International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

https://ijpsat.org/
Vol. 55 No. 1 January 2026, pp. 121-129

# Physical And Dosimetric Characterization Of Silicone Rubber–Silver Composite Bolus For Electron Beam Radiotheraphy At 9 Mev

Tri Setiyo Utami[1*], Heri Sutanto[2], Eko Hidayanto[2], Adnan Cindyana[1], Gita Nubuwwah Harahap[1]

[1]Student, Magister of Physics, Physics Department, Diponegoro University, Tembalang, Semarang, Indonesia
[2]Professor, Physics Department, Diponegoro University, Tembalang, Semarang, Indonesia
Corresponding Author: Tri Setiyo Utami. Email: utrisetiyo@gmail.com



**Abstract: A bolus is a tissue-equivalent material used in radiotheraphy to enhance the surface dose by shifting the depth of maximum dose ($z_{max}$) toward the skin surface. This study aims to develop and evaluate a Silicone Rubber–Silver (SR–Ag) composite bolus as a candidate material for electron beam therapy. The bolus was synthesized using RTV52 silicone rubber, silver (Ag), and PEG 4000. The materials were combined through mechanical mixing and ultrasonic homogenization. Characterization included density measurement and elemental composition analysis using EDX. Relative Electron Density (RED) was determined through CT-simulator imaging. The SR–Ag bolus has a density of 1.19 g/cm³, a RED value of 1.11, and an actual Ag composition of 11.37%, confirming successful incorporation of the metallic filler into the silicone matrix. Surface dose testing with a 9 MeV electron beam showed an increase from 81.78 cGy (without bolus) to 89.46 cGy (with SR–Ag bolus). These findings indicate that the bolus enhances surface energy deposition without significantly altering tissue equivalence. Overall, the SR–Ag bolus exhibits physical, structural, and radiological characteristics supporting its suitability as a bolus material for superficial radiotherapy applications.**
**Keywords: Silicone Rubber-Silver (SR-Ag) Bolus, Electron Beam Radiotheraphy, Surface Dose Value.**

## 1. INTRODUCTION

Cancer is one of the most significant global health issues. It remains a leading cause of death in many countries [1]. Cancer is a group of diseases characterized by abnormal cell growth that is invasive and capable of metastasizing to other organs. Global reports indicate that cancer ranks as the first or second leading cause of death before the age of 70 in more than half of the countries worldwide [2]. In Indonesia, the cancer incidence rate has reached 136.2 per 100,000 [3]. This highlights the need for comprehensive interventions such as improved healthcare facilities, early detection, and optimized treatment, including radiotheraphy. Radiotheraphy employs ionizing radiation to destroy cancer cells and is frequently used for lesions located near the skin surface. However, treatments using LINAC face challenges related to suboptimal surface dose due to the build-up effect. This necessitates the use of additional materials, such as a bolus to enhance the dose delivered to superficial tissue layers.

A bolus is a tissue-equivalent material placed on the skin to conform to surface irregularities and increase the superficial radiation dose. Various materials have been used as bolus, including natural rubber, superflab, polymer gels, HAPRC, plasticine, thermoplastic, and silicone rubber [4], [5], [6]. Despite their use, these materials often exhibit limitations such as poor surface conformity, insufficient stability, or mechanical mismatch with the skin. More recently, silicone rubber (SR) has emerged as a promising alternative, offering the ability to conform to patient anatomy, non-toxicity, non-stick properties, and stability across clinical temperature ranges [7], [8]. However, several studies report that boluses made from pure SR can produce excessively high surface doses (>100%) at certain energies [5], [9], underscoring the need for material modification to control its dosimetric characteristics.

One way to address this issue is to add high-Z metals to the SR matrix, which can enhance radiation absorption efficiency and regulate the Percentage Surface Dose (PSD). Metals such as bismuth, lead, silica, and copper have been studied, but they often introduce chemical instability or reduce tissue equivalence [6], [7], [10], [11]. Silver (Ag) stands out due to its high atomic number, chemical stability, and antimicrobial properties [12]. [13] also showed that Ag can boost radiation absorption and act as a dose enhancer in various radiotherapy modalities. Therefore, this study develops a silicone rubber–silver (SR–Ag) composite bolus with different Ag concentrations to examine its physical properties, internal structure, and dosimetric response. The goal is to create a stable, effective bolus material to improve dose distribution for superficial tumour treatment.

## 2. THEORETICAL FOUNDATION

### Radiotheraphy

Radiotherapy is a primary cancer treatment that uses ionizing radiation to target and destroy malignant cells [14]. It is commonly used alongside surgery and chemotherapy, especially when tumours are inoperable or require precise local treatment. The goal is to deliver a high dose to the tumour while minimizing exposure to healthy tissues. Ionizing radiation—such as X-rays, gamma rays, or charged particles—produces ionization in tissue atoms, damaging cellular structures or causing genetic changes that lead to cancer cell death [15], [16].

In clinical practice, radiotheraphy may be administered with curative, palliative, or prophylactic intent, depending on the patient's condition and therapeutic goals. These intentions shape the delivery approach, which is generally either external beam radiotheraphy—using specialized equipment such as a LINAC to direct radiation from outside the body—or brachytherapy, in which the radiation source is placed inside or near the tumour through natural body cavities [17]. Curative radiotheraphy aims to eradicate cancer. In contrast, palliative radiotheraphy focuses on alleviating symptoms for patients with advanced disease, while prophylactic radiotheraphy is administered to prevent tumour spread or recurrence in high-risk cases.

### Surface Dose

Surface dose refers to the amount of radiation absorbed at the surface layer of tissue (skin). In megavoltage radiotheraphy, whether using photon or electron beams, the surface dose is typically lower than the maximum dose. This is due to the presence of a build-up region, a zone where the fluence of charged particles increases until it reaches a certain depth ($z_{max}$). For electron beams, the surface dose generally ranges from 75–95% of the maximum dose depending on beam energy. Therefore, without additional modification, superficial tissues may receive suboptimal doses for therapeutic purposes [18], [19]. Conversely, the skin-sparing effect associated with photon beams can be beneficial for protecting the skin. However, it becomes less suitable for treating superficial lesions that require high doses at the surface [20].

The use of a bolus as a tissue-equivalent material is one of the primary strategies to enhance surface dose. When placed on the skin, the bolus effectively shifts the build-up region into the bolus material, bringing $z_{max}$ closer to the skin surface. Several studies have demonstrated that adding a bolus in electron and photon therapy significantly increases the percentage surface dose and modifies the depth dose curve to better accommodate superficial tumour treatments [18]. Additionally, bolus thickness, density, tissue equivalence, and geometric conformity, including potential air gaps, critically influence the final surface dose achieved [9]. Therefore, a thorough understanding of surface dose characteristics and influencing factors is essential for the effective design and evaluation of composite bolus materials such as Silicone Rubber–Ag (SR–Ag).

### Bolus in Radiotheraphy

A bolus is a tissue-equivalent material designed to mimic soft tissue. It is placed on the skin surface to improve dose homogeneity and shift the depth of maximum dose toward the surface. This makes it effective for superficial cancer therapy [7], [14]. A bolus thickness of 0.5–1.5 cm is considered ideal because it does not significantly alter the isodose curve [7]. An appropriate

International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

https://ijpsat.org/
Vol. 55 No. 1 January 2026, pp. 121-129

bolus material must be biocompatible, non-toxic, flexible, stable, easy to shape, and possess HU and RED values similar to human tissue [5], [21]. Various materials such as superflab, polystyrene, wax, and elastic gel have been used. Each, however, presents limitations, including uneven dose distribution, high cost, or insufficient flexibility [7], [22]. Silicone rubber (SR) has emerged as a superior alternative. It is valued for its elasticity, biocompatibility, ability to conform to patient anatomy, and mechanical and chemical stability [4], [5].

Silicone rubber (SR) is a polymer based on polydimethylsiloxane (PDMS) and is available in two forms: high-temperature vulcanizing (HTV) and room-temperature vulcanizing (RTV). RTV SR, which cures at room temperature, is commonly used in medical applications [5]. However, SR has a relatively low effective atomic number ($Z \approx 14$, where Z indicates the average atomic number of atoms within a material), which limits its ability to interact with radiation and may result in excessive surface radiation doses (>100%) if used without modification [7]. To address this limitation, high-Z (atomic number) metallic fillers such as silver (Ag) can be incorporated into the SR matrix. Silver has a high atomic number, high-density (mass per unit volume), good chemical stability, and beneficial antimicrobial properties [12], [13]. Adding Ag particles increases material density and relative electron density (RED, which relates to a material's capacity to scatter electrons), enhances electron backscattering (reflection of electrons back toward the source), and improves surface dose—an essential requirement for superficial radiotheraphy [3]. Therefore, SR–Ag (silver) composites combine the flexibility of silicone rubber with silver's dose-enhancing properties, making them a promising and safe bolus (tissue-equivalent material used to increase skin dose in radiotheraphy) candidate for radiotheraphy applications.

## 3. RESEARCH METHODOLOGY

The research methodology consists of several stages. It begins with material preparation and synthesis of the silicone rubber–silver (SR–Ag) composite bolus. Next is material characterization, followed by dosimetric measurements using a linear accelerator (LINAC). The bolus synthesis was carried out at the SMARC Laboratory, Diponegoro University. Material density was then characterized using mass–volume measurements, and elemental composition was analyzed through SEM–EDX. These steps verified the successful integration of Ag particles into the silicone rubber matrix. All numerical data and characterization results were processed with Microsoft Excel and ImageJ prior to dosimetric evaluation. Surface dose measurements used a solid water phantom under a 9 MeV electron beam. This assessed the effectiveness of the SR–Ag bolus in enhancing energy deposition at the surface. This study provides preliminary insight into the potential of SR–Ag as a bolus material for superficial radiotheraphy and serves as a foundation for further development.

### Sample Synthesis

In this study, the bolus was fabricated using silicone rubber (SR) type SR-RTV52 as the base material, silver (Ag) powder, and PEG 4000. PEG 4000 functions as a binding agent to prevent Ag particle sedimentation. The synthesis process consisted of two main stages: (1) preparation of the PEG–Ag solution and (2) mixing of the SR–Ag composite. In the first stage, 20 grams of PEG 4000 were dissolved in 10 mL of aquabidest. This was done using a hot-plate stirrer at 60°C, with a mixing speed of 3 rpm, for one hour before the Ag powder was added. The next stage involved combining all materials to produce the SR–Ag composite. The SR mixture with predetermined volume was stirred using a mixer for 30 minutes. This was followed by ultrasonication for another 30 minutes to improve homogeneity. The mixture was then stirred again for 8 minutes, catalyzed, and homogenized using a dismixer before being poured into a mold. The curing process lasted for 24 hours until the bolus solidified and could be removed from the mold. The variation in Ag concentration was prepared to evaluate its influence on the material properties of SR when used as a bolus in radiotheraphy applications.

### Bolus Density

Density measurements were conducted to determine the compactness of each bolus sample with varying silver (Ag) content, allowing for an analysis of the influence of Ag content on the surface dose percentage in the SR–Ag bolus. Density was calculated by dividing the sample's mass by its volume. Each bolus's mass was measured with a digital balance. Volume was determined from the bolus's dimensions (length × width × thickness). The density was then computed with the following equation 1:

(1)

International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

https://ijpsat.org/
Vol. 55 No. 1 January 2026, pp. 121-129

$$\rho = \frac{m}{V}$$

with $\rho$ representing the density (kg/cm³), $m$ the mass of the sample (kg), and $V$ the volume of the sample (cm³) [21].

**EDX Characterization Test**

The Energy-Dispersive X-ray (EDX) technique is commonly used to qualitatively determine the elemental composition of a material. It also provides a semi-quantitative estimation of the concentration or proportion of elements in a sample. In this study, EDX characterization of the SR–Ag bolus was conducted to examine the elemental composition on both the surface and internal regions. Special focus was placed on the presence of silver (Ag), carbon, oxygen, and other elements that may influence conductivity, density, and the material's interaction with radiation [23]. EDX results are typically reported in terms of weight percentage and atomic percentage. They also include identification of characteristic energy peaks (keV) for each detected element. This enables evaluation of material homogeneity, potential contamination, or compositional variations from the manufacturing process [23]. EDX is a non-destructive technique that requires minimal sample preparation. It generates spectra that can be analyzed to verify the presence and distribution of specific elements within the bolus [24].

**Determination of Relative Electron Density (RED)**

Relative Electron Density (RED) was calculated from the Hounsfield Unit (HU) values obtained through CT-simulator scanning. Axial scanning parameters included tube voltage, tube current, and slice thickness. After image acquisition, ten small circular Regions of Interest (ROIs) were selected horizontally across several slices in the axial or coronal view. The averaged CT-Number values from all ROIs were then used to calculate RED as follows Equation (2) or (3) :

$$\rho = \begin{cases} 1.000 + (0.001 \times N_{CT}) \ ; \text{ for CT } number \leq 100 & (2) \\ 1.052 + (0.00048 \times N_{CT}) \ ; \text{ for CT } number > 100 & (3) \end{cases}$$

where $\rho$ and $N_{CT}$ represent the RED value and the CT-number (HU), respectively [21].

**Surface Dose Analysis**

Surface dose percentage for the bolus was determined by irradiating samples with a 9 MeV electron beam from a LINAC, using a 10 × 10 cm² applicator. The source-to-surface distance (SSD) was set at 100 cm to the solid phantom. The detector was placed directly on the phantom surface to measure dose response, as shown in Figure 1.

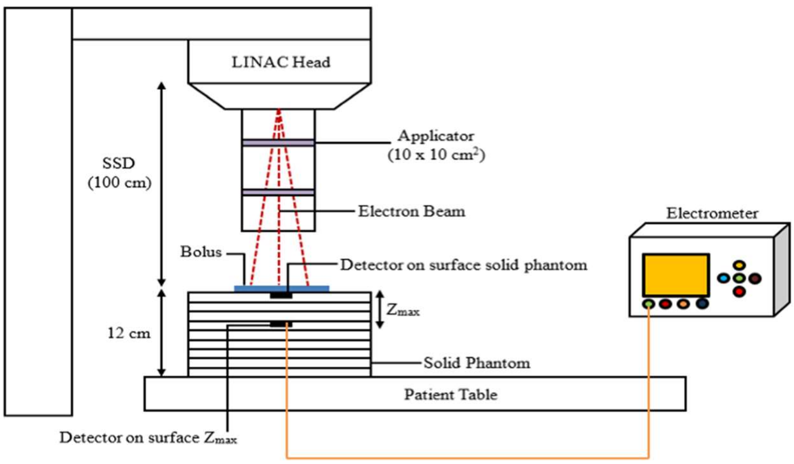


**Figure 1. Surface Dose Measurement Scheme**

International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

https://ijpsat.org/
SCHOLAR AI Be Smart
Vol. 55 No. 1 January 2026, pp. 121-129

The calculation of the absorbed dose ($D_{w,Q_0}$) follows the protocol described in [25]. Equation (4) is used, assuming the dosimeter has a calibration coefficient expressed in absorbed dose to water for the reference beam quality $Q_0$:

$$D_{w.Qo} = M_{Qo} N_{D,w,Q_o} \quad (4)$$

Here, $M_{Q_0}$ is the dosimeter reading under reference conditions used in the standards laboratory, $N_{D,w,Q_0}$ is the calibration coefficient in terms of absorbed dose to water obtained from the standards laboratory, and $M_{Q_0}$ represents the corrected dosimeter reading after accounting for all environmental and detector-related influence factors according to Equation (5):

$$M_{Qo} = M_{baca} K_{T,P} K_{pol} K_s \quad (5)$$

where $M_{\text{read}}$ is the raw electrometer reading, $K_{T,P}$ is the correction factor for air temperature and pressure, $K_{pol}$ is the correction for polarity effects of the chamber voltage, and $K_s$ is the correction factor for ion recombination.

## 4. RESULTS AND DISCUSSION

### SR-Ag Bolus Synthesis Results

The Silicone Rubber–Silver (SR–Ag) composite bolus was successfully fabricated as a sheet measuring 17 × 17 × 0.5 cm³ with good structural stability. Ag concentration variations were prepared to evaluate the influence of high-Z metallic fillers on the physical properties of the bolus. These samples targeted electron beam radiotherapy applications. The dimensions were adjusted

to meet clinical requirements and standard LINAC configurations. Visually, all samples exhibited a smooth surface and uniform thickness, as shown in Figure 2. During the molding process, some air was initially trapped within the SR–Ag mixture. This was minimized through mechanical bubble-removal techniques using a needle prior to curing. As a result, the final bolus sheets were free from macroscopic defects and ready for subsequent characterization

**Figure 2. SR-Ag Bolus Synthesis**

### Bolus Density of SR-Ag

The measurements indicate that the SR–Ag bolus has a density of 1.19 g/cm³, which is slightly higher than that of pure silicone but still within the range of human soft tissue (±1 g/cm³). This enables the material to be categorized as tissue-equivalent. The increased density results from silver's higher atomic mass compared to silicone, as silver has a significantly greater atomic mass and density.

From a radiological perspective, a density of 1.19 g/cm³ potentially increases the probability of radiation interactions at the material's surface due to the higher electron density. Several studies have reported that higher-density bolus materials enhance secondary electron interactions near the surface, thereby shifting the depth of maximum dose closer to the skin while maintaining tissue equivalency [14], [18]. Therefore, the density of SR–Ag not only produces meaningful improvements in surface radiation absorption but also offers a compelling and effective solution for superficial tumor therapy.

**Energy Dispersive X-Ray (EDX) Analysis**

EDX analysis of the SR–Ag bolus sample revealed that silicon (Si) and silver (Ag) are the dominant elements in the composite. At this concentration, Si and Ag contents were detected at 87.95% and 11.37%, respectively, confirming that the addition of 10% Ag precursor successfully increased the actual Ag content within the silicone matrix. This aligns with the general trend that increasing precursor mass increases metal incorporation [7].

EDX data showed minor elements (S, Ca, Ti, Cu, Fe) at very low levels (<0.32%). These are impurities from the silicone rubber or mixing process, not new chemical interactions, consistent with previous reports [26]. Their low levels suggest the material remains stable and uncontaminated.

**Relative Electron Density (RED)**

The RED value for the SR–Ag bolus sample was measured using CT-simulator imaging, analyzing multiple ROI points to determine representative HU values. The SR–Ag bolus measured 128.5 HU, indicating a substantial increase due to Ag. This high HU shows that Ag addition directly increases the material's effective electron density.

Converting HU to RED yields 1.11 for the SR–Ag sample, the highest among all tested compositions. This result reflects increased electron density from high-atomic-number Ag, whose density far exceeds pure silicone. The elevated RED supports radiation principles: materials with greater electron density scatter and absorb high-energy radiation more effectively [27], [28].

Although a RED of 1.11 is slightly above the value of soft tissue (~1.0), the SR–Ag material can still be classified as tissue-equivalent. The deviation remains within clinically acceptable limits. This RED value also shows that the material has enough electron density to enhance dose deposition at the tissue surface during radiotherapy. These characteristics strengthen surface electron scattering and allow more efficient energy transfer. As a result, the SR–Ag composite is a strong candidate for superficial radiotherapy applications requiring a stable and tissue-equivalent bolus.

**Surface Dose Value**

Surface-dose measurements at 9 MeV showed that an SR–Ag bolus clearly enhances the dose compared to no bolus. The surface dose without bolus was 81.78 cGy. With the SR–Ag bolus, the value increased to 89.46 cGy with the SR–Ag bolus, representing a 9.4% increase as shown in Figure 3. This enhancement confirms that the bolus effectively shifts the depth of maximum dose (Zmax) closer to the surface. As a result, more electron energy is absorbed by the skin. This finding is consistent with the principle of electron radiotheraphy. Tissue-equivalent bolus materials on the surface reduce the build-up effect and increase energy deposition in superficial tissues [19].

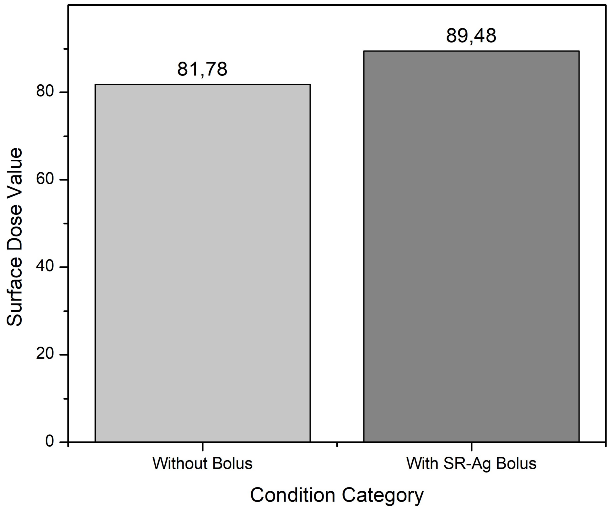


**Figure 3. Comparison Graph of Surface Dose Enhancement With and Without the SR–Ag Bolus**

The effectiveness of the SR–Ag bolus in increasing surface dose at 9 MeV is closely linked to its physical characteristics, particularly the higher electron density from the incorporation of silver (Ag) particles. As a high-atomic-number metal, silver enhances secondary electron scattering.This leads to greater electron fluence at the surface and a higher surface dose, with little change to the penetration profile [29]. This interaction is especially relevant for 9 MeV electron therapy.At this energy, most interactions occur at shallow depths, making surface response highly sensitive to changes in bolus electron density.

Although the SR–Ag bolus does not reach 100% surface dose, the increase from 81.78 cGy to 89.46 cGy is substantial. This shortfall may be due to air gaps, bolus thickness variations, or charged-particle disequilibrium with 9 MeV electrons [29]. These findings indicate strong potential for the SR–Ag composite as an effective bolus for electron radiotherapy of superficial lesions.

## 5. CONCLUSION

This study synthesized and characterized a Silicone Rubber–Silver (SR–Ag) composite bolus.The material is a candidate for superficial radiotheraphy applications. The SR–Ag bolus possesses stable physical form, homogeneous surfaces, and uniform thickness, which makes it suitable for dosimetric evaluation. Density measurements revealed a value of 1.19 g/cm³.This remains within the range of tissue-equivalent materials and meets clinical bolus requirements. EDX analysis confirmed the successful integration of Ag into the SR matrix with an actual Ag composition measured 11.37%, with no significant contamination from other elements. The measured Relative Electron Density (RED) of 1.11 shows that the material has sufficient electron density to enhance radiation interaction at the surface region.

Dosimetric testing with a 9 MeV electron beam increased the surface dose from 81.78 cGy (without bolus) to 89.46 cGy (with the SR–Ag bolus), confirming that the bolus shifts the depth of maximum dose (Zmax) closer to the skin. The SR–Ag composite enhances dose deposition in superficial tissues without affecting electron beam penetration. Based on physical, structural, and dosimetric results, the SR–Ag bolus is a strong alternative and warrants further clinical development for superficial radiotheraphy.

## REFERENCES

[1] "Latest global cancer data: Cancer burden rises to 18.1 million new cases and 9.6 million cancer deaths in 2018," 2018.

[2] H. Sung *et al.*, "Global Cancer Statistics 2020: GLOBOCAN Estimates of Incidence and Mortality Worldwide for 36 Cancers in 185 Countries," *CA A Cancer J Clinicians*, vol. 71, no. 3, pp. 209–249, May 2021, doi: 10.3322/caac.21660.

[3] H. Afrina Sianturi, J. Marbun, . Ikhwanuddin, . Azhari, and L. Sidauruk, "Utilization of Alginate Powder Strenged with Silicon Rubber as Composite Bolus Material for Radiotheraphy 8 Mev Energy:," in *Proceedings of the 1st International MIPAnet Conference on Science and Mathematics*, Medan, Indonesia: SCITEPRESS - Science and Technology Publications, 2019, pp. 209–213. doi: 10.5220/0010139200002775.

[4] L. C. Leony, V. F. Hanif, E. Defira, S. O. Oktamuliani, A. Muttaqin, and M. Ilyas, "Comparison of Absorbed Dose in Plasticine Bolus and Silicone Rubber Bolus," *J. Phys.: Theor. Appl.*, vol. 6, no. 1, p. 25, Mar. 2022, doi: 10.20961/jphystheor-appl.v6i1.59117.

[5] H. Sutanto *et al.*, "The Properties of Bolus Material using Silicone Rubber," *IOP Conf. Ser.: Mater. Sci. Eng.*, vol. 622, no. 1, p. 012002, Oct. 2019, doi: 10.1088/1757-899X/622/1/012002.

[6] S. Y. Astuti, H. Sutanto, E. Hidayanto, G. W. Jaya, A. S. Supratman, and G. P. Saraswati, "Characteristics of Bolus Using Silicone Rubber with Silica Composites for Electron Beam Radiotheraphy," *J. Phys. Appl.*, vol. 1, no. 1, p. 24, Dec. 2018, doi: 10.14710/jpa.v1i1.3914.

[7] H. Azmi Fathin, H. Sutanto, and E. Hidayanto, "Fabrication of Bolus from Composite of Silicone Rubber (SR) - Copper (Cu) for Radiotheraphy Application," *IJSR*, vol. 10, no. 6, pp. 730–734, June 2021, doi: 10.21275/SR21608081053.

[8] G. W. Jaya, H. Sutanto, E. Hidayanto, and G. P. Saraswati, "Studi Penggunaan Bolus Berbahan Silicone Rubber terhadap Dosis Permukaan pada Radioterapi Berkas Elektron," *PPJ*, vol. 1, no. 1, p. 15, Jan. 2020, doi: 10.30872/ppj.v1i1.561.

[9] X. Chen *et al.*, "Physical and Dosimetric Characterization of Silicone Rubber Bolus for Head Photon-Beam Radiotheraphy," *Technol Cancer Res Treat*, vol. 23, p. 15330338241293267, Jan. 2024, doi: 10.1177/15330338241293267.

[10] E. Endarko, "Evaluation of Dosimetric Properties of Handmade Bolus for Megavoltage Electron and Photon Radiation Therapy," *J Biomed Phys Eng*, vol. 11, no. 06, Dec. 2021, doi: 10.31661/jbpe.v0i0.2004-1108.

[11] Nurul Hidayatullah *et al.*, "Evaluation of Elasticity, Dose Reduction, and Image Quality on Sr-Pb Shield for Thoracic CT Examination," *IJSRST*, pp. 154–160, Nov. 2023, doi: 10.32628/IJSRST5231064.

[12] D. E. Marx and D. J. Barillo, "Silver in medicine: The basic science," *Burns*, vol. 40, pp. S9–S18, Dec. 2014, doi: 10.1016/j.burns.2014.09.010.

[13] N. Restuccia and L. Torrisi, "Nanoparticles generated by laser in liquids as contrast medium and radiotheraphy intensifiers," *EPJ Web of Conferences*, vol. 167, p. 04007, 2018, doi: 10.1051/epjconf/201816704007.

[14] H. A. Sianturi *et al.*, "Characterization of physical, mechanical and dosimetric properties of radiotheraphy bolus made from silicone rubber and epoxy resin," *Radiation Physics and Chemistry*, vol. 229, p. 112525, Apr. 2025, doi: 10.1016/j.radphyschem.2025.112525.

[15] W. Winarno, "Radioterapi Kanker Cervix Dengan Linear Accelerator (LINAC)," *JBP*, vol. 23, no. 2, p. 75, Dec. 2021, doi: 10.20473/jbp.v23i2.2021.75-86.

[16] Departemen Farmakologi dan Farmasi Klinik, Fakultas Farmasi, Universitas Padjadjaran, Sumedang, Indonesia, N. Fitriatuzzakiyyah, R. K. Sinuraya, Departemen Farmakologi dan Farmasi Klinik, Fakultas Farmasi, Universitas Padjadjaran, Sumedang, Indonesia, I. M. Puspitasari, and Departemen Farmakologi dan Farmasi Klinik, Fakultas Farmasi, Universitas Padjadjaran, Sumedang, Indonesia, "Cancer Therapy with Radiation: The Basic Concept of Radiotheraphy and Its Development in Indonesia," *Indones J Clin Pharm*, vol. 6, no. 4, pp. 311–320, Dec. 2017, doi: 10.15416/ijcp.2017.6.4.311.

[17] A. Handoko and E. Hidayanto, " Dose Verification Accuracy Analysis Using a Comparison Between a Standard Phantom and a Replica Phantom," vol. 07, no. 1.

[18] D. Kong *et al.*, "Effect of bolus materials on dose deposition in deep tissues during electron beam radiotheraphy," *Journal of Radiation Research*, vol. 65, no. 2, pp. 215–222, Mar. 2024, doi: 10.1093/jrr/rrae001.

[19] E. B. Podgorsak, “Radiation Oncology Physics:”.

[20] A. Jerrin and V. Ramasubramanian, “Surface dose and build-up region depth dose measurements in non-standard beams of Cyberknife and tomotherapy systems,” *Radiol Phys Technol*, vol. 14, no. 3, pp. 309–317, Sept. 2021, doi: 10.1007/s12194-021-00629-z.

[21] A. Hariyanto, F. Mariyam, L. Almira, E. Endarko, and B. S, “FABRICATION AND CHARACTERIZATION OF BOLUS MATERIAL USING PROPYLENE GLYCOL FOR RADIATION THERAPY,” *Iran J Med Phys*, no. Online First, July 2019, doi: 10.22038/ijmp.2019.39798.1537.

[22] H. A. Sianturi *et al.*, “Enhancing Radiotheraphy Bolus Characteristics through Comparative Analysis of Added Sawdust and Bagasse Powder: A Comprehensive Study of Physical and Mechanical Properties,” *J. Phys.: Conf. Ser.*, vol. 2733, no. 1, p. 012022, Mar. 2024, doi: 10.1088/1742-6596/2733/1/012022.

[23] K. Abidin, “ Effect of Annealing Time Variation on Silver Mass Percentage Characterized Using EDX Spectroscopy,” 2023.

[24] Vasile Goldiş Western University of Arad, Faculty of Medicine, Pharmacy and Dental Medicine, Department of Biochemistry, Arad, Romania *et al.*, “Characterization of human erythrocytes as carriers for iron nanoparticles,” *Rom Biotechnol Lett.*, vol. 25, no. 2, pp. 1378–1386, Apr. 2020, doi: 10.25083/rbl/25.2/1378.1386.

[25] INTERNATIONAL ATOMIC ENERGY AGENCY, *Absorbed Dose Determination in External Beam Radiotheraphy*, Rev. 1. in Technical Reports Series. INTERNATIONAL ATOMIC ENERGY AGENCY, 2024. doi: 10.61092/iaea.ve7q-y94k.

[26] F. Xi *et al.*, “Influence of iron, aluminum, calcium, titanium and vanadium impurities removal from silicon based on Cu-catalyzed chemical leaching,” *Journal of Materials Research and Technology*, vol. 10, pp. 502–511, Jan. 2021, doi: 10.1016/j.jmrt.2020.12.043.

[27] Y. S. Shin, S. J. Byun, B. Kim, and M. Kim, “Assessing the Reliability of 3D-Printed Custom Silicone Boluses in Radiotheraphy: Thickness and Air Bubble Considerations,” *Applied Sciences*, vol. 15, no. 19, p. 10486, Sept. 2025, doi: 10.3390/app151910486.

[28] C. Zhang, W. Lewin, A. Cullen, D. Thommen, and R. Hill, “Evaluation of 3D-printed bolus for radiotheraphy using megavoltage X-ray beams,” *Radiol Phys Technol*, vol. 16, no. 3, pp. 414–421, Sept. 2023, doi: 10.1007/s12194-023-00727-0.

[29] F. M. Khan and J. P. Gibbons, *Khan’s the physics of radiation therapy*, 5th edition. Philadelphia, PA: Lippincott Williams & Wilkins, 2014.