

Effect Of Shielding Thickness On The Transmission Factor Of 4 And 8 Mev Electron Beams: A Comparison Of Cerrobend, Silicone-Pb, And Plasticine

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Abstract – Electron radiotherapy using a Linear Accelerator (LINAC) requires effective shielding materials to reduce radiation transmitted to tissues or areas that are not targeted for treatment. This study aimed to analyze the effects of material type and thickness variation on the electron transmission factor and to compare the effectiveness of Cerrobend, Silicone-Pb, and Plasticine at 4 MeV and 8 MeV. The study was conducted at the Radiotherapy Sub-Installation of Prof. I.G.N.G. Ngoerah Hospital, Denpasar, using a LINAC. The materials had thickness variations of 0.5, 1, 1.5, 2, and 2.5 cm, with a 10×10 cm field size and an SSD of 100 cm. Dose measurements were performed using the IAEA TRS-398 protocol, and the transmission factor was calculated as the ratio of the dose after passing through the material to the dose without the material. The results showed that increasing material thickness reduced the transmission factor at both energies. Cerrobend produced the lowest transmission factor across all thickness variations. At 4 MeV, Cerrobend met the <5% transmission limit starting at 0.5 cm, whereas Silicone-Pb and Plasticine met the criterion at 1 cm and 1.5 cm, respectively. At 8 MeV, Cerrobend met the criterion starting at 0.5 cm, Silicone-Pb at 1.5 cm, and Plasticine at 2 cm. Increasing electron energy increased the transmission factor. Cerrobend showed the best shielding effectiveness compared with Silicone-Pb and Plasticine.

Keywords: Transmission Factor, Electron, Cerrobend, Silicone-Pb, Plasticine, LINAC

I. Introduction

Radiotherapy is one of the modalities used in cancer management that employs ionizing radiation to damage cancer cells and control their growth and division. In external radiotherapy, radiation is delivered from a source located outside the patient's body. One widely used radiation source is the Linear Accelerator (LINAC), which can generate electron beams at various energy levels according to therapeutic requirements. [3], [4], [7], [8].

In electron radiotherapy, dose distribution is influenced by electron energy characteristics and interactions with matter. Electrons passing through a material undergo various interactions—such as ionization, excitation, and scattering—that result in energy loss and changes in the direction of electron motion. Therefore, the use of shielding materials is necessary to limit radiation exposure to areas outside the therapeutic target [3], [4], [7].

One parameter that can be used to evaluate a material's ability to reduce radiation is the transmission factor. The transmission factor is the ratio of the measured radiation dose after passing through a material to the radiation dose before passing through the material. A lower transmission factor value indicates a superior ability of the material to attenuate transmitted radiation [1], [2].

Cerrobend (Lipowitz's alloy) is a eutectic metal alloy widely used to form custom shielding blocks in radiotherapy, composed nominally of 50% Bismuth (Bi), 26.7% Lead (Pb), 13.3% Tin (Sn), and 10% Cadmium (Cd) by weight [1], [7]. This composition yields a high physical density of approximately 9.4 g/cm^3 and a low melting point of about 70°C , allowing easy casting into desired block geometries. Because Cadmium and Lead are toxic, proper safety guidelines and protective handling procedures are essential during block fabrication and melting. In addition to Cerrobend, lead-loaded silicone composite materials (Silicone-Pb) can serve as an alternative due to their flexibility and ease of shaping [2].

Plasticine is a non-metallic material that is flexible and easily molded. However, its density is relatively lower than that of materials containing heavy metals; consequently, its radiation attenuation capability is also estimated to be lower [2],[6]. The differences in the characteristics of these three materials provide a basis for comparing their abilities to reduce electron radiation.

Although previous studies have evaluated electron attenuation for Cerrobend blocks [1], comprehensive comparative data evaluating flexible and custom-molded alternative materials under identical low-energy electron beam configurations remain limited. In clinical practice, traditional rigid shielding blocks often present challenges in conforming to irregular anatomical contours, such as the facial regions, head, and neck. Therefore, flexible and moldable shielding materials provide significant clinical advantages by improving contour adaptability, setup stability, and patient comfort.

To address this research gap, this study provides a direct comparative evaluation among three distinct shielding categories: a conventional rigid metallic alloy (Cerrobend), a flexible lead-loaded composite (Silicone-Pb), and an easily moldable non-metallic material (Plasticine). This study evaluated the effects of material type and thickness variation (0.5–2.5 cm) on the transmission factors of 4 MeV and 8 MeV electron beams generated by a Linear Accelerator (LINAC) to determine their relative shielding effectiveness and clinical applicability.

II. EXPERIMENTAL PROCEDURE

1. Research Design and Location

This was an experimental study involving measurements of electron radiation transmission factors for several materials and thickness variations. The study was conducted at the Radiotherapy Sub-Installation of Prof. I.G.N.G. Ngoerah Hospital, Denpasar, Bali. Measurements were performed using a Linear Accelerator (LINAC) with electron beams of 4 MeV and 8 MeV.

2. Research Variables

The independent variables were material type (Cerrobend, Silicone-Pb, and Plasticine), material thickness (0.5, 1, 1.5, 2, and 2.5 cm), and electron energy (4 MeV and 8 MeV). The dependent variable was the electron radiation transmission factor. The controlled variables included the LINAC, SSD of 100 cm, and $10 \times 10 \text{ cm}$ field size.

3. Tools and Materials

The equipment included a glass container, scale, $15 \times 15 \text{ cm}$ mold with a thickness of 0.5 cm, and spoon. The materials consisted of Cerrobend, RTV-52 silicone rubber, lead (Pb), Plasticine, and catalyst. The materials were prepared in several layers to obtain thickness variations of 0.5–2.5 cm.

4. Radiation Measurement

Measurements were performed using a clinical Linear Accelerator (LINAC) with the geometric setup maintained consistently throughout the experiment. A field size of $10 \times 10 \text{ cm}$ was set at a Source-to-Surface Distance (SSD) of 100 cm. In accordance with the IAEA TRS-398 protocol for low-energy electron beams [5], radiation doses were determined at two electron energies (4 MeV and 8 MeV) using a calibrated plane-parallel ionization chamber connected to a digital electrometer, positioned at the depth of maximum dose (d_{max}) within a water-equivalent solid phantom ($30 \times 30 \text{ cm}$). For each energy, a reference dose was first recorded without any intervening material. Subsequently, absorbed dose measurements were conducted with the electron beam passing through Cerrobend, Silicone-Pb, and Plasticine at thickness variations of 0.5, 1, 1.5, 2, and 2.5 cm.

5. Calculation of Transmission Factor

The transmission factor was calculated as the ratio of the dose after passing through the material to the dose without the material using the following equation:

$$T = (D / D_0) \times 100\%$$

In this study, the measurement results were evaluated against a maximum allowable transmission factor limit of <5%, which serves as the established clinical effectiveness threshold for custom electron shielding blocks to minimize unintended radiation exposure to surrounding healthy tissues [7], [8].

III. RESULT AND DISCUSSION

3.1 TRANSMISSION FACTOR AT 4 MEV

The average transmission factors measured at 4 MeV are presented in Table 1. The data show a decrease in the transmission factor as material thickness increases for all three materials tested.

Table 1. Material transmission factors at 4 MeV

Thickness (cm)	Cerrobend (%)	Silicone-Pb (%)	Plastisine (%)
0.5	0.5831	43.9521	64.4864
1	0.4134	1.0919	5.3429
1.5	0.2862	0.4452	0.4346
2	0.2226	0.4134	0.4028
2.5	0.1696	0.3922	0.4134

Cerrobend showed the lowest transmission factor at all thicknesses. At a thickness of 0.5 cm, Cerrobend's transmission factor was 0.5831% and decreased to 0.1696% at a thickness of 2.5 cm. All values were below the 5% limit. Silicone-Pb had a transmission factor of 43.9521% at a thickness of 0.5 cm and decreased to 1.0919% at a thickness of 1 cm. Thus, at 4 MeV, Silicone-Pb met the <5% transmission criterion starting at a thickness of 1 cm. For Plasticine, the transmission factor was 64.4864% at a thickness of 0.5 cm and 5.3429% at 1 cm—still slightly above the 5% limit. This value then dropped to 0.4346% at a thickness of 1.5 cm. Thus, Plasticine met the <5% transmission criterion starting at a thickness of 1.5 cm.

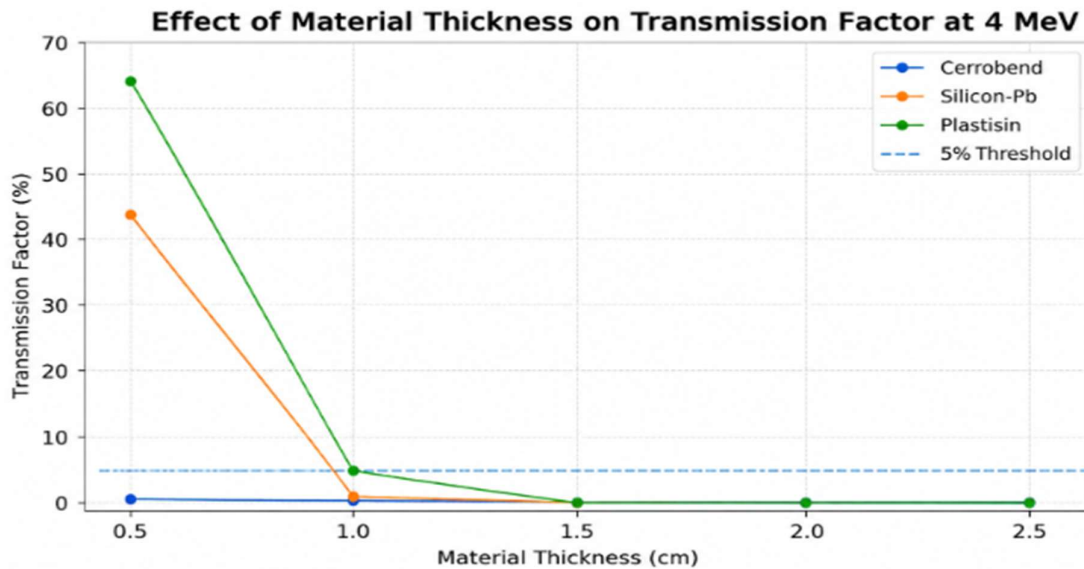


Figure 1. Effect of thickness on the transmission factor at 4 MeV

3.2 TRANSMISSION FACTOR AT 8 MEV

The measurements at 8 MeV are presented in Table 2. Increasing material thickness again resulted in a decrease in the transmission factor; however, transmission values at 8 MeV were generally higher than those at 4 MeV for the same thickness.

Table 2. Material transmission factors at 8 MeV

Thickness (cm)	Cerrobend (%)	Silicone-Pb (%)	Plasticsine (%)
0.5	1.8932	82.6648	90.4114
1	1.3406	33.0843	51.6987
1.5	1.0540	4.7892	9.6807
2	0.8289	1.4122	1.4224
2.5	0.6549	1.3201	1.2075

Cerrobend continued to demonstrate the best shielding performance. At a thickness of 0.5 cm, the transmission factor was 1.8932%, decreasing to 0.6549% at a thickness of 2.5 cm. All these values remained below the 5% limit. For Silicone-Pb, the transmission factor was 82.6648% at a thickness of 0.5 cm and 33.0843% at a thickness of 1 cm. This value dropped to 4.7892% at a thickness of 1.5 cm, meaning Silicone-Pb met the <5% transmission limit starting at that thickness.

Plasticsine exhibited the highest transmission factors at the initial thicknesses: 90.4114% at 0.5 cm and 51.6987% at 1 cm. At a thickness of 1.5 cm, the transmission value was 9.6807%, whereas at 2 cm, it dropped to 1.4224%. Thus, Plasticsine met the <5% transmission criterion starting at a thickness of 2 cm.

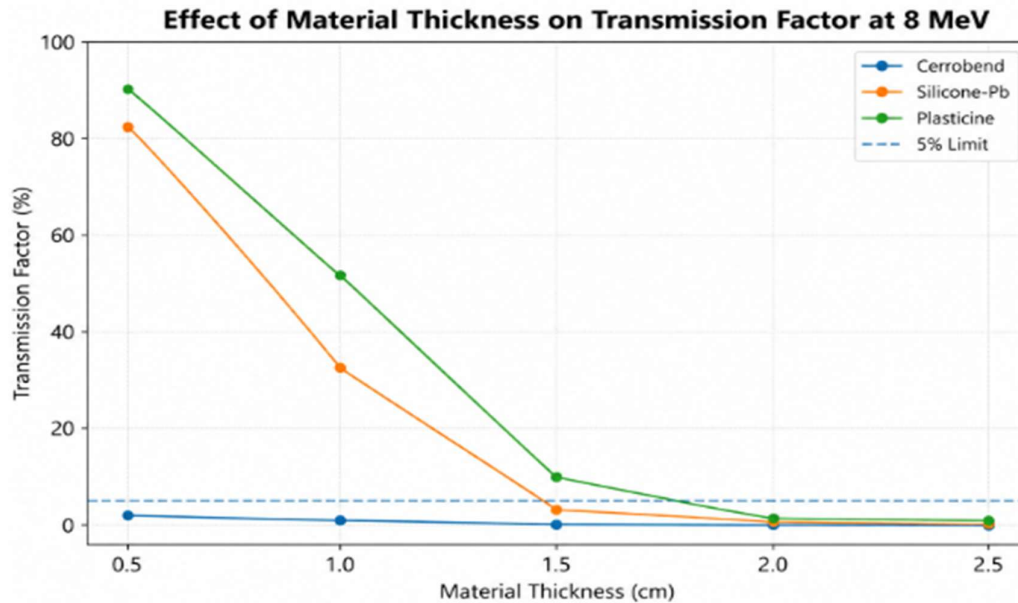


Figure 2. Effect of thickness on the transmission factor at 8 MeV

3.3 EFFECT OF MATERIAL THICKNESS ON THE TRANSMISSION FACTOR

The results show that material thickness affects the transmission factor. In general, increasing thickness decreased the transmission factor for all three materials and both electron energies. As material thickness increases, the electron path length within the material becomes longer, increasing the probability of collision interactions (ionization and excitation) and radiative energy losses. Consequently, fewer electrons penetrate through the material.

Differences in transmission-factor reduction among the materials indicate that their physical density and effective atomic number (Z_{eff}) play a crucial role. Cerrobend, possessing the highest density ($\sim 9.4 \text{ g/cm}^3$) and high-Z components (Bismuth, Lead), demonstrated the highest attenuation capability. Silicone-Pb performed better than Plasticine due to the inclusion of high-Z lead particles suspended within the flexible silicone matrix. Plasticine, composed mainly of lower-Z elements and lower density, yielded relatively higher transmission factors, particularly at lower thicknesses. The shielding effectiveness order obtained at both energies was Cerrobend > Silicone-Pb > Plasticine.

3.4 EFFECT OF ELECTRON ENERGY ON THE TRANSMISSION FACTOR

Comparison of the results at 4 MeV and 8 MeV shows that increasing electron energy resulted in a higher transmission factor. In Cerrobend with a thickness of 0.5 cm, the transmission factor increased from 0.5831% at 4 MeV to 1.8932% at 8 MeV, although both remained below the 5% limit. The effect of energy was more pronounced for Silicone-Pb. At a thickness of 0.5 cm, the transmission increased from 43.9521% at 4 MeV to 82.6648% at 8 MeV. In Plasticine, the transmission value increased from 64.4864% to 90.4114% at the same thickness. These results indicate that higher-energy electrons have greater penetration capability, so materials with the same thickness can produce higher transmission factors.

3.5 COMPARISON OF THE EFFECTIVENESS OF THE THREE MATERIALS

Based on the overall results, Cerrobend showed the best ability to reduce electron radiation. At 4 MeV energy, Cerrobend has provided transmission below 5% even at a thickness of 0.5 cm. The same condition was also observed at 8 MeV. Silicone-Pb showed performance between Cerrobend and Plasticine, whereas Plasticine showed the lowest shielding capability at the initial thickness. The selection of a shielding material should consider electron energy and material thickness simultaneously. Increasing

the energy from 4 MeV to 8 MeV increases the required material thickness, particularly for Silicone-Pb and Plasticine. Thus, shielding effectiveness is determined by the interaction among material characteristics, thickness, and electron beam energy.

IV. CONCLUSIONS

1. Material type affects the electron transmission factor. Cerrobend yields the lowest transmission factor compared to Silicone-Pb and Plasticine at both energy levels used.
2. Increasing material thickness decreases the transmission factor. At an energy of 4 MeV, Cerrobend meets the <5% transmission limit starting at a thickness of 0.5 cm, Silicone-Pb at 1 cm, and Plasticine at 1.5 cm. At an energy of 8 MeV, Cerrobend meets this limit starting at 0.5 cm, Silicone-Pb at 1.5 cm, and Plasticine at 2 cm.
3. Increasing electron energy increases the transmission factor due to higher penetration power.
4. Cerrobend was the most effective shielding material, followed by Silicone-Pb and Plasticine.

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