Study of Dose Measurement and Its Effects Using Relative Hp(10) and Uncertainty Across Different Radiation Field Sizes and Energies

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ABSTRACT

This work investigates the dosimetric behavior of relative Hp (10) at various energy levels and radiation field sizes with particular attention to radiation field positions. The goal is to measure the associated uncertainties and evaluate the relative variations in Hp (10) at various positions. The study seeks to improve accuracy in clinical radiation therapy and protection by analyzing the influence of field size and energy on dose distribution. The calibrated dosimeters were used in clinically relevant conditions, with field sizes ranging from 10 ×10 cm² to 25×25 cm². Six and fifteen Megavolts of energy were studied. Multiple dosimetric behaviors were captured by focusing on central and off-center positions during the three different positions where the measurements were taken within the radiation field. Examining the impact of varying energy levels and field sizes on the dose distribution is a crucial step toward quantifying uncertainties and fluctuations in relative Hp(10). In applications involving clinical radiation therapy, the analysis is essential for safeguarding and maximizing dose delivery.

Keywords: Relative Hp (10), Uncertainty, Radiation field size, Energy levels (MV), Radiation therapy

1. INTRODUCTION

The foundation of cancer treatment is radiation therapy, where precise dosimetry, an accurate measurement and control of the radiation dose administered, is necessary to guarantee that the target tissues receive the right amount of radiation while limiting exposure to nearby healthy tissues. Hp (10) or the dose equivalent for deep tissues is a significant number in dosimetry that is essential for tracking radiation exposure during treatment.

The energy level and field size are two factors that affect how difficult it is to dose radiation accurately. The radiation dose distribution is greatly influenced by these factors; larger field sizes usually result in increased scatter and beam divergence, which lowers the dose at periphery positions. Furthermore, radiation energy influences the penetration depth, influencing the distribution of doses in various tissue layers. To ensure that the dose administered adheres to the recommended treatment plan, these factors must be carefully considered, especially in off-center locations within the radiation field.

Field size and energy effects on dosimetry have been studied in the past. The need for standardized dosimetry across various field sizes was highlighted when the International Atomic Energy Agency (2000) established protocols for calculating absorbed doses in external beam radiation. By concentrating on relative Hp (10) measurements across various field sizes and energy levels, this work expands on that basis and contributes to a better understanding of dose distribution in clinical settings. Uncertainty is a crucial component of dosimetry and can be attributed to several factors, including patient variability, measurement technique, and calibration.

There are two types of uncertainty: random, which changes with every measurement, and systematic, which affects all measurements equally (e. g. calibration errors). Both types of uncertainty must be reduced for patient safety and accurate dosage administration. To ensure accurate dosage administration and patient safety, both kinds of uncertainty need to be reduced. Understanding the sources of uncertainty, particularly about different energy levels and field sizes, can help improve the accuracy of radiation therapy.

This work looks at relative Hp (10) at different energy levels and different positions in the radiation field. The study's results will provide a comprehensive analysis of the related uncertainties in addition to quantifying the influence of these factors on dose distribution, which will aid in the creation of more exacting protocols for precise dosimetry in clinical practice.

2. MATERIALS AND METHODS

2.1 Experimental Setup

For the experimental study, Harshaw 6600 plus model Thermo luminescent Dosimeter Instrument is used to read the dosimeters, which is shown in Figure 2. Also, Thermo Luminescent Dosimeter (TLD) cards, as shown in Figure 1, were used to assess the radiation dose distribution. The dosimetric study was conducted using calibrated dosimeters placed at positions P1, P2, and P3, corresponding to different geometric locations of the radiation field. The experiments were carried out under controlled conditions, ensuring that external variables such as room temperature, pressure, and humidity were consistent throughout the measurements.

Precise dosimetric measurements are crucial for ensuring patient safety and accurate radiation therapy. The use of personal dosimeters for measuring Hp (10), which represents the dose equivalent at a 10 mm depth in tissue, is one of the key methods to assess radiation exposure. This paper aims to analyze the relative Hp (10) for different field sizes and energies, comparing them across three distinct positions (P1, P2, and P3) and investigating the associated uncertainties.

***Fig 1:** Thermo luminescent Dosimeter (TLD) Card*

Fig. 2: Harshaw 6600 plus model Thermo luminescent Dosimeter (TLD) Instrument

2.2 Field Sizes and Energy Levels

Four different field sizes were used for the

measurements:

10×10 cm²

15×15 cm²

20×20 cm²

25×25 cm²

These field sizes represent a range of conditions typically encountered in clinical radiotherapy. Each field size was tested with two energy levels:

6 MV: Commonly used for superficial radiation treatments.

15 MV: Utilized for deeper tissue penetration.

2.3 Positions

The dosimeters were placed at three positions:

P1: Located near the central axis of the field.

P2: Situated slightly off-center.

P3: Positioned near the edge of the field.

The placement of the dosimeters allow for a thorough investigation of how radiation dose varies across the field. For each combination of field size, energy, and position, the mean relative Hp (10) was recorded, and the corresponding standard deviation (S.D.) was used to calculate the uncertainty.

2.4 Calculation of Uncertainty

Uncertainty in dosimetric measurements arises from both statistical and systematic sources. The statistical uncertainty was derived from the standard deviation of repeated measurements, while systematic uncertainty was estimated based on equipment calibration and environmental factors. The overall uncertainty was calculated using the formula.

Uncertainty in dosimetric measurements is a crucial factor affecting the reliability of results. In this experiment, the uncertainty was quantified using standard deviation (S.D.) and percentage uncertainty.

The different influential factors contributed to uncertainty, such as detector sensitivity, beam stability, and environmental conditions. Due to these factors, the uncertainty values observed were not as finely controlled as desired. Uncertainty was more pronounced for smaller fields and peripheral positions (P1 and P3). However, in this study, instrumental error is the only factor for uncertainty. Statistical analysis was conducted using Python programming in Jupyter Notebook.

3. RESULTS AND DISCUSSION

Table 1: The following data summarize the relative Hp(10), standard deviation (S.D.), and calculated uncertainty for each field size (dimension), energy in MV, and position.

S.N	Dimension (cm²)	Energy (MeV)	Position	Relative Hp(10)	S.D.	Uncertainty (%)	Scattered Dose % (5 cm)
1	1010	6	P1	1.05	0.043	4.096	3.98
2	1010	6	P2	0.95	0.036	3.797	
3	1010	6	P3	0.88	0.091	10.418	
4	1515	6	P1	1.11	0.011	0.994	5.86
5	1515	6	P2	0.96	0.004	0.372	
6	1515	6	P3	0.9	0.053	5.847	
7	2020	6	P1	1.28	0.013	0.997	6.69
8	2020	6	P2	1.19	0.043	3.609	
9	2020	6	P3	1.14	0.026	2.302	
10	2525	6	P1	1.28	0.01	0.779	7.67
11	2525	6	P2	1.24	0.027	2.142	
12	2525	6	P3	1.21	0.021	1.765	
13	1010	15	P1	1.26	0.008	0.596	3.93
14	1010	15	P2	1.21	0.007	0.537	
15	1010	15	P3	1.17	0.026	2.244	

16	1515	15	P1	1.28	0.013	1.018	3.93
17	1515	15	P2	1.24	0.036	2.936	
18	1515	15	P3	1.21	0.006	0.455	
19	2020	15	P1	1.3	0.009	0.717	9.49
20	2020	15	P2	1.26	0.015	1.19	
21	2020	15	P3	1.23	0.023	1.91	
22	2525	15	P1	1.35	0.014	1.025	11.49
23	2525	15	P2	1.31	0.027	2.03	
24	2525	15	P3	1.27	0.03	2.317	

Table 1 presents the measured relative Hp (10), standard deviation (S.D.), and calculated uncertainty percentages for various radiation field sizes (ranging from 10×10 cm² to 25×25 cm²), energies (6 MV and 15 MV), and three detector positions (P1, P2, and P3). The data reveals that higher relative Hp (10) values are generally recorded at central position P1, with values increasing as the field size enlarges. The 15 MV energy consistently produces higher and more stable dose readings across all positions compared to 6 MV, as indicated by the lower uncertainties. Notably, uncertainties are highest at P3 and in smaller fields (especially for 6 MV), reflecting greater dose fluctuation near the edges of the radiation field and at lower energies. The scattered dose values, reported for selected field sizes, further support the observation that dose dispersion increases with field size, with 25×25 cm² showing the highest scattered dose percentages.

Table 2: Radiation Dose Received by 4 walls during exposure time

TLD ID	Position	1st Exposure (mSv)	2nd Exposure (mSv)	3rd Exposure (mSv)	Distance from Center (cm)
a1001498t	P(e)	1.97	1.29	0.5	410
a1001091t	P(w)	0.48	0.66	0.22	420
a1000469t	P(s)	1.3	0.95	0.37	380
a1001501t	P(n)	0.48	0.55	0.21	370

Table 2 summarizes the radiation dose received by four walls of the treatment room during three exposure events, with dosimeters placed at designated positions: east (P(e)), west (P(w)), south (P(s)), and north (P(n)). The data indicates that the wall located east (P(e)) received the highest cumulative dose over three exposures, reaching up to 1.97 mSv in the first exposure. In contrast, the west and north positions received relatively lower doses. Dose measurements show a declining trend from the first to the third exposure in all positions, which may be attributed to time-dependent decay of scattered radiation or beam directionality. Additionally, the distance of each wall from the radiation field center ranges between 370 cm and 420 cm, correlating to a gradient in dose intensity with increasing distance, reinforcing the importance of room shielding and layout in radiotherapy environments.

From Fig. 3, at P1 (dashed blue lines): Both energies show increasing doses as the field size increases. However, the 15 MV dose (solid line) is consistently higher than the 6 MV dose (dashed line), indicating higher dose deposition at this position for the higher energy. At P2 (dashed green lines): The 6 MV dose (dashed) shows a more noticeable increase between 15×15 and 20×20 field sizes, while 15 MeV (solid) has a steadier trend, with a small but consistent rise. And at P3 (purple lines), Doses are generally lower than at P1 and P2. Both energies show a gradual increase in dose as the field size increases, but the rise is more significant for the 6 MV dose.

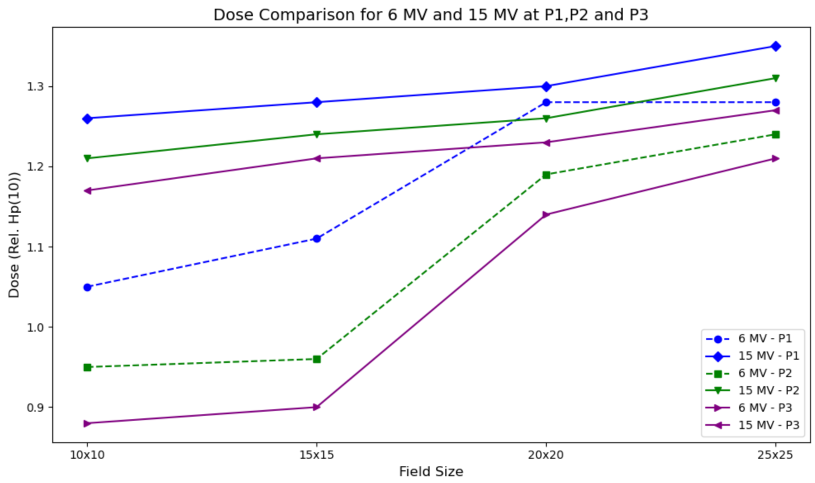

Fig 3: *The line graph compares Relative Hp(10) doses for 6 MV and 15 MV radiation energies at three positions (P1, P2, and P3) across different field sizes (10×10, 15×15, 20×20, and 25×25)*

P1 is likely closer to the high-dose region, indicating this position is subject to the most radiation. P2, being at the center, experiences a more uniform distribution of dose. P3 is farther away, resulting in lower doses compared to P1 and P2. Larger field sizes (20×20 and 25×25) generally result in higher doses at all positions and energies, with more significant differences at 6 MV. For 6 MV at P2 and P3, there's a sharp rise in dose between 15×15 and 20×20, showing a non-linear response to field size changes. The field size significantly influences the dose, particularly for 6 MV radiation at P2 and P3.

This graph likely highlights how field size and energy level affect radiation dose distribution at different points, which is important in dosimetry and treatment planning.

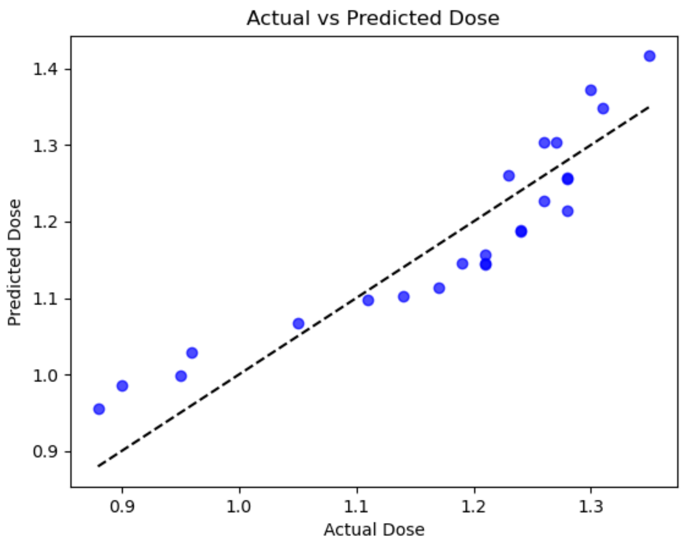

Fig 4: *The regression analysis of actual dose vs. predicted dose*

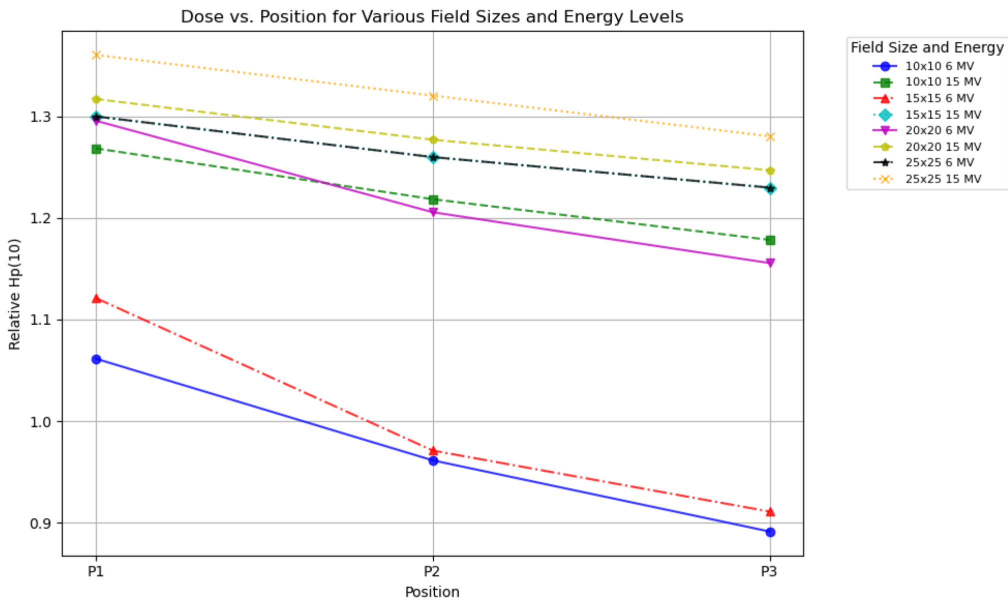

Fig 5: *Percent depth dose (PDD) for different field sizes and energies to understand how these factors influence relative Hp(10) in dosimetric measurements*

From Fig. 5, the PDD curve generated from the dataset offers several key insights into how field size, energy, and position affect relative Hp(10) measurements. Figure 5 shows energy dependence on 15 MV Photon Fields consistently show higher relative Hp(10) values compared to 6 MV fields across all positions and field sizes. Since 15×15 for 15 MV and 25×25 for 25 MV overlap with each other due to similar data points. This suggests that higher energy beams (15 MV) deposit more dose at the measurement positions compared to lower energy beams (6 MV), which is consistent with the deeper penetration capability of higher-energy photons. To determine the field size dependence in both energy levels, as the field size increases (from 10×10 cm² to 25×25 cm²), the relative Hp(10) values increase, especially at P1 and P2. Larger fields provide more uniform radiation distribution, leading to higher and more consistent doses across positions, as observed from the flatter curves for larger fields. The dose variation is more pronounced in smaller fields (e.g., 10×10 cm²), where P1 and P3 exhibit greater deviation from P2 (center), indicating that smaller fields have greater dose inhomogeneity, especially at the edges of the field.

To determine position dose variation, P2 which lies at the center consistently exhibits lower variability compared to P1 (right) and P3 (left), reflecting the fact that the center of the beam receives a more uniform dose (P1 and P3), particularly in smaller fields, show more variation, with P3 (left) generally receiving a lower dose compared to P1 (right), indicating an asymmetry in dose distribution at the edges of the field. The larger fields (15×15 cm² to 25×25 cm²) show improved uniformity across all positions, with smaller dose differences between P1, P2, and P3.

The higher uncertainty in smaller fields and peripheral positions (especially at P3) is visually reflected by the steeper slope for smaller fields, indicating greater positional sensitivity and dose variation. Larger fields and higher energies exhibit reduced uncertainty and more consistent dose delivery across all positions, as evidenced by the flatter curves, especially for P1 and P2.

- Higher photon energy (15 MV) results in higher and more uniform dose distributions compared to **6 MV**.
- Larger field sizes significantly reduce dose variability, creating more homogeneous radiation fields, which is particularly important for minimizing over- or under-dosing in treatment areas.
- Smaller fields should be used with caution, as they introduce more variability at non-central positions, increasing the risk of uneven dose distribution, especially at the edges of the field.

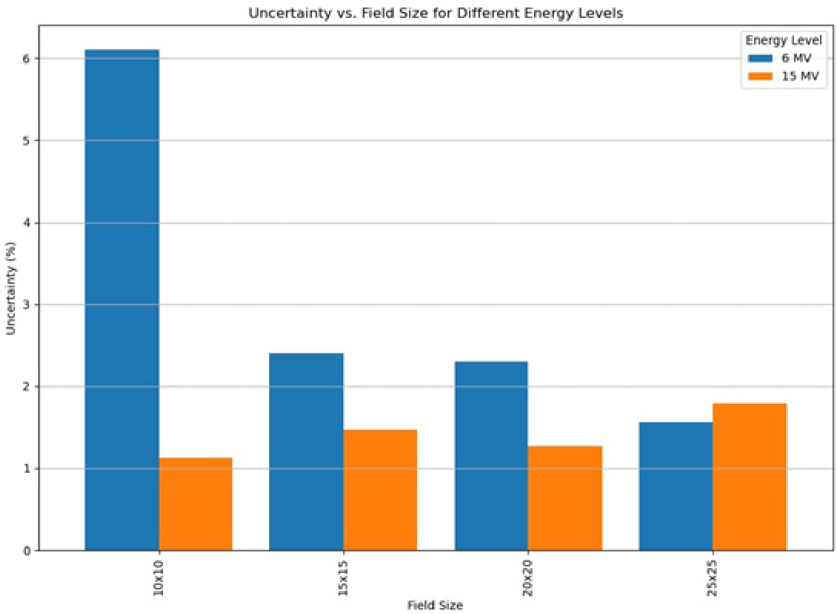

***Fig 6:** The relationship between uncertainty vs field size for different energy levels.*

From Fig. 6**,** the uncertainty for each measurement was calculated using the relative standard deviation formula. The uncertainty for Energy Level 6 MV is particularly high at the 10×10 field size is around (6%), whereas Energy Level 15 MV shows a much smaller uncertainty of around (~1%) at the same field size. This could indicate that smaller field sizes are more sensitive to variations or external factors, particularly at lower energy levels. For 15 MV measurements, the uncertainties are notably lower (< 2%), especially for larger field sizes. This suggests better stability and reduced variation in the dosimetric readings at higher energy levels.

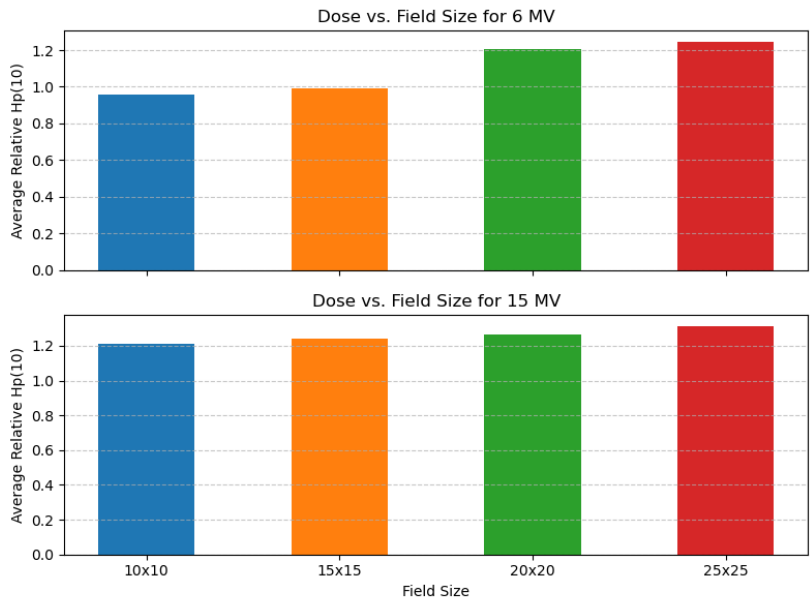

***Fig 7:** Average relative dose (Hp(10)) vs. field size at 6 MV and 15 MV energy levels*

From Fig. 7, as the field size increases from 10×10 to 25×25 concerning 6 MeV energy, the average relative dose increases. At 10x10, the relative dose is just below 1.0. And that of 25×25, the dose is just above 1.2. There is a notable increase in dose as the field size increases, suggesting that the 6 MV energy level becomes more effective or intense with larger fields.

For 15 MV, the dose values are relatively consistent across all field sizes. The relative dose remains near or slightly above 1.2 for all field sizes (10×10, 15×15, 20×20, and 25×25). This suggests that the 15 MV energy level provides a stable dose output regardless of field size, indicating less sensitivity to changes in field size compared to 6 MV.

4. DISCUSSION

From Fig. 3, at P1 (dashed blue lines): Both energies show increasing doses as the field size increases. However, the 15 MV dose (solid line) is consistently higher than the 6 MV dose (dashed line), indicating higher dose deposition at this position for the higher energy. At P2 (dashed green lines): The 6 MeV dose (dashed) shows a more noticeable increase between 15×15 and 20×20 field sizes, while 15 MeV (solid) has a steadier trend, with a small but consistent rise. And At P3 (purple lines), Doses are generally lower than at P1 and P2. Both energies show a gradual increase in dose as the field size increases, but the rise is more significant for the 6 MV dose.

P1 is likely closer to the high-dose region, indicating this position is subject to the most radiation. P2, being at the center, experiences a more uniform distribution of dose. P3 is farther away, resulting in lower doses compared to P1 and P2.

Larger field sizes (20×20 and 25×25) generally result in higher doses at all positions and energies, with more significant differences at 6 MV. For 6 MV at P2 and P3, there's a sharp rise in dose between 15×15 and 20×20, showing a non-linear response to field size changes. The field size significantly influences the dose, particularly for 6 MV radiation at P2 and P3.

This graph likely highlights how field size and energy level affect radiation dose distribution at different points, which is important in dosimetry and treatment planning.

The data suggests that both field size and energy level significantly impact the relative Hp (10) and the associated uncertainties. The central axis (P1) consistently records higher dose values, reflecting the expected dose distribution profile in therapeutic beams. Larger field sizes tend to exhibit more variation in Hp (10) across different positions due to the spread of the beam and increased scatter, particularly at lower energy levels.

The higher uncertainty at position P3 for 6 MV and larger field sizes may be attributed to edge effects, where the dosimeter is exposed to a region of rapidly changing dose gradients. In contrast, measurements at 15 MV show lower uncertainties, potentially due to the more uniform dose distribution associated with higher energy photon beams.

Understanding the variation in Hp (10) across different field sizes and energies is crucial for both radiation protection and therapy planning. The findings of this study suggest that while uncertainties remain low overall, particular attention should be paid to off-center positions, especially when using lower energy levels. The Hp (10) measurements at higher energy levels are more consistent, supporting their use in situations requiring higher accuracy. Higher photon energy (15 MV) results in higher and more uniform dose distributions compared to 6 MV**.** Larger field sizes significantly reduce dose variability, creating more homogeneous radiation fields, which is particularly important for minimizing over- or under-dosing in treatment areas. Smaller fields should be used with caution, as they introduce more variability at non-central positions, increasing the risk of uneven dose distribution, especially at the edges of the field.

5. CONCLUSION

The findings underline the vital role that these parameters play in determining the accuracy and consistency of dose delivery, particularly in clinical radiotherapy and radiation protection settings. It was observed that larger field sizes generally contributed to more uniform dose distributions, especially at the central position (P2), which showed the least variability across different configurations. Conversely, peripheral positions (P1 and P3) exhibited higher uncertainty levels, with the most significant variations occurring at smaller field sizes and lower energy levels, and as the field size increases, scattered dose also increases. These observations highlight the potential risks of under- or overdosing in off-center positions when using narrow beams or lower energy settings.

Moreover, the results demonstrated that higher energy photons produced more stable and homogeneous dose distributions across all positions and field sizes, suggesting their suitability for treatment scenarios demanding higher precision and deeper tissue penetration.

Overall, this work contributes valuable insights into the optimization of dosimetric practices.

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