained by effect of electrical field inside of dielectric produced by stopping electrons during the irradiation. Analysis of experimental data and computer simulations shows that for low and middle level of doses for conducting and dielectric materials we can use these three computer codes. For conducting materials we also can use these codes for all level of absorbed doses. But for dielectrics we need to understand and introduce practical corrections in the algorithm used to propagate electron through media and dissipate its energy.

6 CONCLUSIONS

Our future plans include an investigation of the influence of dielectric constant on the value of absorbed doses and an investigation of effects of electrical discharge inside of the dielectric materials. The effect of internal discharge was observed for high current electron beam hitting the dielectrics with high dielectric constant [10]. The other effect of anomaly conductivity for dielectrics also could have place [11]. Other interesting experiments which we are planning to conduct are using DC and RF Linacs (different time scale of beam parameters) for comparison with results of computer simulation by those 3 codes.

As a result of this study we can make following main conclusions. The computer codes could give the user average error on the level 12-15% for conducting materials for all levels of absorbed doses. The computer codes could produce results with average error on the level 15-20% for dielectric materials for absorbed doses up to 70 kGy. The distribution of absorbed doses in dielectrics has different position of the dose maximum in comparison with conducting materials. The MCNP, GEANT3 and MARS can be used for simulation of absorbed doses for conducting materials. The MCNP code is quite accurate for practical applications and is probably more useful for radiation industry. Correct normalization procedures for industrial scanning electron source are very important for comparison with those computer codes.

7 REFERENCES

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