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CHANGE OF d_{max} VALUES OF ELEMENTS WITH Z≤54 FOR ELECTRON BEAMS

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Abstract: In dealing with electron interactions with matter, it is important to reveal the relationship between parameters such as stopping power, range and absorbed dose. It is known that the change of mean excitation energy values, which is a quantity affecting stopping power and range calculations, according to the atomic number of the elements, confirms the shell model of the elements. In this study, it was revealed that the d_{max} value, which is closely related to dose values, is also compatible with the shell model of the elements and exhibits similar behavior with the mean excitation energy. For this purpose, EGSnrc Monte Carlo code was used to determine the d_{max} values. Calculations were carried out for three electron energies (4, 9 and 15 MeV) in medically important energy ranges. As a result, the shell structure of the elements should be taken into account in the calculation of electron interaction parameters.

Keywords: Dose, EGSnrc, Electron beams, Maximum dose depth

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1. Introduction

In determining the radiation effect of incoming electrons, it is important to reveal the dosimetric parameters and express the relationship between them. In clinical applications, when electron beams are handled physical aspect, dosimetric parameters such as energy and spectrum of the electron beam, beam depth dose parameters, percentage depth dose, field size, therapeutic range, flatness and symmetry are expressed. On the other hand, in theoretical approaches, parameters such as energy of electron beams, stopping power, range, mean excitation energy, absorbed dose and percentage depth dose values are introduced. The use of electron beams for therapeutic purposes requires precise measurements and calculations in which these dosimetric parameters are verified by experimental and theoretical approaches.

Although there are many studies expressing the relationship between dosimetric parameters, we have contributed to the literature studies in which the stopping power, dose and mean excitation energy for electrons are determined and their relationships with each other are revealed (Yüksel and Tufan 2018; Tufan and Yüksel, 2019; Yüksel and Tufan, 2021a). In the light of these studies, a linear relationship between stopping power and dose and the change of mean excitation energy for elements according to atomic number have been revealed separately. Based on this, the curiosity about the change of d_{max} values versus target atomic number revealed the subject of this study.

Although there has been a more detailed definition recently, in the most general approach the absorbed dose is known as the energy stored per unit mass of ionizing radiation (Protection, 2007; Grusell, 2015). Absorbed dose is often expressed using a percent depth dose curve where the dose is shown relative (Burlin et al., 1973; Andreo, 1991; Katagiri et al., 2000; Björk et al., 2002; Rogers, 2006). Distance the beam travels along its central axis from the surface to the depth where the dose is maximum is defined as the Maximum Dose Depth (d_{max}). Percentage depth dose (PDD) curve is obtained by expressing the dose at any reference depth in terms of the value at d_max distance (Khan and Gibbons, 2014). In the PDD curves for electrons, it is observed that i) a rapid rise at low energies and then a partially sharp decline, ii) a wider plateau region after the rapid rise at high energies, and iii) the d_{max} value increases with increasing energy (Strydom et al., 2005; Eldib et al., 2010; Yüksel and Tufan, 2021b). On the other hand, it is known that properties such as primary ionization energy, electron affinity, and atomic volume vary depending on the atomic number. The relationship between d_{max} value and atomic number in the interaction of electrons with target elements has not been discussed so far. In this study, dose values were obtained for elements atomic number Z≤54 using the EGSnrc code and the variation of d_{max} values with atomic number were revealed.

2. Materials and Methods

The absorbed dose values of the target materials for incident electron beams at therapeutic energies were obtained with the EGSnrc code. This code, which is more preferred in medical applications, examines the interaction of photons and electrons in matter in the range of 10 KeV to 50 MeV. EGSnrc is an extended and improved version of the EGS4 code system developed jointly by the NRC and the Stanford Linear Accelerator Center (Nelson et al., 1985). One of the included components, DOSXYZnrc, allows the estimation of radiation dose in certain volumetric geometries.

In this study, dose values were calculated with the DOSXYZnrc sub package using the ICRU data (Balashov et al., 1984) available in the program content with density and content information for each target material. Target materials were determined as elements with atomic number Z≤54.

The geometry of the cylinder target material with a radius of 5 cm in the direction of the central axis was simulated with a total height of 15 cm, the first 5 cm depth was simulated in 0.1 cm slices, and the next 10 cm depth was simulated in 1 cm slices. The source surface distance (SSD) was determined as 100 cm in the light of the literature (Cygler et al., 1997; Günhan et al., 2005; Kim et al., 2014). The number of particles in the simulation was planned to be 10^7, and the cut-off energy of the electrons was determined as 10KeV. Finally, using absorbed dose values, d_{max} values of elements with atomic number Z≤54 were calculated for electrons at energies of 1-20MeV.

3. Results and Discussions

As described in previous section, d_{max} values were calculated for the atoms from Z≤54 by using EGSnrc code. Figure 1 shows the change of d_{max} value according to atomic number for 3 different energies. Since the energy range of 4-15 MeV is frequently used in clinical applications, d_{max} max values with respect to atomic numbers (Z) have plotted for the energies 4, 9 and 15 MeV in Figure 1.

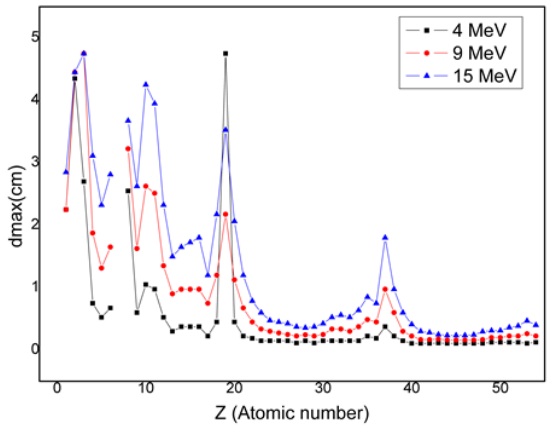

Figure 1. d_{max} values of elements with atomic number Z≤54.

It is seen that the d_{max} value gradually increases in each period, and it becomes maximum around the group 8A, then it decreases suddenly at next period. This situation shows that d_{max} values are connected with the shell structure of the atoms. When the shell structures of atoms are taken into account, the relationship between the occupancy rate and their stability is seen in d_{max} values. It is expected that d_{max} values are decreases when the atomic number increases in same energy.

d_{max} values of group 7A elements (Z= 9, 17, 35 and 53) with respect to the incident energy shows in Figure 2. As seen from the Figure 2, when atomic number increases, d_{max} values decrease. This is also expected since incident electrons interact more atomic electrons. A similar situation is seen in ionization energy. As the atomic number increases within the same group, the ionization energy decreases.

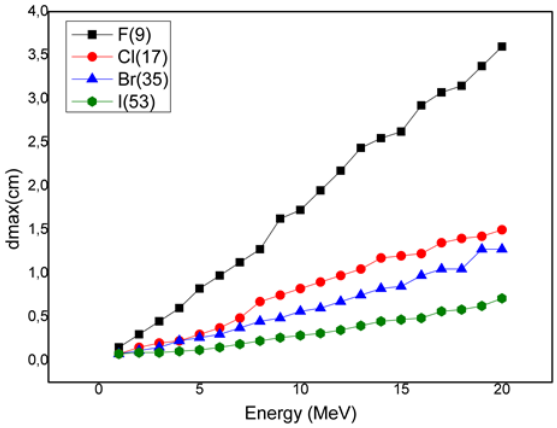

Figure 2. The change of d_{max} value with energy for elements in the 7A group.

4. Conclusions

In this study, the interaction between electron beams and elements atomic number Z≤54 is discussed in the therapeutic energy range. For this purpose dose values were obtained with the Monte Carlo approach using the EGSnrc code and d_{max} values were determined. When investigating the d_{max} values change with atomic number, shell structure in the atoms is also seen. Similar results are also observed in the mean excitation energies of the elements (Tufan and Yüksel, 2019), which is important in the calculation of stopping power and range of incident particles. Dose values and also d_{max} values are closely related with these parameters. Thus, the hypothesis question put forward in the planning of the study was confirmed and a contribution to the literature was made.

The similar behavior of d_{max} and mean excitations energy values can be lead to the new interaction models between incident particle and matter. Especially shell structure of element should be considered in the calculation of interaction parameters.

Author Contributions

The percentages of the author' contributions are presented below. The author reviewed and approved the final version of the manuscript.

	Z.Y.
C	100
D	100
S	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100
PM	100
FA	100

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The author declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

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