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by

L. Varga, E. Horvath and K.G. Balmain

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ABSTRACT

A novel method of simulating charging of dielectrics by high energy electrons is introduced. The method uses a 3D Monte Carlo computer code and in-house developed codes to determine the charge and potential distribution inside the dielectric specimen. The results are compared with the results of the charging experiment carried out at the University of Toronto. This method can provide space system designers with the means of analyzing the charging of satellites and satellite components at the design stage.

RÉSUMÉ

Une méthode innovative pour simuler la charge des diélectriques par électrons à haute énergy est présentée. La méthode utilise un logiciel Monte Carlo à trois dimensions ainsi que du code "fait à la maison" pour déterminer la distribution de charge et de potentiel à l'intérieur du spécimen diélectrique. Les résultats sont comparés avec ceux de l'expérience de charge conduites à l'Universitée de Toronto. Cette méthode peut offrir aux concepteurs de systèmes de l'espace un moyen d'analyser la charge des satellites et des composantes des satellites à l'étape de la conception.

EXECUTIVE SUMMARY

The subject of orbital electrostatic charging/discharging of satellites and satellite components has been investigated over the past two decades. Many satellite components are made of dielectrics, which, as insulators, are also capable of storing charge injected by penetrating high energy space environment electrons. A spontaneous discharge occurs when the electric field due to these stored charges exceeds the breakdown field of the dielectric. The EMP generated during uncontrolled electrostatic discharges creates problems with normal satellite operation that range from simple upsets to system burnout.

Studying the charging/discharging characteristics of various dielectrics can provide information about the suitability of specific materials for space-based applications. A 3-dimensional Monte Carlo simulation of the charging of an acrylic dielectric specimen by high energy electrons has been carried out at DREO. The results of charging simulation were then used to calculate the potential distribution inside the dielectric specimen. The results were compared with the results of a charging experiment carried out at the University of Toronto and good agreement has been reached between the calculated and experimentally determined potentials. This provides support to the simulation method used, in expectation of it becoming a valuable tool for future electrostatic charging/discharging investigations.

CONTENTS

1. INTRODUCTION

Many satellite components such as thermal blankets, solar cell windows, cable insulators, electronic boards, and solid-state electronic device packages are made of dielectric materials. However, as insulators, when exposed to the space radiation environment, these materials will trap charged particles and result in a build-up of internal electric field. Consequently, without a sufficient charge dissipation rate, the electric field strength will increase, eventually exceeding the breakdown field of the dielectric material (typically ~1×10^6 V cm^{-1}). When this occurs, a spontaneous electrostatic discharge takes place. Consequences of uncontrolled discharge in spacecraft vary from simple signal upsets or dielectric material damage to system burnout

Laboratory and computer simulations form valuable methods to study the charging characteristics of various dielectric materials. The purpose of this work is to use a 3-dimensional Monte Carlo code to model charging of a dielectric specimen and compare the results to a laboratory experiment carried out at the University of Toronto. It is hoped that favourable comparison of results will validate the utilization of the code for future dielectric charging simulation work.

2. EXPERIMENT

The dielectric charging experiment described here has been conducted at the University of Toronto with the experimental setup as shown in Figure 1.

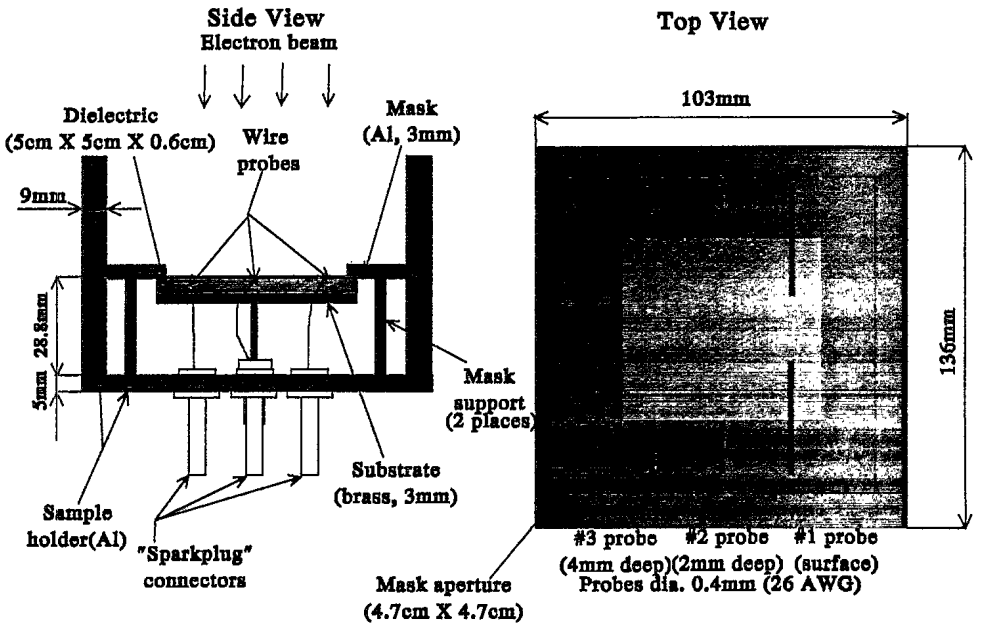

Figure 1. Experimental setup of the acrylic specimen

The dielectric sample is made of an acrylic block with dimensions 5.0 cm x 5.0 cm x 0.6 cm. As shown (Figure 1), the specimen is supported within the the aluminum sample holder by a brass plate. There are two surface probes, two probes at 2 mm depth, and two probes at 4 mm. The probes allow tracking of potential buildup and discharge current. The dielectric specimen is covered by an aluminum mask; the mask aperture size is 4.7 cm x 4.7 cm so that the mask overlaps the specimen by 1.5 mm on each side and prevents direct exposure of the probes to the particle beam. Two charging scenarios were carried out, one with a 20 keV electron beam and the second with a $^{90}Sr/^{90}Y$ 0.1 Ci beta source.

3. SIMULATION

The experimental setup and the charging of the dielectric specimen has been modelled at DREO. The hardware components of the experiment were assembled from simple geometrical bodies using combinatorial geometry. The definition of a complex structure becomes very difficult if the number of bodies composing the structure is large. Thus a software program called BUILDER was developed to handle the assembly. The software is capable of manipulating (rotation, displacement) the simpler bodies that define the structure. With offsets supplied by the user, BUILDER creates the input file for the Monte Carlo simulator. During the assembly, BUILDER also sets the necessary file parameters that are used by the Monte Carlo code during the course of the simulation run. At any stage of the assembly, the correctness of the structure generated can be examined using the 3D graphical software called "DOCKER", which allows visual checking of the assembly. The simulated experimental setup (a cut away view) is shown in Figure 2.

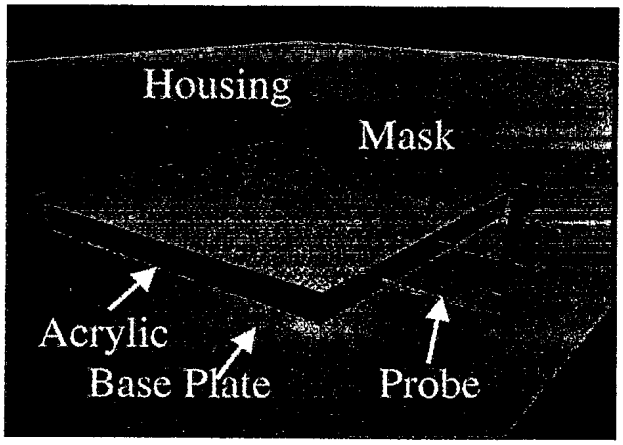

Figure 2. Display of the simulated experimental setup from the DOCKER output

Charge deposition into the dielectric specimen was modelled by utilizing the electron/photon transport code "ACCEPT". ACCEPT is a 3D module of the ITS suite of Monte Carlo codes suitable for application where electron/photon penetration into complex 3D multimaterial structures is being studied. The acrylic target was also subdivided into a 50 x 100 x 72 array of subzones to enable determination of the charge distribution inside the specimen. As in the experiment, two sources were used in the computer simulation. The first was a monoenergetic 20 keV electron isotropic source with an opening angle of 8°, large enough to cover the whole experimental assembly in order to ascertain whether there was any scattering into the probes from behind the mask. The strength of the source was 1.0×10^8 electrons which corresponds to the number of electrons at 1 nA over a time period of 0.016 seconds.

The second simulation modelled the beta spectrum of the $^{90}Sr/^{90}Y$ source having a strength of 100 m Ci. There were 8 energy channels over the spectrum from 0 MeV to 2.3 MeV. The output of the Monte Carlo simulation was then utilized to determine the time independent potential distribution inside the acrylic specimen using an iterative Poisson equation solver.

4. SUMMARY OF RESULTS

4.1 MONOENERGETIC SOURCE

Charge deposition simulation results with the 20 keV monoenergetic source are shown in Figures 3a) and 3b). Figure 4 shows the result of the potential calculations.

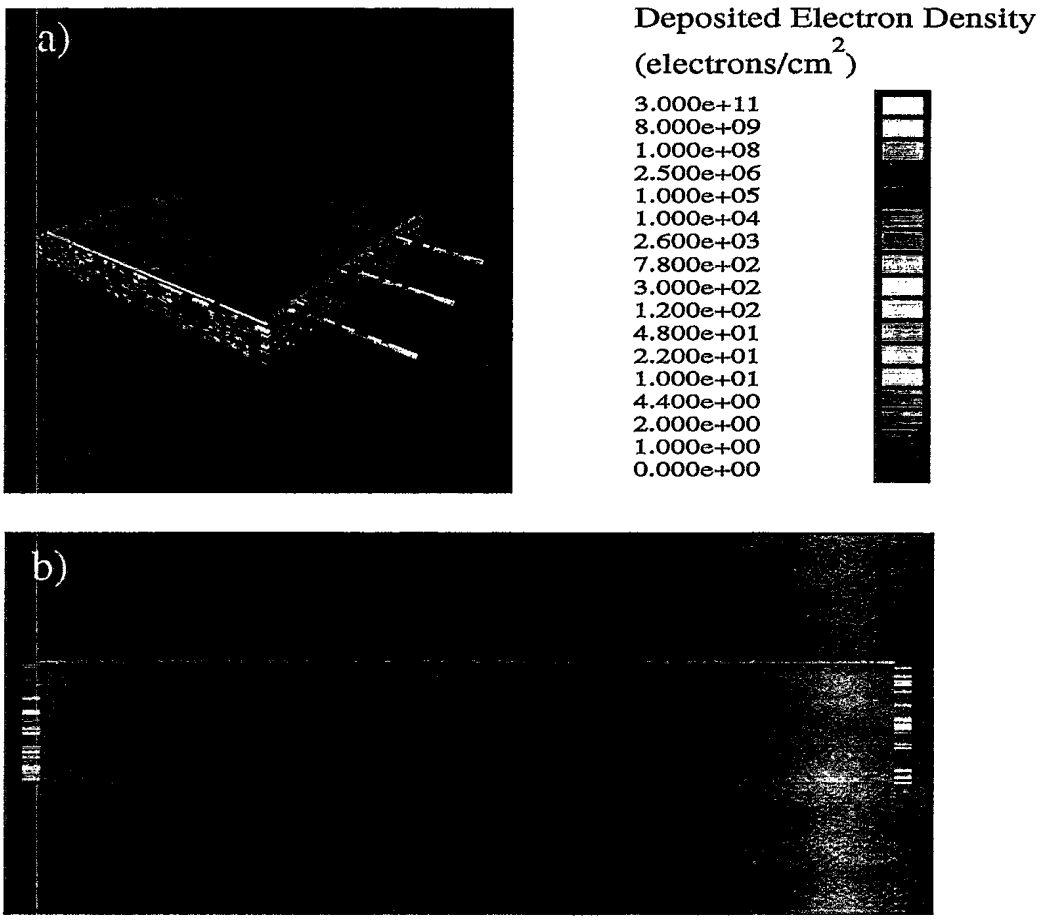

Figure 3. a) Electron density distribution - a whole specimen view
b) Cross-sectional view of the electron density distribution

Figure 3a) shows that the electron deposition density is maximum at the top surface of the acrylic specimen reaching a value of $1x10^5$ electrons cm^{-2}. Deposition to the sides and the masked probes is due to scattering at the interface of the mask and the sample holder where a 0.5 mm gap exists for clearance. Figure 3b), a cross-sectional view of the specimen, shows that due to the low energy of the electron beam, deposition occurs only into the outermost layers and the interior of the acrylic is void of charges. Figure 4 shows the calculated potential distribution. This potential is 41 mV at the top of the specimen (note that the base plate was grounded and the voltages are negative). The 41 mV at the top over 0.016 seconds corresponds to about 1500 volt if extrapolated to 10 minutes of exposure. This compares favourably with the experimental value of 1200 V after 10 minutes of exposure. At the depth of the second probe, the simulated potential varies from 350 V to 600 V (extrapolated to 10 minutes of exposure), again compares favourably with the experimental value of 400 V. The simulated potential at the third probe depth varies between 170 V and 290 V. The experimental value at this depth was 250 V.

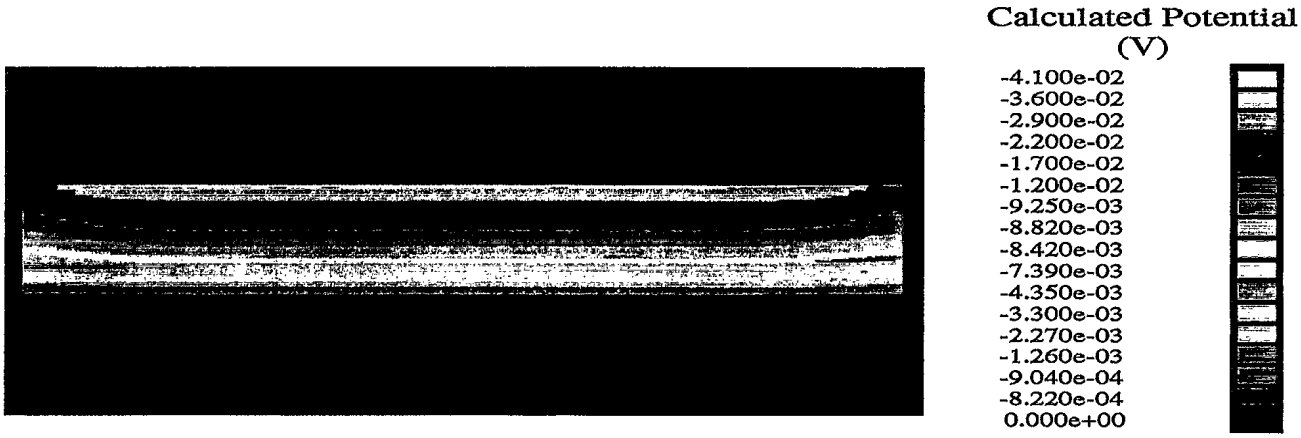

Figure 4. Calculated potential distribution inside the acrylic specimen after 0.016 seconds exposure to a 20 keV monoenergetic beam.

4.2 $^{90}Sr/^{90}Y$ SOURCE

The simulated charge deposition distribution due to $^{90}Sr/^{90}Y$ beta source is shown in Figure 5a) and 5b). Figure 5a) shows the whole specimen while Figure 5b) gives a detailed view of the internal charge deposition. The maximum electron density occurs near the surface of the acrylic specimen. This is not surprising due to the fact that the source spectrum has a large component at low energy. Deposition to the sides and into the masked probes is due to a combination of scattering at the mask/sampler holder interface (a 0.5 mm gap exists for clearance) and high energy transport through the specimen. The calculated surface potential (Figure 6) is between 17 mV and 22 mV for 1 second of exposure to correspond to a value between 51 V and 66 V integrated over 50 minutes of exposure as was the case during the experiment. At the depth of the second probe, the calculated potential is between 36 V and 51 V compared to experimental value of 150 V. At the third probe depth, the simulated results were between 13 V and 19 V compared to the experimental 90 V. The results of both experimental and simulated irradiations are summarized in Figure 7.

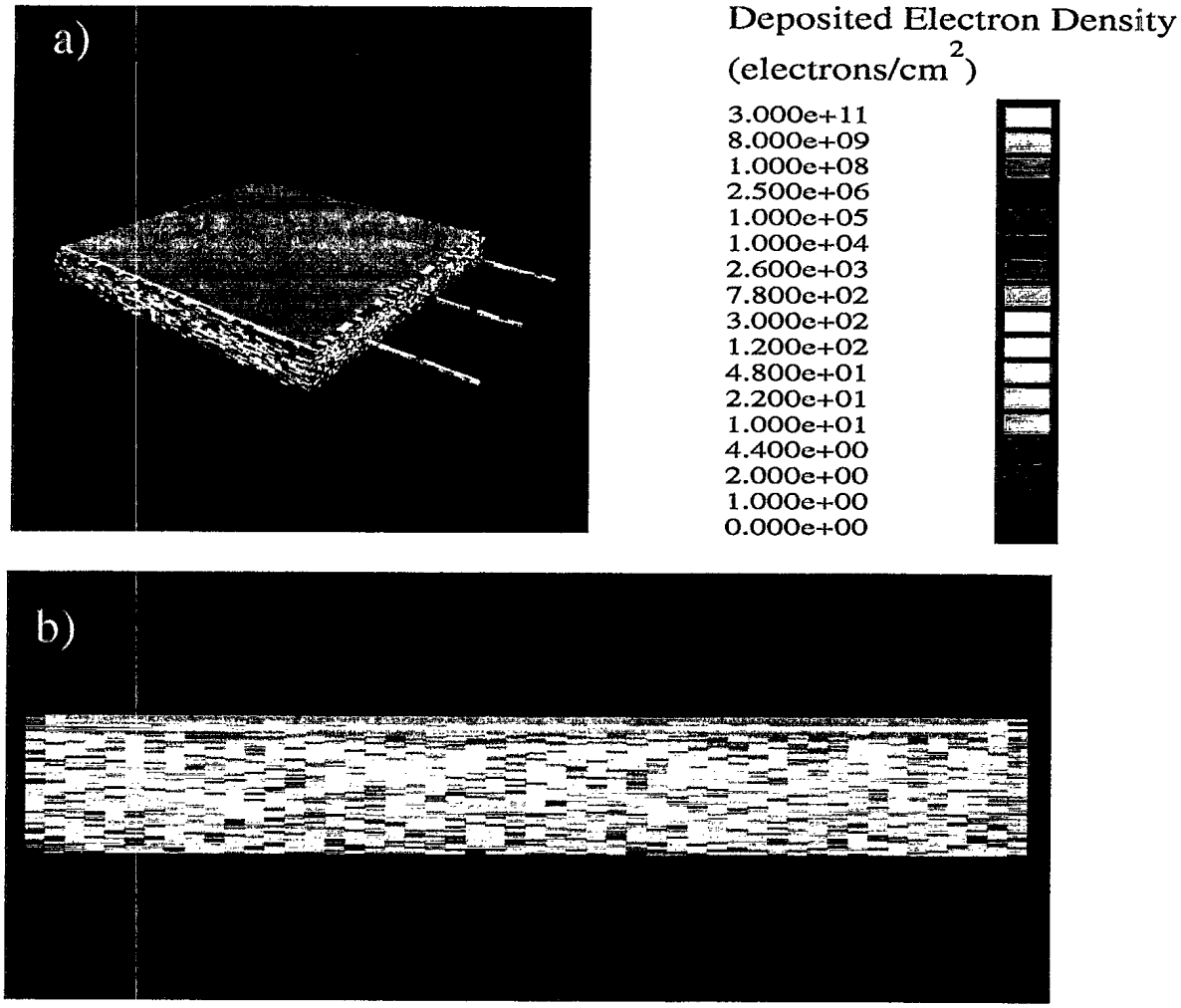

Figure 5. $^{90}Sr/^{90}Y$ beta source: a) Electron density distribution - a whole specimen view
b) Cross-sectional view of the electron density distribution

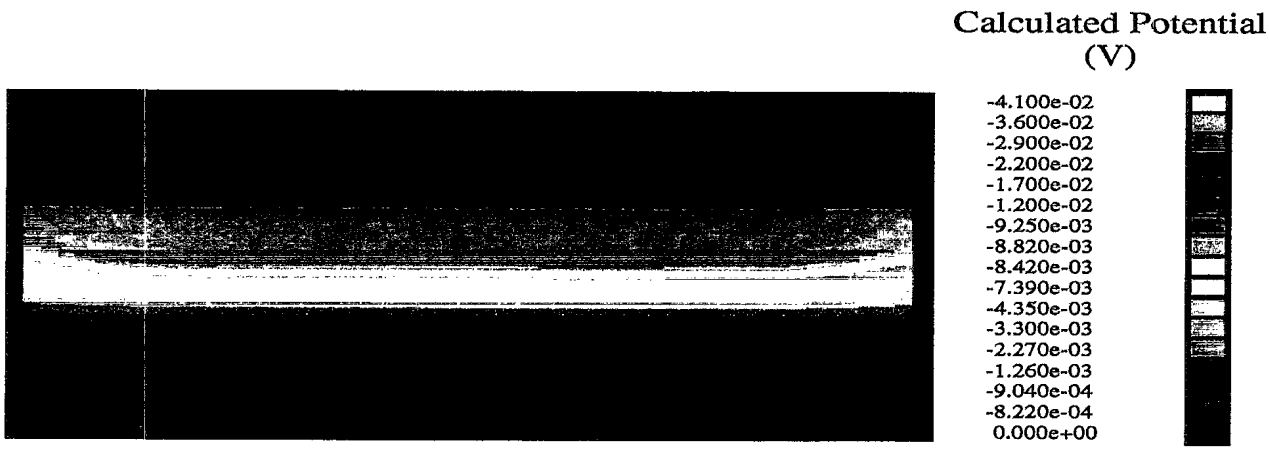

Figure 6. Calculated potential distribution inside the acrylic specimen after a 1 second exposure to a 0.1 Ci $^{90}Sr/^{90}Y$ source

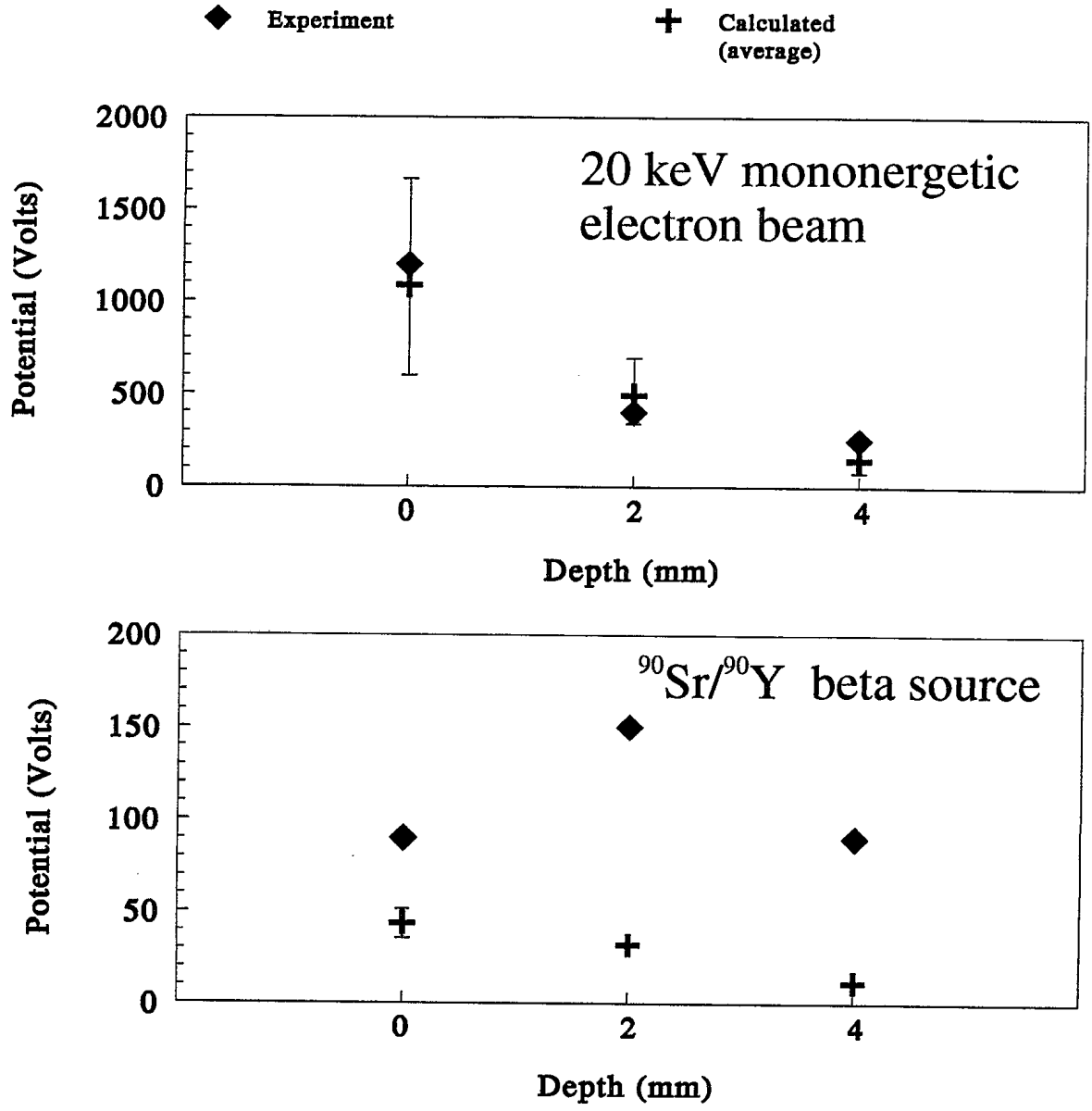

Figure 7. Plot of experimental and simulated results for the two types of electron sources

5. CONCLUSION

The simulation results have shown a good agreement with the experimental results. The method employed will be a valuable tool for future electrostatic charging analysis of dielectric materials used in space-based applications..

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