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A FLUKA STUDY OF CROSSTALK BETWEEN MEASURING VOLUMES IN A 2D ION CHAMBER ARRAY

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In this paper we present a preliminary study of the reciprocal influences (crosstalk) of the individual measuring volumes in a 2D ion chamber array. The array was designed to be used in the charged particle beams generated by ultra-high-power laser - target interactions. FLUKA Monte Carlo code simulations were performed to obtain dose values in a single detector placed in the geometrical center and in the individual measuring volumes of the array. A quantitative measure of crosstalk was obtained by calculating relative dose deviation values for several divergence angles of a 6 MeV spatially extended electron source and for a range of external distance values between individual measuring volumes. The results show that the relative dose deviation values are very low. No functional dependency on the considerend parameters was found. This indicates that the array can be successfully used in measurements of the radiadion generated by the ultra-high power laser pulses and that it can be calibrated relative to the central dose.

Keywords: ion chamber array, crosstalk, FLUKA, relative dose deviation

1. Introduction

The measurement of radiation produced by the interaction of ultra-high power laser pulses with targets raises particular problems due to their short duration and low repetition rate. Methods of instantaneous dose measurement were developed mostly for medical applications and they rely on the use of ion chambers, which are still considered a golden standard. However, when used in very short pulses, these detectors have the shortcoming that they require performing several corrections in order to calculate an accurate dose from the measured electrical charge. The methods for calculating and applying these correction factors have been thoroughly documented and described in IAEA TRS 398: Absorbed Dose Determination in External Beam Radiotherapy: An International Code of Practice for Dosimetry Based on Standards for Absorbed Dose to Water [1].

Within the ELIDOSE project [2] we proposed a new type of 2D ion chamber array, based on 4 ionizing chambers, in order to circumvent the practical

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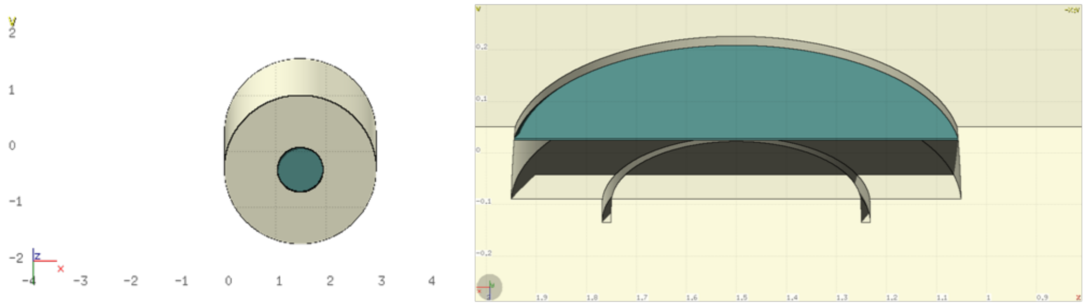
difficulty of measuring all the quantities necessary for retrieving the correct dose over the ultra-short pulse duration. The array detector will allow the measurement of the dose, the recombination and bias polarity corrections in a single shot, still making use of the classical formulae given by IAEA TRS 398.

In this paper we present the results of a preliminary study of the reciprocal influences (crosstalk) of the individual detectors in a 6 MeV electron beam with a half-divergence angle in the $[0^{\circ}, 40^{\circ}]$ range (a typical spatial distribution for the source terms used in radiation protection calculations at the ELI-NP research facility, for example [3]). For this study, the FLUKA Monte Carlo code [4], [5] was used, in order to transport the radiation through a simplified geometry containing the detectors (individual and as a system) placed in air.

2. Simulation setup

FLUKA simulations were performed using the latest version of the code, FLUKA 2011.2x.3. The PRECISION set of defaults was selected, and transport thresholds for the electromagnetic shower particles were set to 1 keV for the charged ones, and 100 eV for the photons. Delta rays were produced above 1 keV. The geometry of the detector represented in Fig. 1 is a model of the PTW Advanced Markus chamber type 34045 in which the dimensions are according to PTW chamber manual, version D661.131.00/05. The plane-parallel chamber consists in a 9mm-diameter cylindrical cavity filled with air at normal conditions of pressure and temperature, embedded in a 5-cm-diameter PMMA body.



(a (b)

Fig. 1. a) Markus chamber FLUKA model - 1 cavity configuration; b) detail: vertical cross section through the active volume. The polyethylene window and the guard ring can be noticed. The drawings were obtained in Flair [6]

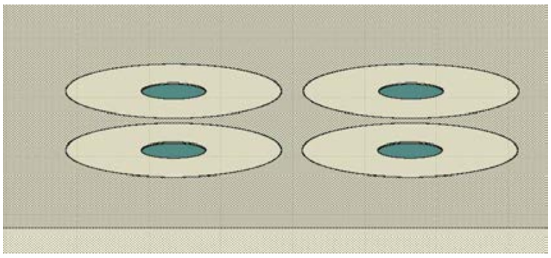


Fig. 2. Detail of a model 10-cm-diameter detector whose cavities are placed at a 1mm external distance; the green region is the entrance window (see also Figure 1(b) for 3D representation of the individual cavities cross section.

The cavity is separated from the external air by a 0.03 mm thick polyethylene entrance window. The active volume (0.02 cm^3) is delimited by a wide guard ring designed to reduce the effects of radiation scattered from the body of the detector.

In order to study the influence of the relative distance between the individual cavities in a 4-cavity array detector, we modelled a 10-cm diameter PMMA cylinder housing four cavities which were placed at increasing external distances, starting with 0.1 cm, and continuing with 0.5 cm up to 3.0 cm, with a step of 0.5 cm. A geometry detail corresponding to the smallest distance between adjacent cavities is presented in Fig. 2. The system was placed at a distance of 3.5 cm from the spatially extended source term.

3. Methods and results

In a first set of calculations we placed the central 1-cavity detector, modeling an advanced Markus chamber, at close proximity (0.5 cm) to the extended square (10cm x 10cm) electron source, which is similar to the source obtained with a medical linac electron accelerator when the corresponding applicator is used. This choice was mainly motivated by the conditions of actual measurements, partially reported in [2]. The other reason is that experiments where ultrahigh power laser pulses interact with targets [7] are expected to produce beams expanding over large areas, with divergence values covering a wide range. In this study, we considered that the half-divergence angle is limited to the interval $[0^\circ, 40^\circ]$. Similar calculations were produced for larger distances between the source and the detector, at 50cm and 100cm, respectively. A graph representation of the dose value scored in the active volume of the detector as a function of the primary electron divergence is presented in Fig. 3. The dose is expressed in the customary FLUKA units, namely GeV/g/primary electron.

It can be seen that for the short distance considered in the simulations, the dose values are almost constant at all divergence values. The small increase at higher divergence angles can be explained if we take into consideration the large dimensions of the source field as compared to the detector dimensions. At small divergence, the dose is produced mainly by the fluence of particles which are leaving the source from positions that roughly correspond to the detector area. At higher divergence, fluence of primaries from outer zones of the source contribute to the "all particle" fluence inside the active region of the detector. Naturally, this effect diminishes with the increase of the distance from the source to the detector (see the graph for 50 cm). When the dimension of the source "seen" by the detector becomes insignificant (see the graph for 100cm), the registered dose exhibits the expected decrease with divergence, due to a decrease of fluence.

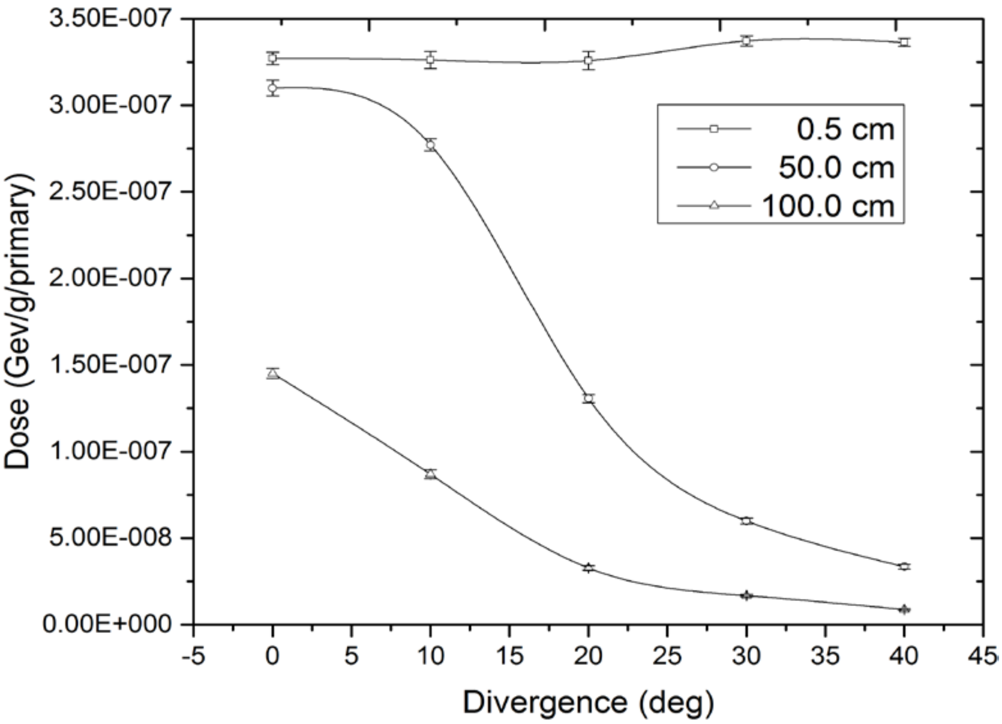


Fig. 3. Dose values (GeV/g/primary electron) scored in the active volume of a central detector, as a function of the half-divergence angle (degrees); the ionizing chamber was placed at 3 positions with respect to the extended source: 0.5cm, 50cm, and 100cm.

The reciprocal influence of an array of detector cavities was studied by considering a system of four cavities which replaced the central cavity. In Fig. 4, the results of dose value calculations corresponding to the single central measuring volume detector represented in Fig. 1 and to the system of four measuring volumes represented in Fig. 2, are shown. The cavities are separated by an external distance of only 1 mm. Due to the reciprocal influences, the dose values scored by detectors A - D deviate from the values registered in the case of a unique central active volume, as illustrated in Fig. 4. In order to describe this effect quantitatively, at each divergence angle relative values of the deviations were calculated in percents as $\varepsilon_{\mathrm{rA,B,C,D}} = \frac{D_{\mathrm{A,B,C,D}} - D_0}{D_0} \times 100$ (where $D_{\mathrm{A,B,C,D}}$ are the dose values in the four measuring volumes, and D_0 is the dose obtained in the case of a one measuring volume). The results are presented in Table 1.

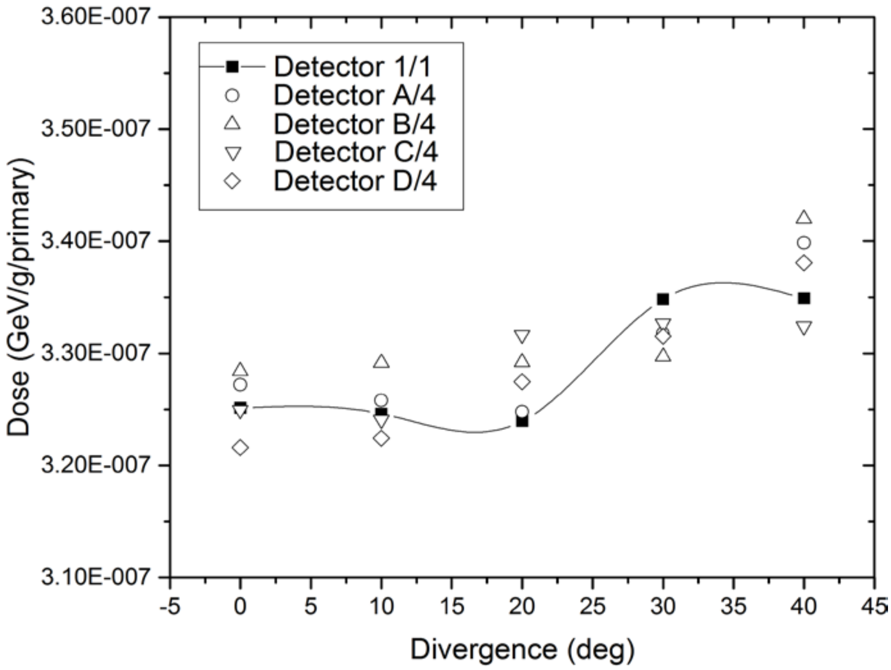


Fig. 4. Comparative representation of the dose scored in a central detector (Detector 1/1) and in the four scoring volumes of a four-detecting-volumes array (Detector A/4 - Detector D/4); for guidance an interpolated curve corresponding to the central detector is presented. The distance from the source to the detector entrance plane was 0.5cm. The number of primaries in the FLUKA runs were chosen such that the statistical errors were less than 1% in each case.

Table 1

Relative dose deviation in detectors A/4 to D/4 vs the dose in a central detector 1/1, as a function of the primary electron beam divergence. The distance from the source to the detector entrance plane is 0.5 cm

Divergence (deg)	0°	10°	20°	30°	40°
$\varepsilon_{rA}(\%)$	+0.63	+0.36	+0.26	-0.91	+1.47
$\varepsilon_{rB}(\%)$	+1.01	+1.39	+1.62	-1.52	+2.12
$\varepsilon_{rC}(\%)$	-0.06	-0.18	+2.38	-0.65	-0.75
$\varepsilon_{rD}(\%)$	-1.09	-0.67	+1.08	-0.99	+0.95

It is easily noticeable that the relative dose deviations are random and have very low values, ranging from -1.52% to 2.38%. The values do not show a consistent functional dependency on the divergence in the four measuring volumes, which could also be explained by the small distance between the source and detector plane. The variations from the central dose value are due to a large number of factors, including, among other, the lack of field uniformity and the reciprocal influences of the chamber volumes, as each ion chamber slightly modifies both the fluence and the energy spectra of the radiation field measured by the other ion chambers. The low values of the relative dose deviations are very encouraging for our array design, as they indicate that crosstalk is very reduced and allows the array to be calibrated versus the measurement in the central position, as required by the dosimetry standards.

As part of our study, we also needed to check the effect of the distance between measuring volumes on their crosstalk. For that purpose, we first calculated the dose in the central detector placed at a distance of 3.5 cm from the extended source. A zero divergence electron beam was used in order to analyze the simplest case, that of a parallel beam, and to avoid as much as possible the overlap of all other effects. Subsequently, we performed several simulations involving the four-cavity array, in which the external distance between adjacent cavities was changed in the range of 0.1 cm to 3.0 cm. Table 2 below shows the results of these calculations.

Table 2.

Relative dose deviation in detectors A/4, B/4, C/4 and D/4 vs. the dose in a central detector 1/1 as a function of the external distance between adjacent detecting volumes. The distance from the source to the detector entrance plane was 3.5cm.

Distance (cm)	**0.1**	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**
$\varepsilon_{rA}(\%)$	+0.54	+0.48	-0.58	0.02	-0.65	+0.43	+0.35
$\varepsilon_{rB}(\%)$	+0.62	-1.16	+0.29	-0.65	-0.32	-0.50	+1.91
$\varepsilon_{rC}(\%)$	+0.87	+0.62	-0.19	+0.48	-0.67	+1.12	-1.01
$\varepsilon_{rD}(\%)$	+0.68	+1.09	-0.09	+1.21	-0.85	-1.29	-0.75

As can be seen, there is no monotonical dependence between the relative dose deviations and the distance between the detecting volumes. This indicates that there exists no simple relation between the two quantities, for the selected distance range and beam energy. Furthermore, the values of the relative dose deviations are very low, most of which are less than 1%, meaning that the measuring volumes can be brought as close as 1 mm external distance. This is a very encouraging indication that such an array can have the reduced dimensions that would allow dose measurements in laser accelerated particle beams.

4. Conclusions

Crosstalk of the individual detectors used in a 2D ion chamber array have been studied using FLUKA simulations, for a 6 MeV electron beam with a half-divergence angle in the $[0^\circ, 40^\circ]$ range (a typical spatial distribution for the source terms used in radiation protection calculations at the ELI-NP research facility).

The results of this study indicate that the relative dose deviation values in the four detectors of the array **vs.** the dose in one detector placed in the geometrical center of the array are very small (between -1.52% and 2.38%) and show no dependency on either the beam divergence or the external distance between the detectors. This indicates that the array can be successfully used in the charged particle beams generated at ELI-NP and that the calibration of the array can be performed relative to the central dose.

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REFERENCES

[1] IAEA TRS-398, Absorbed Dose Determination in External Beam Radiotherapy, IAEA Vienna, 2000

[2] *Radu A. Vasilache, Maria – Ana Popovici, Mihai Straticiuc, Mihai Radu, Andreea Groza*, The Development of Novel Array Detector for Overcoming the Dosimetry Challenges of Measuring in Very Short Pulsed Charged Particle Beams - The ELIDOSE Project, Micros 2017 - 17th International Symposium on Microdosimetry, 5-10 November 2017, Venice, Italy

[3*] I. O. Mitu et al.*, Radiation Protection and Safety at ELI–NP, Rom. Rep. in Phys., vol. 68, Supplement, 2016, pp. S885-S945

[4] *Ferrari, P.R. Sala, A. Fasso`, J. Ranft*, FLUKA: a multi-particle transport code", CERN-2005-10, 2005, INFN/TC_05/11, SLAC-R-773

[5] *T.T. Böhlen, F. Cerutti, M.P.W. Chin, A. Fassò, A. Ferrari, P.G. Ortega, A. Mairani, P.R. Sala, G. Smirnov, V. Vlachoudis*, The FLUKA Code: Developments and Challenges for High Energy and Medical Applications, Nuclear Data Sheets vol. 120, 2014, pp. 211-214

[6] *V. Vlachoudis*, FLAIR: A Powerful But User Friendly Graphical Interface For FLUKA, Proc. Int. Conf. on Mathematics, Computational Methods & Reactor Physics (M&C 2009), Saratoga Springs, New York, 2009

[7] *M A. Popovici et al.*, Shielding assessment of high field (QED) experiments at the ELI-NP 10 PW laser system, J. Radiol. Prot., vol. 37, 2017, pp 176–188