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Effect of Radiation Position of Photon Beam at Axis Point and Field Edge on Absorbed Dose on Linear Accelerator (Linac)

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ABSTRACT

Radiotherapy is a medical treatment that uses ionizing radiation to kill cancer cells using a Linear Accelerator (Linac). One of the errors in radiotherapy irradiation can occur because the radiation beam that comes out is not in accordance with the planning. Therefore, radiation absorbed dose measurement is needed to carry out as a quality assurance to control the accuracy and suitability of the dose to be received by the patient by following the standards of the Technical Report Series (TRS) 398. This study was conducted at Radiotherapy Installation of RSUD A.W. SjahranieSamarinda. In the measurement of radiation absorbed dose, the detector was placed in the center of the water phantom with a certain depth and placed in an axis position perpendicular to the radiation source. The detector is not only placed in the axis position, but also placed on the 4 edges of the field with the aim of knowing the effect of the location of the detector on the absorbed dose on the Linac plane. Medium water phantom, Farmer type ionization detector with a depth of 10 cm, and radiation source distance to the phantom surface of 100 cm were applied in this study. The measurement deviation results at the axis position and 4 field edges are 0.01%, 0.06%, 0.03%, 0.05%, and 0.05%. These values are within the tolerance limits written in the IAEA TRS 398 protocol, which is ± 2%. This states that the radiation absorbed dose by the water phantom is homogeneous in all directions.

I. Introduction

Radiotherapy is a medical treatment that uses ionizing radiation to kill cancer cells. The principle of radiotherapy is to give a precise dose to a predetermined volume of cancer cells and reduce the dose to healthy tissue to a minimum [13]. One of the radiotherapy equipment used for cancer treatment, namely Linear Accelerator (Linac). Linac is a plane designed to accelerate the movement of electrons in a linear manner so as to produce photon beams and linear so that it can produce photon and electron beams [6]. Electron beam used for treatment on the surface of the body such as skin cancer, while photon beams is used for treatment inside the tissue, such as cervical, breast, and nasopharyngeal cancer [5].

Linac aircraft often experience output instability because Linac is made of a series of electronic devices. One of the errors in radiotherapy irradiation with Linac can occur because the radiation beam that comes out is not as planned. Therefore, the measurement of radiation dose in radiotherapy must be done precisely and according to the standard because it is very important to check the accuracy in giving the dose from the radiotherapy process. Linac aircraft output dose measurement is part of the Quality Assurance (QA) and Quality Control (QC) program at radiotherapy facilities[11]. Quality Assurance (QA) in radiotherapy aims to ensure that quality control procedures are adequate and implemented in accordance with planning [7]. Measurement of radiation absorbed dose is carried out as quality assurance to control the accuracy and suitability of the dose to be received by patients by following the standards of the Technical Report Series (TRS) 398

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protocol issued by the International Atomic Energy Agencyc (IAEA). This TRS 398 protocol recommends the use of parallel chip ionization detectors for electrons and cylindrical detectors for high energy photons with radiation beam measurements calibrated directly in water or water phantom [4]. Based on TRS 398, water is recommended as the reference medium for absorbed dose measurements for photon and electron beams. The phantom used should be 5 cm longer on all four sides than the field used and at least $5\ g/cm^2$ beyond the maximum measurement depth with a radiation irradiation field size on the phantom surface of (10×10) cm, and a radiation source distance to the phantom surface of 100 cm [2].

Puspitasari, et al. (2020) have conducted research on analyzing the quality of Linac radiation beams for radiotherapy effectiveness. The result is that in a photon beam with an energy variation of 6 MV, the output value per 1 MU is 0.9938 cGy with a measurement deviation of 1.173%. The quality of radiation beam output of Linac therapy aircraft at Dr. Ramelan Surabaya Naval Hospital is in accordance with the IAEA TRS 398 standard, which is still within the tolerance limit of ± 2%.

Sugiarta, et al. (2022) have conducted research on the analysis of the output dose of the Clinac Cx brand Linac aircraft X-ray beam based on the IAEA TRS 398 dosimetry protocol. The research was conducted with variations in X-ray energy, namely 6 MV and 10 MV. The size of the irradiation field used was (10 x 10) cm with a Source to Surface Distance (SSD) of 100 cm. From the measurement results obtained the output dose value at 6 MV energy, which is 1.00138 cGy / MU and at 10 MV energy, which is 0.99456 cGy / MU with the deviation obtained has met the tolerance limits of IAEA TRS 398.

Abrar, et al. (2022) have conducted research on verifying the radiation dose of 6 MV photon beam of Clinical CX type Linac aircraft using ionization booth detector. The measurement results show that the larger the irradiation field area, the smaller the radiation dose obtained. The results of verification of radiation dose in TPS with measured radiation dose, which is 0.076% to 0.584%, still meet the tolerance limits set by the IAEA TRS No.398 protocol, which is ± 2%.

Based on the description of previous studies, the researcher is interested in conducting research on measuring the radiation output of photon beams by adjusting the position of the detector, where the detector is not only placed in the axis position, but also placed on the 4 edges of the field. Then, the effect of the position of the detector location on the absorbed dose of photon radiation on the Linac aircraft was compared and calculated in accordance with the TRS 398 standard. The research was conducted at Radiotherapy Installation of RSUD A.W. Sjahranie Samarinda.

I. Method

This study was conducted using an Elekta brand Linac aircraft as a photon beam source with an energy of 6 MV. Measurements were made using a water phantom with a distance from the source to the surface (SSD) of 100 cm and using a Farmer type detector. The area of the irradiation field was 10 cm × 10 cm, which was carried out at the axis point and 4 edges of the field. The measurement results were calculated based on the IAEA TRS 398 protocol.

The tools used in this study are the Linear Accelerator (Linac) therapy plane as a source for generating photon radiation beams. Water phantom as a substitute for patients to measure radiation output beams. Farmer ionization detector is used to carry the dose received. Electrometer used to measure ionization charge. Thermometer and barometer as temperature humidity and pressure gauges. Computer Control Unit (CCU) is used to read the photon output on the Linac aircraft. Measurements were made based on the IAEA TRS No. 398 protocol [4]. Figure 1 shows the positioning of the radiation beam measurement on the water phantom in this study.

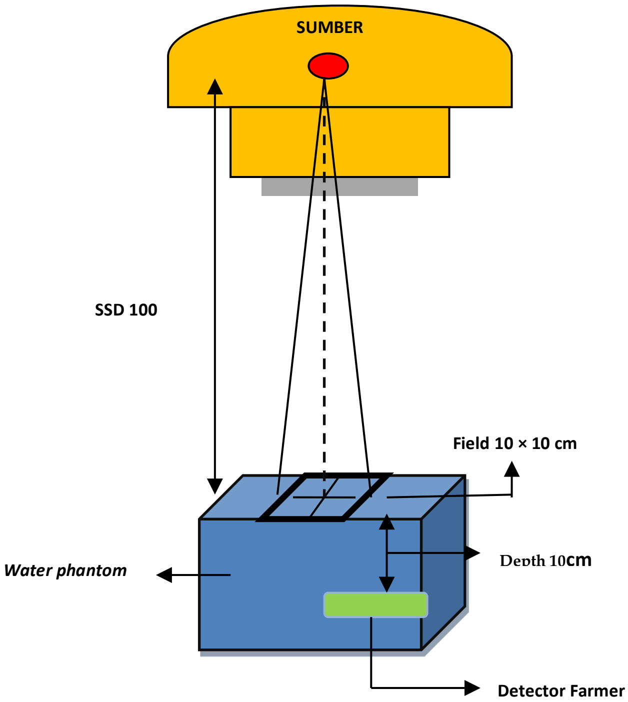

Fig. 1. Radiation beam measurement set up on water phantom

Based on IAEA TRS 398, the recommended ionization chamber in absolute measurement of electron beam output is a plane parallel ionization chamber, while the ionization chamber in absolute measurement of photon beam output is a farmer ionization chamber. The irradiation field area set at TRS 398 is (10 x 10) cm with a Source to Surface Distance (SSD) of 100 cm. Measurements in this study were carried out by adjusting the position of the detector at the axis point and the edge of the field. Measurements were made three times for each measurement position with voltage variations of +400 V, -400 V, and +100 V. Measurements using ionization detectors require a temperature and pressure correction factor (K_{TP}) to correct for changes in air mass inside the detector volume that changes due to ambient temperature and pressure.

Correction factors are required to determine the absorbed dose rate of the photon beam in water. Measurements are made according to the methods described in each TRS 398 protocol. These factors include:

a. The ionization detector response correction factor (K_{Q,Q_0}) is the response of the difference between the response of the ionization chamber in the beam quality used for detector calibration (Cobalt 60) to the photon beam quality.

b. Air pressure and temperature factor (K_{TP}) calculated using the equation:

$$K_{Tp} = \frac{(273.15 + T)P_0}{(273.15 - T_0)P} \tag{1}$$

K_{Tp} = The correction factor of pressure and temperature to the reference state

P_0 = 101.13 kPa

$T_0 = 20°C$

P =The ambient temperature of the room at the time of measurement

T = The ambient temperature of the room during measurement

c. The electrometer correction factor (K_{elec}) is the calibration factor of the electrometer which is 1, this means that the ionization chamber is calibrated together with the electrometer.

d. The polarity correction factor (K_{pol}) is calculated with the equation:

$$K_{pol} = \frac{|M_+| + |M_-|}{2M} \quad (2)$$

K_{pol} = The correction factor of the ionization dosimeter response to the effect of the polarity change given to the detector

M_+ = is the charge reading obtained at positive polarity $(+)$

M_- =is the charge reading obtained at negative polarity $(-)$

M =the charge reading obtained with polarity (positive or negative)

The value of M can be calculated using the equation:

$$M = \frac{dosimeter\ readings}{MU\ Dose} \quad (3)$$

e. The ion recombination correction factor (K_s) is derived using the two-voltage technique. K_s is calculated using the equation:

$$K_s = a_0 + a_1 \frac{(M_1)}{(M_2)} + a_2 \frac{(M_1)^2}{(M_2)} \quad (4)$$

where $a_0,\ a_{1,}a_2$ are constant values taken from Table 9.IV of IAEA TRS 398 and seen in table 2.1 [4].

The value reading on the ionization chamber (M_Q) can be determined by the following equation:

$$M_Q = M_1 K_{TP} K_{elec} K_{pol} K_s \quad (5)$$

with $M_Q$is the value reading in the ionization chamber corrected by the correction factor K_{TP}, $K_{pol,}K_s$ dan M_1 is the *chamber* response at standard pressure [3].

The equation used to measure the absorbed dose in water at the reference depth Z_{ref})follows:

$$D_{w,Q(Z_{ref})} = M_Q N_{DWQ_0} K_{Q,Q_0} \quad (6)$$

Where is the value of the absorbed dose in water in a beam of quality q (G_y/MU), N_{DWQ_0} is the detector calibration factor against the reference beam, and $M_Q$is the dosimeter reading at voltage and $K_{Q,Q_0}$is the correction factor for the detector radiation quality [4].

After determining the absorbed dose at the reference depth, the absorbed dose in water at the maximum depth can be calculated using the following equation:

$$D_{w,Q}(Z_{\max}) = \frac{100 D_{w,Q}(Z_{ref})}{PDD(Z_{ref})} \quad (7)$$

Where $D_{w,Q}(Z_{ref})$ is the absorbed dose at the reference depth and $PDD(Z_{ref})$is the percentage value for measurement at depth. Determination of the X-ray beam output at maximum depth aims to set the *monitor detector* reading in MU units so that 1 cGy is equal to 1 MU [10]. The deviation in the measurement of the radiation output beam is calculated using equation (8)

$$Deviation \ = \frac{D_{w,Q}(Z_{\max}) - \ MU\ Dose}{MU\ Dose} \times 100\% \quad (8)$$

with $D_{w,Q}(Z_{\max})$is the absorbed dose at maximum depth [4].

II. Results and Discussion

The measurement results of the average amount of photon beam charge at voltages $+400$V, -400V and$+100$ V obtained were used to calculate the correction factor. The polarity correction factor (K_{pol}) is determined using the average value of the charge at voltages $+400$ V and -400V using Equation (2). The ion recombination correction factor (K_s) is determined using the average value of the charge at voltages V and V with Equation (4). Based on Table 1, the values of the correction factors, namely temperature and pressure correction factor (K_{Tp}), polarity correction factor (K_{pol}), electrometer calibration factor (K_{elec}), ion recombination correction factor (K_s) and photon beam quality correction factor (K_{Q,Q_0}) are obtained for each measurement point.

Table 1. Result of Correction Factor Calculation.

No	Correction Factor	Detector Position				
		Axis	C1	C2	C3	C4
1	K_{TP}	0,99519	0,99519	0,99519	0,99519	0,99519
2	K_{elec}	1	1	1	1	1
3	K_{pol}	1,00078	1,00041	1,0000	1,00078	0,99918
4	K_s	1,00212	1,00223	1,00221	1,00195	1,00275
5	$K_{Q,Q0}$	0,989	0,989	0,989	0,989	0,989

The temperature and pressure correction factor values (K_{Tp})calculated by comparing the temperature and pressure at the time of measurement with the standard state. Temperature and pressure measurements were only taken once before irradiation, so the temperature and pressure values in each measurement were the same, namely at a temperature value 20,3°C and a pressure value of 101.9 kPa. For the calculation of temperature and pressure correction factor values (K_{Tp}) using equation (2). The value of the ion recombination correction factor (K_s) has a different value for each measurement point. This is due to the value of the number of photon beam charges that are read at voltages$+400$ V and $+100$V. Furthermore, the value of the electrometer calibration factor(K_{elec}) is 1. This is because the ionization chamber is calibrated together with the electrometer.

The results of the calculation of the correction factor obtained show that the results of the correction factor in this study are not far from the results of Puspitasari, et al. (2020) and Abrar, et al. (2022). All correction factor values on the photon beam that have been obtained are 1. This shows that the value of the correction factors is in accordance with IAEA TRS No.398. Furthermore, the values of the correction factors obtained are used for the calculation of the photon radiation beam output. Measurement of photon radiation beam output on Linac aircraft using a dose of 100 MU at a depth of 10 cm with a field area of 10×10. The results of absorbed dose measurements in water at maximum depth and reference depth can be seen in Table 2.

Table 2. Result of Correction Factor Calculation

Position	M_Q	$D_{w,Q}(Z_{\text{ref}}))$	$D_{w,Q}(Z_{\max})$
Axis	0,12775	0,00675	99
C1	*0,12153*	0,00642	94
C2	0,12267	0,00649	96
C3	0,12184	0,00644	95
C4	0,12204	0,00645	95

Based on Table 2. For values M_Q that are the results of ionization *chamber* readings corrected by the correction factor K_{TP}, while $K_{pol,}K_s$ and M_1 are the total *chamber* response at standard pressure. The resulting value is different because the charge value used is different. The value of M_Q is obtained using equation (5). $D_{w,Q}(Z_{\text{ref}})$ is the absorbed dose in the water at the reference depth which can be calculated using equation (6). $D_{w,Q}(Z_{\max})$ is the absorbed dose at the maximum depth which is calculated using equation (7). Table 3 shows the calculation results of the deviation in the photon beam.

Table 3. Deviation Calculation Results on Photon Beam Output

Position	Deviation (%)	Standar IAEA TRS 398
Axis	0,01	±2%
C1	0,06	±2%
C2	0,03	±2%
C3	0,05	±2%
C4	0,05	±2%

The deviation values obtained in the measurement *axis*, C1, C2, C3 and C4 are respectively. According to the IAEA TRS 398 protocol, the radiation dose deviation between the MU dose calculation and the measurement radiation dose does not exceed the tolerance limit, which is. The photon beam output results that have been obtained at 6 MV energy show that the results of this study are not much different from the results of Puspitasari, et al. (2020) and Abrar, et al. (2022). C1, C2, C3 and C4 are the detector positions at the edge of the field. C1 is placed in the upper left corner, C2 is placed in the upper right corner, C3 is placed in the lower left corner and C4 is placed in the lower right corner of the *water phantom*. Figure 2 shows the graphical results of the comparison of absorbed dose to MU dose.

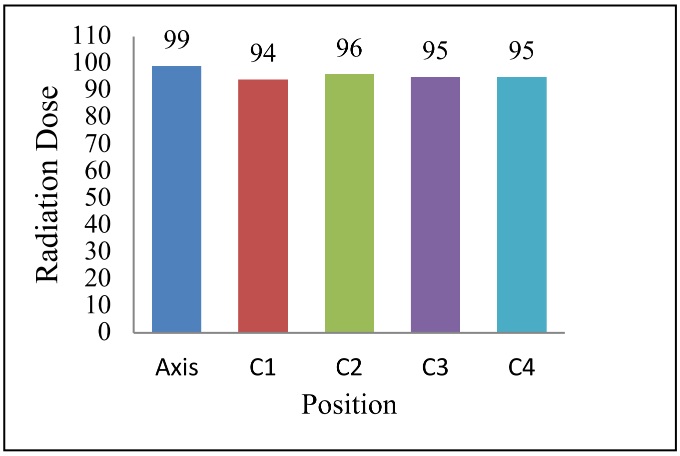

Fig. 2. Comparison Chart Result of Radiation Absorption Dose to MU Dose

Figure 2 shows the comparison of the absorbed dose obtained from measurements using a *water phantom* with the radiation dose in the monitor unit (MU) used as a reference in the measurement, which is 1 cGy/MU. Suharmono, et al. (2020) mentioned that the output of the *water phantom* shows the output of the Linac aircraft during use with reference to the value of 1 cGy equivalent to 1 MU. The radition dose on the monitor unit used in this study is 100 MU. The resulting absorbed dose at the *axis*, C1, C2, C3 and C4 positions is 99, 94, 96, 95 and 95 cGy, respectively.

The graph in Figure 2 shows that the absorbed dose results obtained at each measurement position have a value that is not far from the radiation dose on the monitor unit (MU). This shows that the position of the detector does not affect the absorbed dose results because it is still within the TRS

398 tolerance limit. Therefore, measurements for radiation absorbed dose can be done not only at the *axis* point, but can also be done at the edge of the field.

Another factor is that the difference in absorbed dose produced can be due to differences in the charge of the photon beam being read. According to Ramona, et al. (2020), when irradiating there is a difference between pressing the *beam on* button on the Linac computer and the *start* button on the electrometer, thus affecting the charge read by the detector. This difference is because the operator on the Linac computer is different from the operator on the electrometer.

III. Conclusion

This study produces radiation absorption doses that are not much different for the axis and field edge measurement positions. The position of the detector placed at the axis and the edge of the field produces absorbed dose values that are not much different and are still within the tolerance limits of the IAEA TRS 398, which is ±2%.

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