The Monte Carlo Method: Versatility Unbounded In A Dynamic Computing World
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DOSE ASSESSMENT IN A 650 keV ELECTRON IRRADIATOR FOR INDUSTRIAL APPLICATIONS

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ABSTRACT

The irradiator consists of an electron beam of 650 keV and a maximum current of 50 mA incident on a beam stopper of stainless steel with 4 mm thickness. This electron irradiator possesses a scanning system of 91.4 cm (60º) in order to irradiate electric cables which are rolled in cylinders. The setup is located inside a steel chamber with outer dimensions of 210×210×266 cm and wall thickness of 36 cm in the direction of the beam and 30 cm in the other directions. The interaction of the radiation with the polyethylene that constitutes the insulator material of the electric cables will improve their electric isolation and thermal properties (higher melting point) through reticulation. This process consists in removing hydrogen atoms from the polymer molecule resulting in the improved polyethylene designated by XLPE (Cross Linked Polyethylene). This work using the Monte Carlo code MCNPX aims at obtaining the electron and photon flux distributions as well as the dose distribution inside and outside the chamber. Variance reduction techniques have been used in order to reduce the computational time required for a detailed calculation of the dose distribution deep in the steel shield and outside the chamber. From the results obtained it was concluded that the dose rates outside the steel chamber are negligible, well bellow the limit of 0.50 μSv/h corresponding to an annual effective dose limit of 1 mSv/year for members of the public.

Key Words: Dose assessment, electron irradiator, industrial application, MCNPX.

1 INTRODUCTION

The experimental setup consists on a 650 keV electron beam (maximum current of 50 mA) impinging on a stainless steel beam stopper, of 117.5x32 cm and 4 mm thickness The interaction of the beam with the stainless steel beam stopper produces X-rays that irradiate electric cables situated before the beam stopper. This setup is situated inside a steel chamber of 36 cm thickness in the beam direction and 30 cm thickness in the other directions in order to fulfill the recommended dose limits in public zones, namely of 20 mSv/year and 1mSv/year for professionals and for members of the public, corresponding to dose limits of 10 μSv/h and 0.5 μSv/h respectively.

The physical processes that take place at this facility consist in the interaction of ionizing radiation with the polymeric molecules (polyethylene) of the electric cables resulting in the so called reticulation. As the electrons and photons pass through the insulating material, break the molecular bonds and generate free radicals that escape from the material. Newly created bonds with molecules of other molecular chains in the material give rise to a combination of bonds in

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the form of a grid. This mechanism improves the electric isolation and thermal properties of the electric cables irradiated.

In this work the state-of-the-art Monte Carlo code MCNPX [1] was used to compute the fluxes and dose distributions inside and outside the steel chamber.

2 SIMULATIONS

2.1 Flux and Dose Distributions on the Stainless Steel Beam Stopper

A detailed description of the geometry of the system was implemented in MCNPX. The photon fluxes produced forward and backward the direction of the electron beam after impinging on the beam stopper were calculated and the corresponding energy distributions are shown in Fig. 1.As can be noticed, in the energy range from 1 to 500 keV the flux is higher in the backward direction than in the forward one.

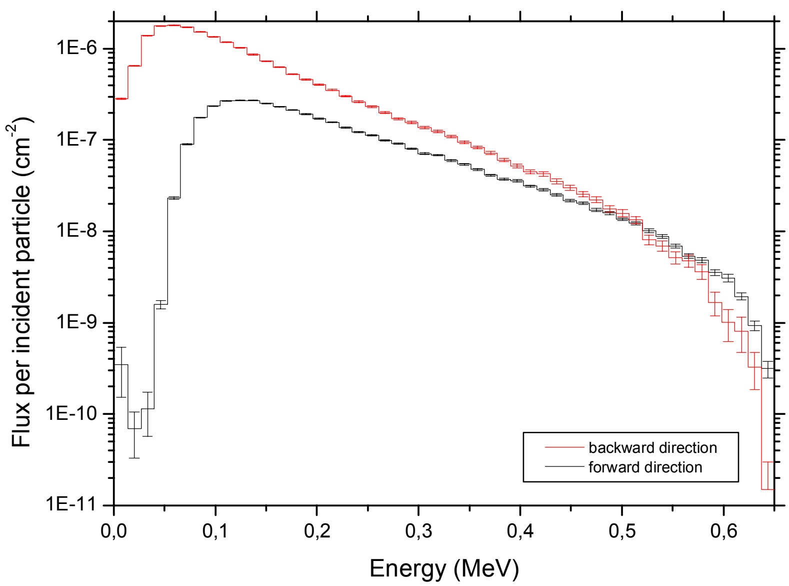

Figure 1: Photon flux distribution at the beam stopper, forward (along) and backward (opposite) to the electron beam direction

The depth distribution of the dose inside the beam stopper was also calculated to show the very rapid attenuation of the electron beam that is stopped in approximately 0.5 mm of stainless steel. For depths smaller than 0.5 mm, the main contribution to the calculated dose is due to the energy deposited by the electrons. Beyond 0.5 mm, the main contribution to the dose is due to the photons. Fig. 2 shows the obtained results.

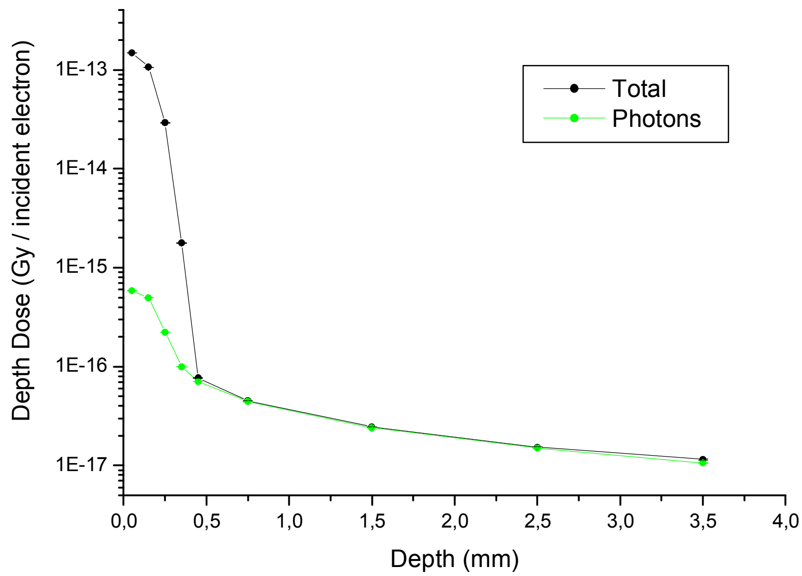

Figure 2: Depth-dose distribution for the 650 keV/50 mA electron beam in stainless steel, showing the individual contribution from electrons and photons

2.2 Flux inside the Chamber

In order to obtain a complete map of the photon flux inside the chamber and the magnitude of the photon fluxes impinging the shielding walls, a mesh tally calculation was carried out with MCNPX. As will be shown in one of the next sections, this was a key information to understand the computed results of the doses and fluxes outside the chamber. Fig. 3 shows the mesh tally results for the flux in a transverse plane containing and intersecting the beam (y-direction).

Fig. 4 shows the mesh tally flux results for the lateral wall of the chamber. It can be noticed that the flux reaching this wall is not negligible but approximately one order of magnitude lower than in the forward direction.

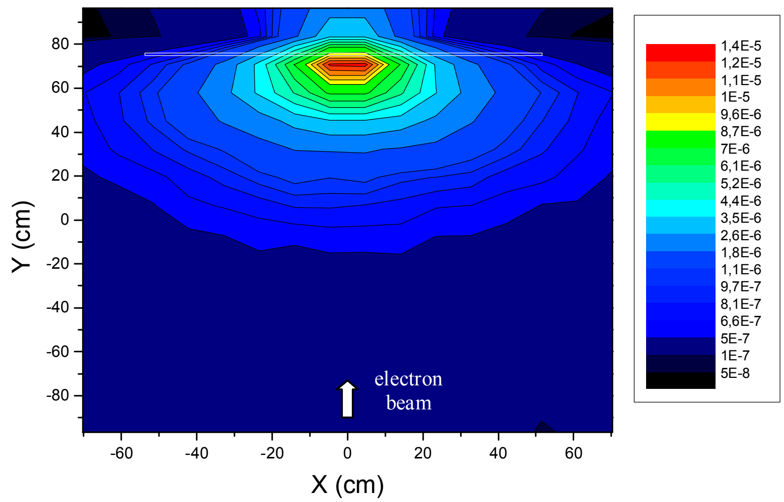

Figure 3: Photon flux per incident electron (cm^{-2}) evaluation inside the chamber along the beam direction. The white rectangle corresponds to the beam stopper

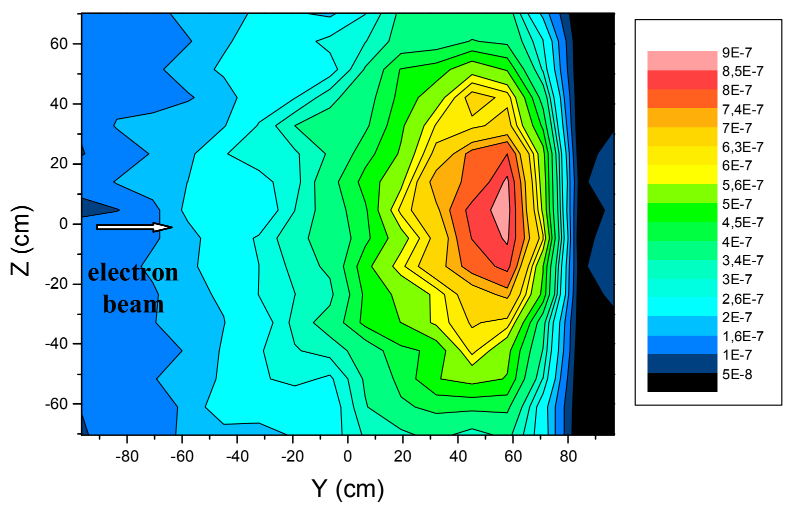

Figure 4: Photon flux impinging the lateral wall of the chamber, per incident electron

2.3 Attenuation in the Shielding

The steel chamber used as shielding is a box with 36 cm thickness wall in the direction of the beam and 30 cm thickness in the other directions. This work aims at assessing the doses obtained outside the shielding, and confirm if the recommended dose limits are not exceeded.

The doses due to electrons will be negligible due to the large thickness of the steel chamber. Therefore, the objective is to assess the doses due to the photons originating in the beam stopper and crossing the shielding walls. Given the thickness of the shield and the energy of the photons, a simple analog calculation with several hundreds of millions of histories will produce zero results in the MCNPX tallies. As it is not possible to simulate the real number of electrons corresponding to the beam current (50 mA, equivalent to 3.12×10^{17} electrons per second) with a simple MCNPX calculation, it is mandatory to use variance reduction techniques in order to assess the doses outside the shielding. In this study the techniques used were geometry splitting with Russian roulette. In a succinct way, the combination of these two techniques consists on artificially increasing the weights of the particles when they enter the cells located at greater depths inside the shield, while reducing the weight of those particles entering a cell with a given importance coming from another cell with a greater importance.

Anyway, it is extremely important to know how meaningful the results obtained using these variance reduction techniques are. To assess it, we have compared the photon fluxes at different depths inside the shielding obtained with and without these techniques. That comparison is shown in Fig. 5, for 25 and 276 millions simulated particles for the cases with and without the variance reduction techniques respectively. As can be seen the results agree quite well up to 18 cm depth (no values at greater depths were available using a purely analog calculation).

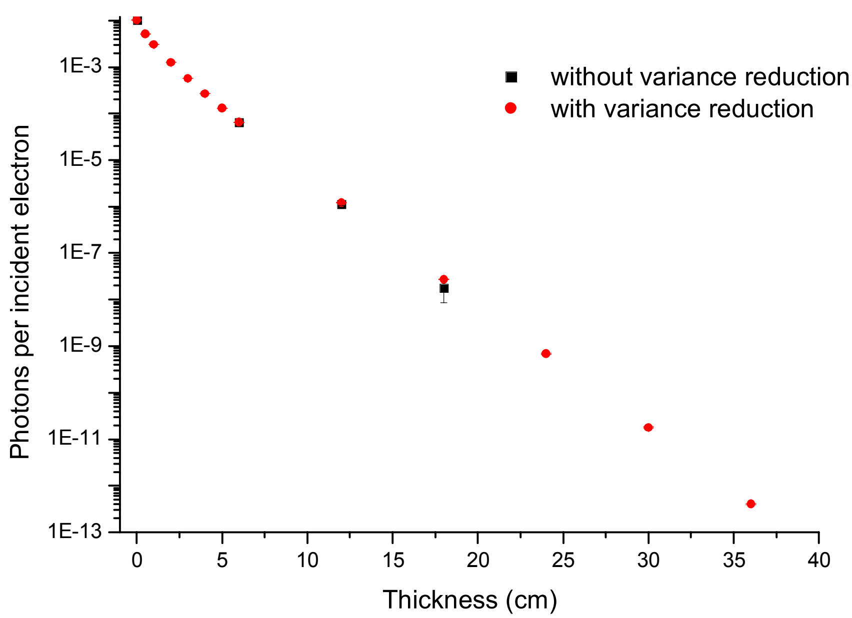

Figure 5: Photons per incident electron. Comparison of the variance reduction results with those obtained without this technique, respectively 25 and 276 million primary electrons

This is in support of using the variance reduction techniques for assessing the doses deep inside the shield and outside it.

For this purpose, cell flux tallies were used. For the simulation, the geometry of the shielding was divided in cells of 1 cm thickness and the tally evaluated every six cells. Afterwards, the dose values are obtained using flux-to-dose conversion factors. Fig. 6 shows the corresponding results obtained in the forward direction. The last two points in Fig. 6 correspond to doses computed outside the shielding in the air.

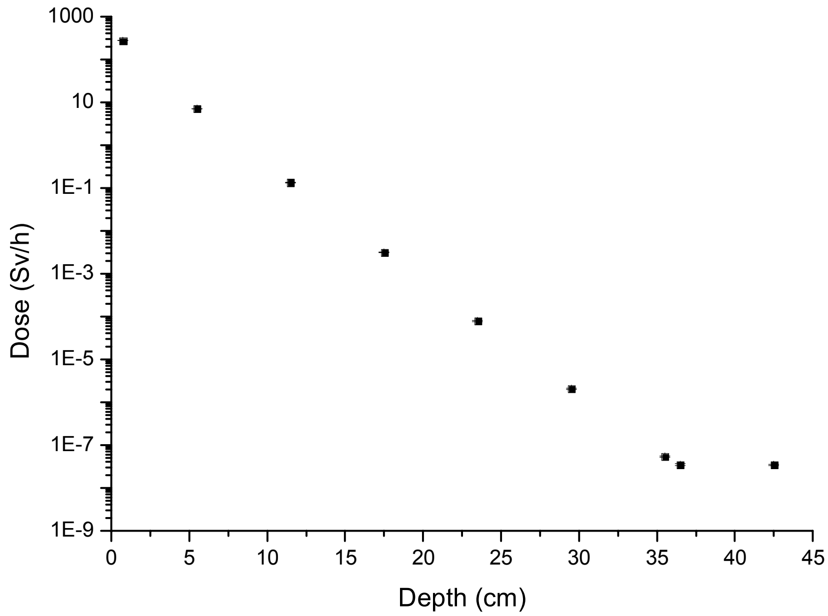

Figure 6: Dose attenuation in the shielding (forward direction)

As can be seen from Fig. 6 the dose immediately after the shield (outside the chamber) is approximately 35 nSv/h.

Simulations were also performed to calculate the doses outside the 30 cm thickness shielding walls in the other directions The value obtained in the backward direction is approximately 23 nSv/h whereas the one obtained outside the shielding in a perpendicular direction is approximately 67 nSv/h.

Fig. 7 shows the photon fluxes (cm^{-2}) in the last cells inside the chamber walls for the different directions previously mentioned. The figure illustrates the photon fluxes outside the shielding for a wall thickness of 36 cm (real thickness) and the fluxes that would exist if a shielding wall with only 30 cm thickness would have been designed. In this case, the dose limit outside the shielding would be exceeded.

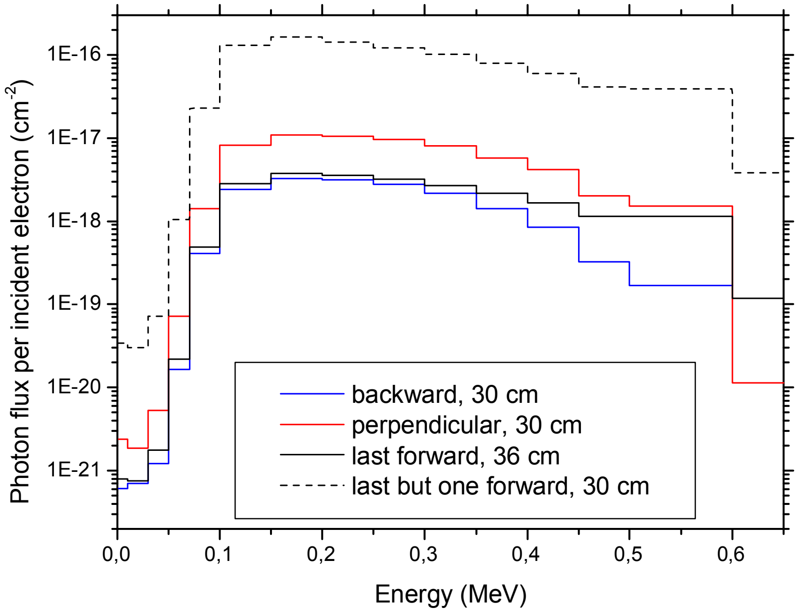

Figure 7: Photon flux distribution per incident electron (cm^{-2}) in different directions

3 CONCLUSIONS

The use of variance reduction techniques was essential to obtain results of dose and flux distributions inside the shielding walls at great depths and outside the steel chamber. The comparison of the results obtained for the number of photons inside the shielding with and without the variance reduction techniques showed a good agreement

It can be concluded that for nominal working conditions of the irradiator the dose limits outside the chamber are not exceeded. Moreover, these simulations allowed assessing the equivalent doses outside the shielding of about 35 nSv/h in the beam direction, 23 nSv/h in the backward direction and 67 nSv/h in the perpendicular direction.

The equivalent dose obtained outside the lateral walls of the steel chamber was higher than the obtained in the beam direction. This can be explained by the different thickness of the walls in the steel chamber (6 cm thicker in the beam direction) and by the fact that the fluxes backward the beam stopper is higher than the corresponding flux in the forward direction.

4 ACKNOWLEDGMENTS

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5 REFERENCES

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