DOSIMETRY FOR LOW-ENERGY ELECTRON BEAMS

Marshall R. Cleland and Richard A. Galloway

RDI-Member of the IBA Group: 151 Heartland Boulevard, Edgewood, NY, 11717, marshall.cleland@iba-group.com

This paper describes a method to determine the absorbed dose at the surface of a dosimeter when the absorbed dose within the dosimeter varies with depth because of the short range of the low-energy electron beam being used. This method requires the following steps: calibrate the dosimeters with penetrating radiation; simulate the energy deposition vs depth distribution with a suitable Monte Carlo code; choose the thickness of the surface layer of interest; calculate the average energy per electron absorbed in this surface layer; calculate the total simulated energy in the dosimeter, assuming that the average energy absorbed in the surface layer had been constant throughout the dosimeter; calculate the ratio between the simulated energy assuming constant energy vs depth and the simulated energy according to the variable energy vs depth; multiply the average dose determined with the calibrated dosimeter by the ratio calculated as described above to determine the average dose in the surface layer of the dosimeter.

I. INTRODUCTION

Methods to determine the absorbed dose at or near the surface of materials that have been irradiated with low-energy electrons are important for applications such as sterilizing containers for medical products, curing inks and coatings on plastic, paper, wood and metal substrates, and crosslinking thin plastic films. When the absorbed dose within the dosimeter decreases with depth because of the short range of the incident electrons, then the reading of the dosimeter gives the average internal dose, which is less than the surface dose.

Another method to determine the surface dose in this situation has been described in Refs. 1 and 2. That utilizes a calorimeter to measure the total energy deposited by the electron beam and a Monte Carlo simulation to convert that energy measurement to a surface dose. The method described in this paper is somewhat easier to use. It does not require a calorimeter, which is a complex device that may not be suitable for some irradiation processes.

This method involves determining the average dose with conventional dosimeters, whose thickness may be comparable to or greater than the maximum range of the incident electrons. The distribution of absorbed energy vs depth within the dosimeter, when it is irradiated with low-energy electrons, is simulated with a suitable Monte Carlo code. The average dose and the energy distribution curve can be used to calculate the dose at the dosimeter surface in the manner described below.

II. CALCULATION PROCEDURE

Calibrate the dosimeters with penetrating radiation, such as high-energy electrons or gamma rays from ^{60}Co. See Refs. 3 and 4 for calibration with ^{60}Co gamma rays.

Simulate the energy deposition vs depth distribution with a suitable Monte Carlo code. The Integrated Tiger Series[5] or Penelope[6] can be used for this purpose.

Choose the thickness of the surface layer of interest. A thickness of 1 micron has been assumed in Ref. 3, and this dimension is also used in the examples given below.

Calculate the average energy per electron absorbed in this surface layer.

Calculate the total simulated energy in the dosimeter, assuming that the average energy absorbed in the surface layer had been constant throughout the dosimeter.

Calculate the ratio between the total simulated energy assuming constant energy vs depth and the total simulated energy according to the variable energy vs depth.

Multiply the average dose that was determined with the calibrated dosimeter by the ratio calculated with the procedure described above to determine the average dose in the surface layer of the dosimeter.

III. INFORMATION REQUIRED

Energy of the electrons inside the accelerator.

Thickness, density and atomic composition of the electron beam window of the accelerator.

Thickness, density and atomic composition of the air or other gas between the beam window and the dosimeter.

Thickness, density and atomic composition of the dosimeter.

Thickness, density and atomic composition of the material supporting the dosimeter. This information is important if the electron energy is high enough or the dosimeter is thin enough to allow the beam to penetrate and scatter back from the supporting material.

IV. EXAMPLES

The ITS3 TIGER Monte Carlo code[5] has been used to calculate the electron energy deposition vs depth with the following conditions:

Incident electron energy = 75, 100, 125 and 150 keV.
Electron beam window = 6 μm titanium.
Air thickness = 2.0 cm (normal temp. and pressure).
Nylon dosimeter total thickness = 50 μm.
Nylon dosimeter layer thickness = 1.0 μm.
Dosimeter supporting material = polypropylene.

Fig. 1 shows the electron energy deposition vs depth in a stack of the materials listed above with an incident electron energy of 75 keV. The vertical axis is in units of MeV per electron per dosimeter layer divided by the layer thickness in grams per square centimeter. The horizontal axis is the depth in units of grams per square centimeter. The area under the curve gives the total energy deposition in units of MeV per electron.

In this example, it is evident that a 75 keV electron cannot pass through the combination of a 6 μm titanium window, a 2 cm air space and a 50 μm nylon dosimeter. The calculated ratio between the total energy deposition in the dosimeter, assuming constant energy vs depth equal to the surface value in a 1.0 μm layer, and the total energy deposition in the dosimeter, according to the variable energy vs depth, is 3.09. This means that the surface dose is higher than the average dose by a factor of 3.09.

Fig. 2 shows a similar electron energy deposition vs depth curve with an incident electron energy of 100 keV. This curve shows that some of the energy can penetrate the dosimeter, and the average energy deposition within the dosimeter is higher. So, the ratio of the surface dose in a 1.0 μm layer to the average dose has decreased to 1.35.

Fig. 3 shows a similar electron energy deposition vs depth curve with an incident electron energy of 125 keV. This curve shows that more of the electron energy can pass through the dosimeter, and that the average energy deposition within the dosimeter is higher than in the previous case. The ratio of the surface dose in a 1.0 μm layer to the average dose has decreased to 1.09.

Fig. 4 shows a similar electron energy deposition vs depth curve with an incident electron energy of 150 keV. This curve shows that the energy deposition within the dosimeter is nearly constant with depth, although there are some slight variations. The ratio of the surface dose in a 1.0 μm layer to the average dose in this case is 1.00.

Values of the ratios of the average surface dose to the average depth dose are listed in Table 1 for surface layer thicknesses of 1, 5, 10 and 15 μm. The ratios decrease as the surface thicknesses increase because the average dose in the surface layer decreases with increasing thickness.

V. CONCLUSIONS

This paper describes a method to determine the surface dose when a dosimeter is irradiated with a low-energy electron beam. All of the items listed in Section III will affect the results. If any are modified, then the ratio between the surface dose and the average dose within the dosimeter will be changed and the calculation will have to be repeated with the modified conditions.

However, this method will indicate when and by how much the surface dose could be higher than the average dose within the dosimeter.

REFERENCES

1. J. Helt-Hansen, A. Miller and P. Sharpe, "Dose Response of thin-film dosimeters irradiated with 80-120 keV electrons," *Radiat. Phys. Chem.* **74**, 341 (2005).
2. J. Helt-Hansen, A. Miller, S. Duane, P. Sharpe, M. McEwen and S. Clausen, "Calorimetry for dose measurement at electron accelerators in the 80-120 keV energy range," *Radiat. Phys. Chem.* **74**, 354 (2005).
3. J.M. Puhl, "Calibration Irradiations of Customer Supplied Dosimeters with ^{60}Co Gamma Rays," *Ionizing Radiation Division, National Institute of Standards and Technology*, 49010C, IRD-P-11 (2005). Available at **http://physics.nist.gov**. Starting with the home page of the Physics Laboratory, select Ionizing Radiation, Quality System, IRD Procedures, then select Procedure Number 11.
4. M.F. Desrosiers, "Dose Interpretation of Customer-Irradiated NIST Transfer Dosimeters," *Ionizing Radiation Division, National Institute of Standards and Technology*, 49020C, IRD-P-12 (2005). Ibid 3.

5. J.A. Halbleib, R.P. Kensek, T.A. Mehlhorn, G.D. Valdez, S.M. Seltzer and M.G. Berger, "ITS Version 3.0, The Integrated TIGER Series of Coupled Electron/Photon Monte Carlo Transport Codes," SAND91-1634 (1992), CCC-467/ITS Code Package (1994). Available from the Radiation Safety Information Computational Center (RSICC), Oak Ridge, TN 37831, USA.

6. F. Salvat, J.M. Fernandez-Varea and J. Sempau, "PENELOPE-2006, A Code System for Monte Carlo Simulation of Electron and Photon Transport," NEA-1525/12, OECD ISBN 92-64-02301-1 (July 2006).

TABLE 1. Ratios of the average surface dose to the average depth dose in a 50 μm nylon dosimeter.

Electron Energy (keV)	Surface Layer (1 μm)	Surface Layer (5 μm)	Surface Layer (10 μm)	Surface Layer (15 μm)
75	3.09	2.85	2.59	2.34
100	1.35	1.31	1.28	1.25
125	1.09	1.06	1.05	1.04
150	1.00	0.98	0.98	0.98

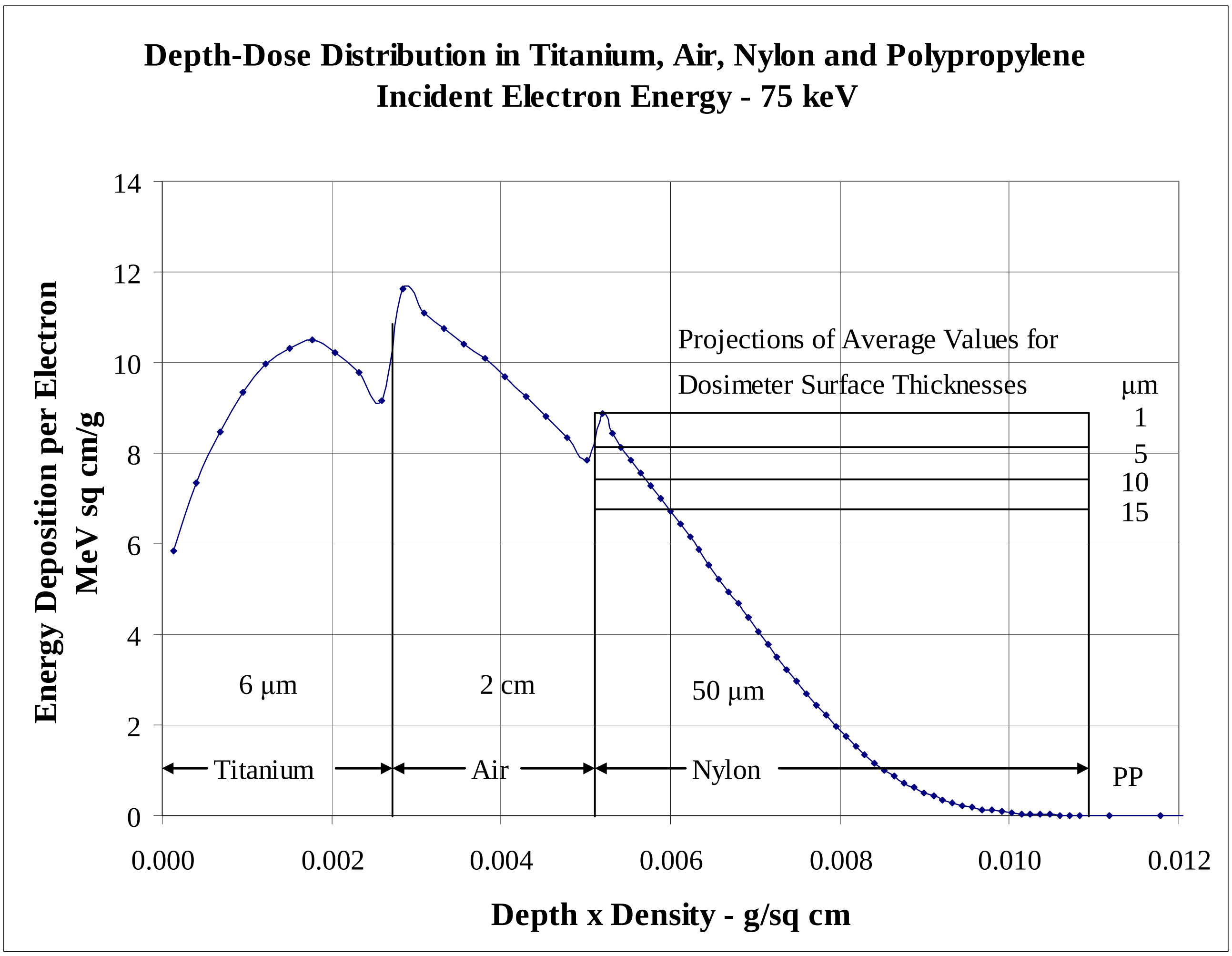

Fig.1. Energy deposition per electron vs depth x density in titanium, air, nylon and polypropylene at 75 keV.

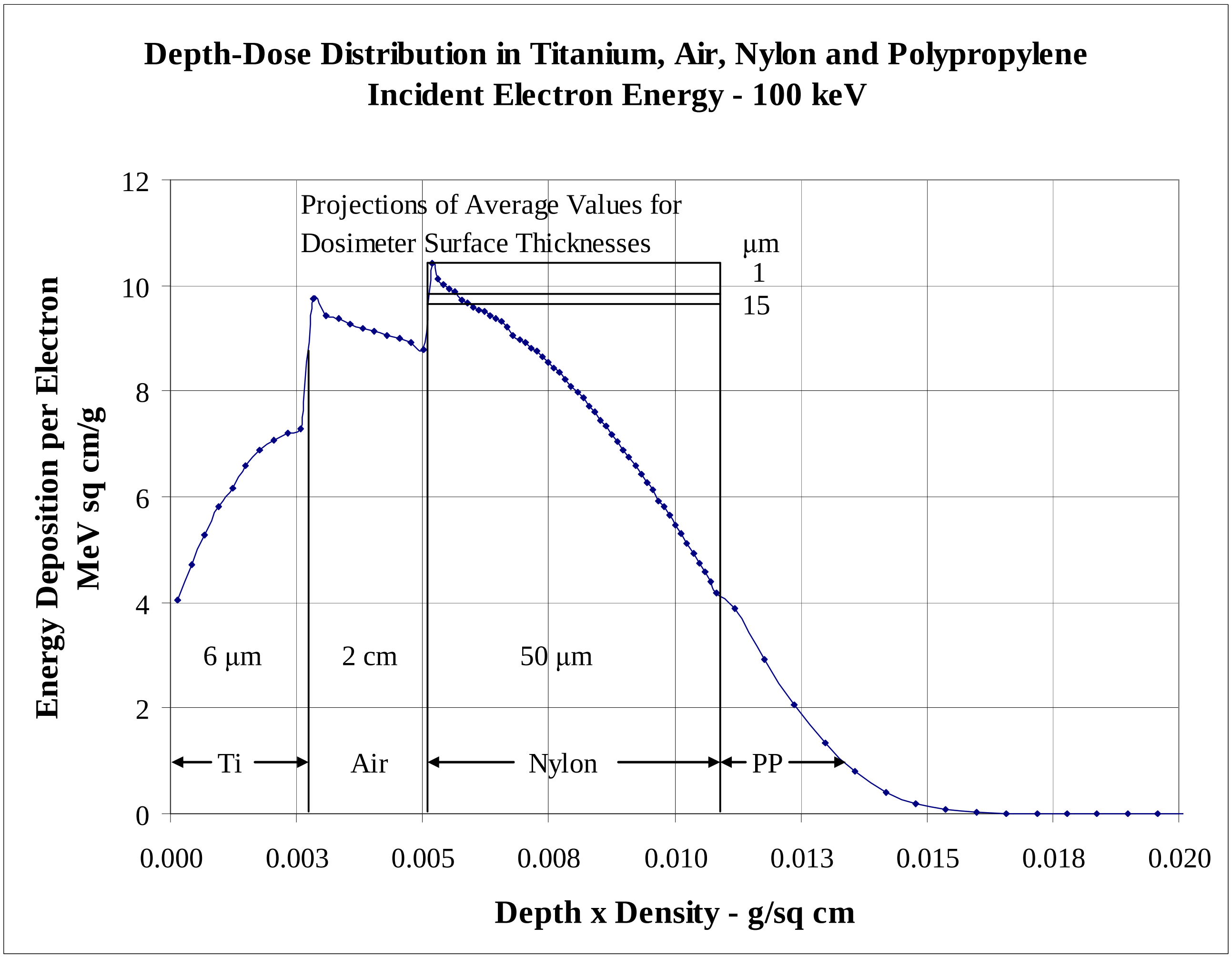

Fig. 2. Energy deposition per electron vs depth x density in titanium, air, nylon and polypropylene at 100 keV.

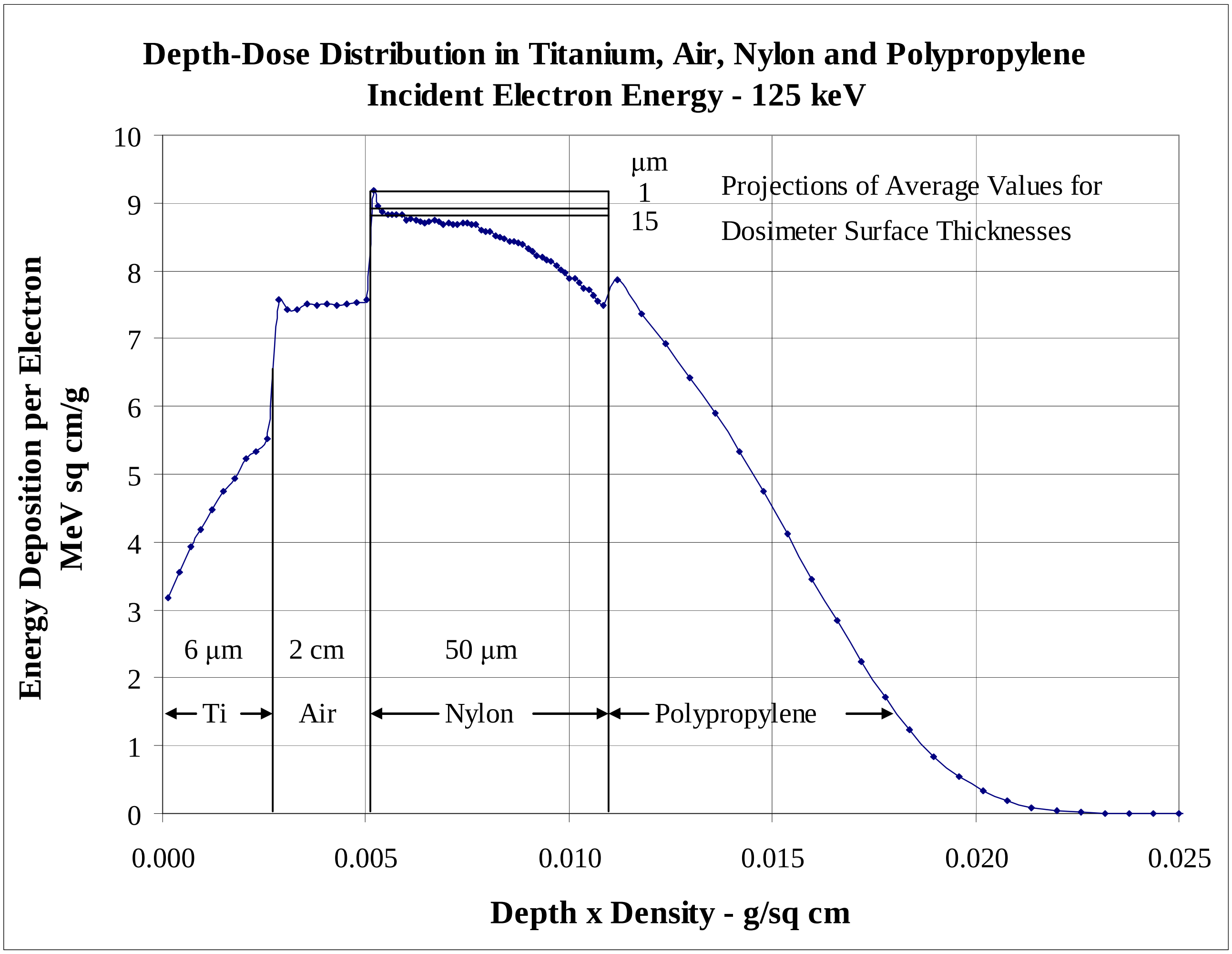

Fig.3. Energy deposition per electron vs depth x density in titanium, air, nylon and polypropylene at 125 keV.

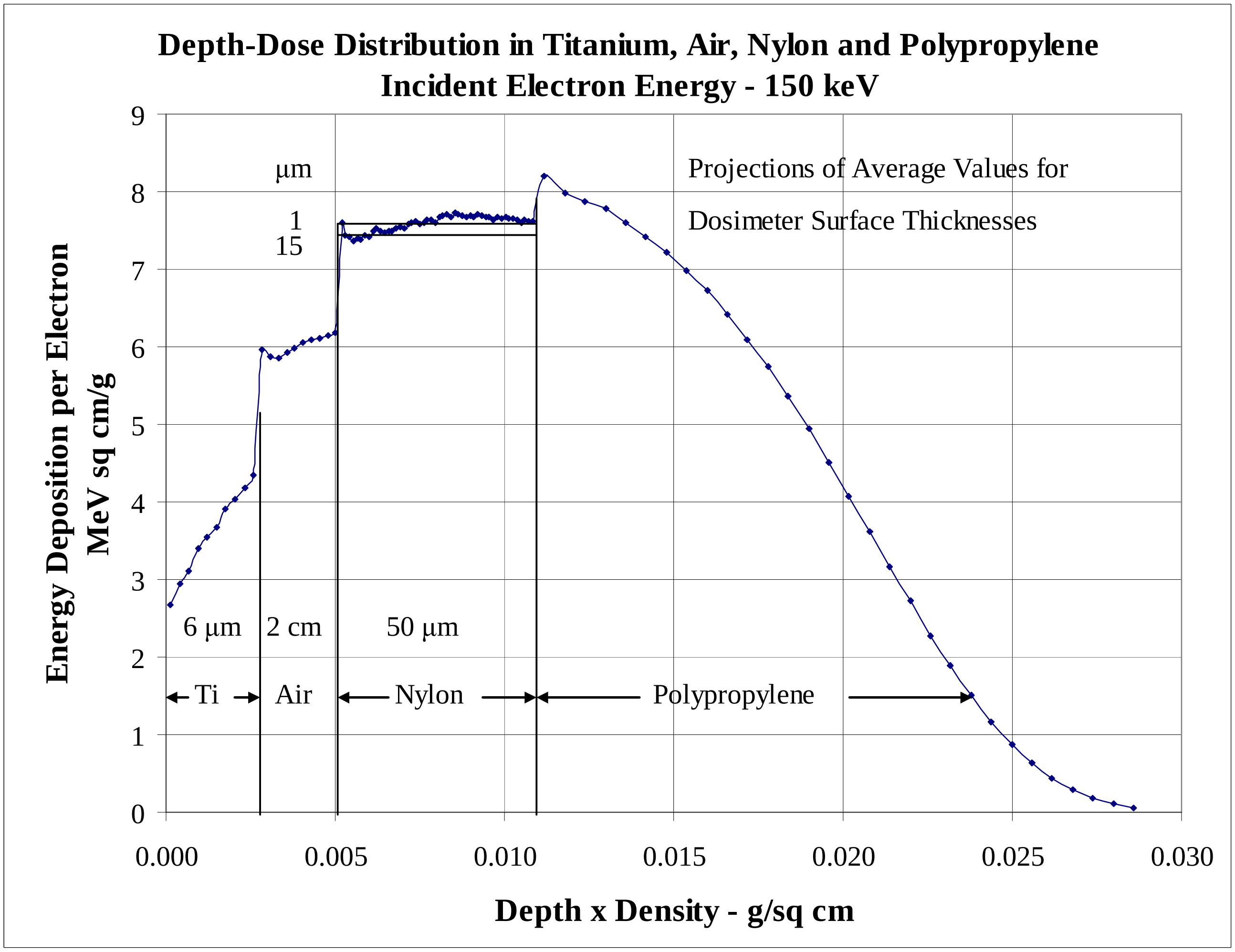

Fig. 4. Energy deposition per electron vs depth x density in titanium, air, nylon and polypropylene at 150 keV.