

Comparative Analysis of Absolute Dosimetry of a Varian 2300iX LINAC for Photon and Electron Beams Using IAEA TRS-398 Rev. 1

Sovi Anggraini Armita Dewi¹, Primasari Cahya Wardhani², Arie Chintya Martania³

^{1,2} Department of Physics, Universitas Pembangunan Nasional “Veteran” Jawa Timur, Surabaya, Indonesia, 60294.

³ Radiation and Radiotherapy Measuring Instrument Calibration Installation, Center for safety of Medical Devices and Health Facilities (BPAFK) Surabaya, Surabaya, Indonesia, 60286

Article Info	ABSTRACT
Article History: Received 09 14, 2026 Revised 10 09, 2026 Accepted 10 13, 2026 Published 10 16, 2026 Keywords: Absolute dosimetry, Varian 2300iX LINAC, IAEA TRS-398 Rev. 1, Radiotherapy, Quality assurance Corresponding Author: Primasari Cahya Wardhani, Email: primasari.cahya.fisika@upnjati.ac.id	<i>Accurate dosimetry plays a crucial role in radiotherapy by ensuring that radiation output is delivered in accordance with the prescribed dose under standardized measurement conditions. This research investigated the absolute dose output of a Varian 2300iX linear accelerator operating at 6 MV for photon beams and 6 MeV for electron beams, following the IAEA TRS-398 Rev. 1 dosimetry protocol. Measurements were carried out in a water phantom using a PTW 30013 Farmer ionization chamber for photon dosimetry and a PTW 34045 Advanced Markus chamber for electron dosimetry. Both beam types were assessed with a 10 × 10 cm² field size and a monitor unit setting of 200 MU under reference conditions. The absorbed dose to water was calculated by incorporating the relevant temperature-pressure, polarity, ion recombination, and beam-quality correction factors. Prior to adjustment, the photon and electron beams produced dose outputs of 1982.9 cGy and 1988.0 cGy, respectively, representing deviations of −0.860% and −0.600% from the reference dose. Following adjustment, the corresponding outputs increased to 1999.5 cGy for photons and 2004.0 cGy for electrons, with reported deviations of −0.027% and +0.190%, respectively. Both post-adjustment results satisfied the ±2% tolerance criterion adopted in this investigation. These findings demonstrate improved agreement between the measured outputs and the reference dose for the tested beams. However, the conclusions are specific to the accelerator, beam energies, and measurement setup investigated in this study.</i> Copyright © 2026 Author(s)

1. INTRODUCTION

Radiotherapy is an established treatment modality in cancer management that employs ionizing radiation to control or eliminate malignant cells. The effectiveness of radiotherapy depends substantially on the accuracy with which the prescribed radiation dose is delivered to the target volume while limiting unnecessary exposure to surrounding healthy tissues. Consequently, accurate determination and verification of radiation output are fundamental components of a radiotherapy quality assurance program. Even relatively small discrepancies between the prescribed and delivered dose can influence treatment effectiveness and the protection of normal tissues (Bugani et al., 2024).

The development of linear accelerator (LINAC) technology has enabled radiotherapy facilities to deliver photon and electron beams with controlled energy and dose characteristics.

The Varian 2300iX is one of the LINAC systems used to generate therapeutic photon and electron beams. In this study, a 6 MV photon beam and a 6 MeV electron beam were evaluated. Photon beams at megavoltage energies are commonly used for irradiation of targets located at greater depths because of their relatively high penetration, whereas electron beams are generally applied to superficial targets because their dose decreases more rapidly beyond a certain depth. These differences in radiation transport and depth-dose characteristics require beam-specific dosimetric verification and appropriate detector selection (Al-saleh & Almatani, 2025).

Absolute dosimetry is performed to determine the absorbed dose to water under defined reference conditions. The measurement generally employs an ionization chamber connected to an electrometer, with the detector calibrated against a traceable standard. The measured electrical charge must be corrected for factors that influence detector response, including temperature and pressure, polarity, ion recombination, and beam quality. The corrected measurement is subsequently used to determine absorbed dose to water and to establish the radiation output of the LINAC. Therefore, absolute dosimetry provides an important reference for verifying the stability and accuracy of therapeutic radiation output. Recent studies have demonstrated that ionization chamber arrays can support routine linear accelerator dosimetry quality assurance, with measurement accuracy depending on detector settings and beam characteristics (Taneja & Barbee, 2024).

The International Atomic Energy Agency (IAEA) provides an international code of practice for reference dosimetry in external beam radiotherapy through TRS-398. The revised edition, IAEA TRS-398 Rev. 1, provides an updated framework for determining absorbed dose to water using calibrated ionization chambers. The application of the revised protocol requires appropriate consideration of beam quality, detector characteristics, reference conditions, and correction factors. Therefore, studies that apply the revised edition should distinguish their implementation from measurements performed using earlier editions of the protocol ("International Atomic Energy Agency," 2024).

Previous studies have reported the use of reference dosimetry to evaluate LINAC output and support radiotherapy quality assurance. However, the present study focuses specifically on the application of IAEA TRS-398 Rev. 1 to a Varian 2300iX system and examines both photon and electron beams under reference measurement conditions. In addition, the study evaluates the dose-output values before and after an output adjustment. This before-and-after assessment provides a direct comparison of the measured output under the two operating conditions. The study is therefore intended as a dosimetric evaluation of the investigated LINAC rather than as a comprehensive assessment of the entire clinical quality assurance program.

The measurements were conducted during an internship period in February 2026 at a radiotherapy installation in Central Java. The identity of the institution is anonymized in this article to protect operational information and comply with the relevant publication policy. The measurement data were obtained from an operating clinical radiotherapy system and were analyzed using the reference dosimetry procedure described in IAEA TRS-398 Rev. 1.

The objective of this study was to determine and compare the absolute dosimetry results of 6 MV photon and 6 MeV electron beams generated by a Varian 2300iX LINAC using the IAEA TRS-398 Rev. 1 protocol. The analysis includes the relevant dosimetric correction factors, absorbed dose to water, dose output, and percentage deviation before and after output adjustment. The results are intended to document the dosimetric behavior of the investigated

beams under the measurement conditions used in this study and provide supporting information for routine radiotherapy quality assurance.

2. METHOD

2.1. Study Location and Equipment

The measurements were carried out at the radiotherapy installation of a hospital in Central Java, Indonesia. To maintain institutional confidentiality, the facility is identified as Hospital X. The measurements were conducted on a Varian 2300iX linear accelerator using reference dosimetry equipment appropriate for photon and electron beams.

Table 1. Research Equipment

Equipment	Specification
Linear Accelerator	Varian 2300iX
Water Phantom	Material PMMA
Farmer Ionization Chamber	PTW 30013 (0.6 cc)
Advance Markus Chamber	PTW 34045
Electrometer	PTW Unidos Webline
Thermometer	MedgeTech PRHTemp2000
Barometer	Greisinger GMH
Computer	-

2.2. Measurement Produce

Absolute dosimetry measurements were conducted using the reference-dose-to-water methodology outlined in IAEA TRS-398 Revision 1. For each beam, the ionization chamber was placed in the water phantom in accordance with the specified reference measurement geometry. The LINAC was operated with a nominal delivery of 200 MU, an SSD of 100 cm, and a field size of 10 × 10 cm², following the measurement conditions documented in the original measurement record.

For the 6 MV photon beam, a Farmer-type ionization chamber was employed for reference dosimetry. Measurements were carried out at depths of 10 cm and 20 cm to determine the beam-quality parameters needed to calculate the photon beam-quality correction factor. The chamber readings were recorded using an electrometer, and the temperature and pressure were monitored during irradiation.

For the 6 MeV electron beam, an Advanced Markus ionization chamber was placed at the designated electron reference depth. Beam quality was assessed using the R₅₀ parameter, and the corresponding beam-quality correction factor was calculated in accordance with the relevant procedure outlined in IAEA TRS-398 Revision 1. Based on the original measurement dataset, the electron reference depth was 1.33 cm, and the measured R₅₀ value was 2.39 cm.

For each measurement condition, three electrical-charge readings were acquired. The repeated readings were used to determine the mean chamber response. Measurements at different polarities or voltages were treated as measurements for determining the corresponding correction factors and were not interpreted as independent repeatability measurements.

The ionization chamber readings were corrected by applying the relevant correction factors in sequence, including the temperature–pressure correction factor (k_{TP}), polarity correction factor (k_{pol}), ion recombination correction factor (k_s), electrometer calibration factor (k_{elec}), and beam-quality correction factor (k_Q). The resulting corrected reading was then used to determine the absorbed dose to water. Finally, the measured dose output was compared

with the prescribed reference dose, and the percentage deviation was calculated to evaluate the accuracy of the dose output.

The general measurement sequence consisted of preparing the LINAC and dosimetry system, establishing the reference geometry, positioning the appropriate ionization chamber, recording temperature and pressure, acquiring electrical-charge readings, determining the required correction factors, calculating the corrected chamber response, determining absorbed dose to water, and calculating the deviation from the reference dose. (Akter et al., 2022).

Three measurements were performed for each condition to obtain the mean electrical charge reading. The mean value was then used as the basis for calculating correction factors and absorbed dose to water.

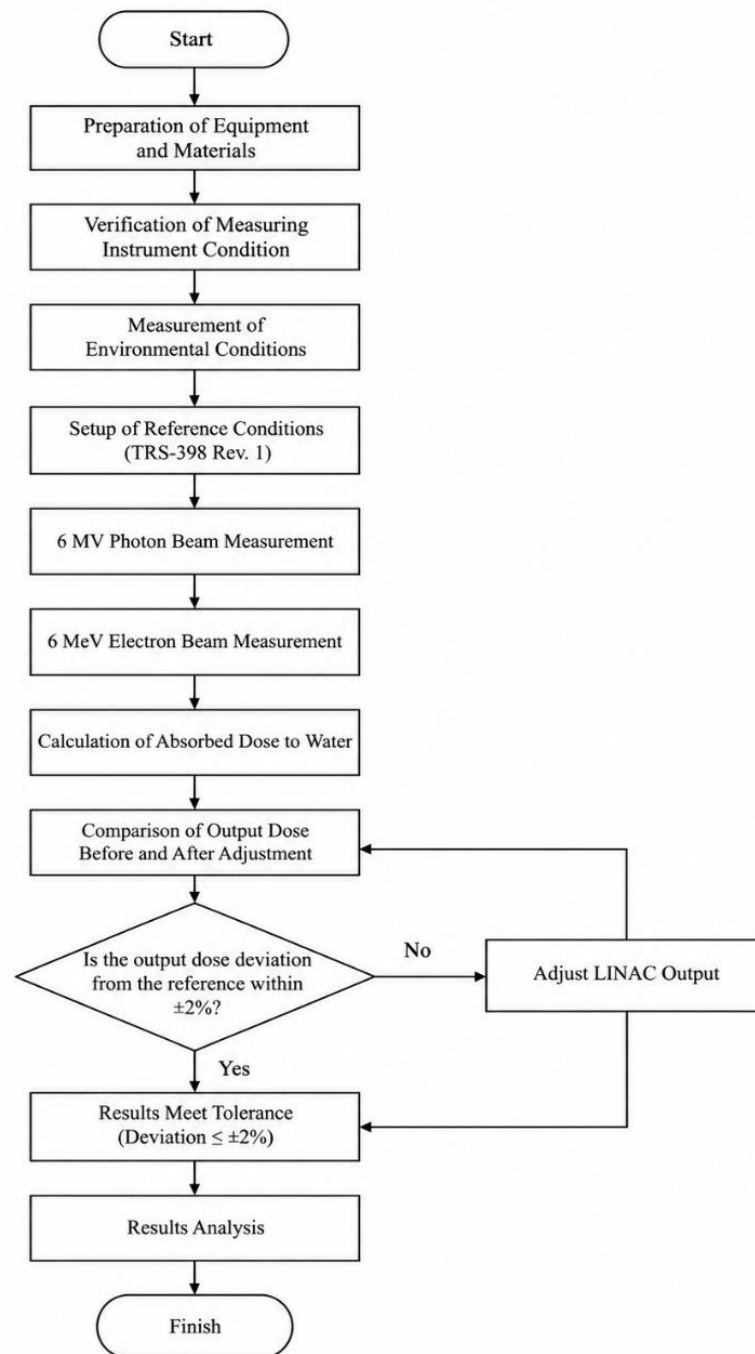


Figure 1. Flowchart of the Absolute Dosimetry Measurement Method

2.3. Data Analysis

The measurement data were evaluated in accordance with the International Atomic Energy Agency (IAEA) TRS-398 Revision 1 protocol. The electrical charge readings obtained from the ionization chamber were initially corrected for environmental influences and detector-related effects before being applied to the calculation of absorbed dose to water. The calibration coefficient and beam quality used for ionization chamber dosimetry can influence the agreement between measured absorbed doses for photon and electron beams, highlighting the importance of appropriate calibration procedures in reference dosimetry (Tani et al., 2024).

The temperature–pressure correction factor (k_{TP}) accounts for variations in the ionization chamber response resulting from changes in ambient temperature and atmospheric pressure during measurements. As described by (Sulistiana et al., 2024), (Kawurung et al., 2018), and (Sugiarta et al., 2022), this correction factor can be calculated using the following equation:

$$k_{TP} = \frac{273.15 + T}{293.15} \times \frac{101.325}{P} \quad (1)$$

Polarity Factor:

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

Ion Recombination Factor

$$k_s = a_0 + a_1 \left(\frac{M_1}{M_2} \right) + a_2 \left(\frac{M_1}{M_2} \right)^2 \quad (3)$$

Beam Quality Factor

$$D_{w,Q} = M_Q N_{D,w,Q_0} k_Q \quad (4)$$

For photons

$$k_Q = f(TPR_{20,10}) \quad (5)$$

For electrons

$$k_Q = f(R_{50}) \quad (6)$$

2.4. Statistical Analysis

The measurements were evaluated descriptively using the individual chamber readings, mean value, standard deviation, coefficient of variation, correction factors, absorbed dose, and percentage deviation. For each unchanged measurement condition, the repeated readings were considered when evaluating measurement repeatability.

The before-and-after results were compared to determine the change in dose output associated with the documented adjustment. The observed deviation was then considered in relation to the applicable output tolerance criterion used in the study. The interpretation was limited to the measured beam energies and reference conditions and was not extended to the performance of the entire clinical radiotherapy system.

The uncertainty value reported in the original manuscript was $\pm 1.5\%$. However, because the original manuscript does not provide a complete uncertainty budget, including individual contributions from repeatability, chamber calibration, positioning, environmental

corrections, and beam-quality conversion, this value should be verified against the original uncertainty calculation before publication. Similarly, the uncertainty should be explicitly identified as standard or expanded uncertainty, together with its coverage factor and associated confidence level (“International Atomic Energy Agency,” 2024).

3. RESULTS AND DISCUSSION

3.1. Electrical Charge (nC) and Deviation (%) of the 6 MV Photon Beam

Measurements of the 6 MV photon beam were carried out under reference conditions using a PTW 30013 Farmer-type ionization chamber. The measurements were performed at depths of 10 cm and 20 cm, with a field size of 10 × 10 cm² and a source-to-surface distance (SSD) of 100 cm. The recorded charge readings were corrected using the temperature–pressure correction factor (k_{TP}) to compensate for variations in ambient temperature and atmospheric pressure. The results showed a slight increase in the corrected charge values compared with the uncorrected readings, reflecting the adjustment for environmental conditions.

Table 2. Measurement Result of Electrical Charge for the 6 MV Photon Beam

Depth	Electrical Charge (nC)	Voltage (V)	Temperature (°C)	Pressure (hPa)	k_{TP}	Corrected Charge (nC)
20 cm	14,376	+400	21,6	1011,3	1,00623	14,466
10 cm	25,194	+400	21,6	1011,4	1,00613	25,344
10 cm	25,020	+100	21,5	1011,3	1,00589	25,170
10 cm	25,232	−400	21,5	1011,3	1,00589	25,382

Table 2 presents the electrical charge measurements obtained from the 6 MV photon beam using the PTW 30013 Farmer ionization chamber. Measurements were conducted at depths of 10 cm and 20 cm using an SSD of 100 cm and a 10 × 10 cm² irradiation field. The electrical charge measured at 10 cm was higher than the value obtained at 20 cm. At 10 cm depth, the charge measured at +400 V was 25.194 nC, whereas the measurement at 20 cm produced 14.376 nC. The temperature and pressure values were recorded during each measurement and were used to determine the reported k_{TP} correction factor. The k_{TP} values listed in the table ranged from 1.00589 to 1.00623, indicating that an environmental correction was applied to the chamber readings. Measurements at +100 V and −400 V were also performed to evaluate the polarity response of the ionization chamber (Choi et al., 2023).

Table 3. Correction Factors for the 6 MV Photon Beam

Correction Factor	Value
k_{TP}	1,000
K_{elec}	1,000
K_{pol}	1,0006
K_s	1,0023
k_Q	0,9901

Table 3 summarizes the correction factors used in the absolute dosimetry calculation for the 6 MV photon beam. The reported values were 1.000 for k_{TP} , 1.000 for k_{elec} , 1.0006 for k_{pol} , 1.0023 for k_s , and 0.9901 for k_Q . The polarity correction factor indicates a relatively small correction associated with the operating polarity of the ionization chamber. Similarly, the reported ion recombination factor indicates a small correction to account for charge losses during ion collection. The k_Q value was incorporated into the absorbed-dose calculation to account for the beam-quality dependence of the ionization chamber response. These correction

factors were combined with the measured chamber response to determine the absorbed dose to water. Therefore, Table 3 provides the correction parameters required for the subsequent absolute dosimetry calculation (Suharmono et al., 2020).

Table 4. Absolute Dosimetry Calculation Result for the 6 MV Photon Beam

Condition	MQ (nC)	Dw,Q (Zref) (cGy)	Dw,Q (Zmax) (cGy)	Deviation (%)
Before Adjustment	24,970	1327,8	1982,9	-0,86
After Adjustment	25,175	1338,9	1999,5	-0,027

Table 4 shows the absolute dosimetry results obtained for the 6 MV photon beam before and after adjustment. Before adjustment, the measured charge was 24.970 nC, producing an absorbed dose of 1327.8 cGy at the reference depth and 1982.9 cGy at the maximum-dose depth. The corresponding dose-output deviation before adjustment was reported as -0.860%. After adjustment, the measured charge increased to 25.175 nC, while the calculated doses increased to 1338.9 cGy and 1999.5 cGy, respectively. The reported deviation after adjustment was -0.027%, indicating closer agreement between the measured output and the reference value. The change in deviation shows that the adjustment altered the measured dose output under the conditions evaluated in this study. However, the post-adjustment photon deviation must be verified because the abstract and conclusion of the original manuscript report -0.050% rather than -0.027%.

3.2. Electrical Charge (nC) and Deviation (%) of the 6 MeV Electron Beam

Table 5. Measurement Result of Electrical Charge for the 6 MeV Electron Beam

Depth Referensi	Electrical Charge (nC)	Voltage (V)	kTP	Muatan Terkoreksi (nC)
1,33 cm	1,543	+300	1,006	1,552
1,33 cm	1,531	+75	1,006	1,540
1,33 cm	1,548	-300	1,006	1,557

Table 5 presents the electrical charge measurements obtained for the 6 MeV electron beam using the PTW 34045 Advanced Markus chamber. The measurements were performed at a reference depth of 1.33 cm under three different polarization voltages. The recorded charge values were 1.543 nC at +300 V, 1.531 nC at +75 V, and 1.548 nC at -300 V. After applying the reported kTP correction, the corresponding corrected charge values were 1.552 nC, 1.540 nC, and 1.557 nC. The differences among the measured charge values were relatively small under the applied voltage conditions. These measurements were used to characterize the chamber response and determine the correction factors required for the absolute dosimetry calculation. The resulting charge values were subsequently used to calculate the absorbed dose to water for the 6 MeV electron beam (Kurnianto et al., 2023).

Table 6. Correction Factors for the 6 MeV Electron Beam

Correction Factor	Value
kTP	1,000
Kelec	1,000
Kpol	1,0018
Ks	1,0031
kQ	0,9395

Table 6 summarizes the correction factors applied to the 6 MeV electron beam measurement. The reported values were 1.000 for kTP, 1.000 for kelec, 1.0018 for kpol, 1.0031 for ks, and 0.9395 for kQ. The polarity correction factor indicates a relatively small correction associated with the chamber operating polarity. The ion recombination factor was also close to unity, indicating that only a small correction was applied for ion recombination under the measurement conditions. The beam-quality correction factor kQ was determined using the reported R50 value of 2.39 cm. These correction factors were subsequently incorporated into the calculation of absorbed dose to water for the electron beam. The resulting values provided the basis for determining the absolute dose output reported in Table 7.

Table 7. Absolute Dosimetry Calculation Result for the 6 MeV Electron Beam

Condition	MQ (nC)	Dw,Q (Zref) (cGy)	Dw,Q (Zmax) (cGy)	Deviation (%)
Before Adjustment	1,543	1325,4	1988,0	-0,60
After Adjustment	1,555	1336,0	2004,0	0,190

Table 7 presents the absolute dosimetry results obtained for the 6 MeV electron beam before and after adjustment. Before adjustment, the measured charge was 1.543 nC, corresponding to 1325.4 cGy at the reference depth and 1988.0 cGy at the maximum-dose depth. The reported deviation before adjustment was -0.600% . After adjustment, the measured charge increased to 1.555 nC, while the calculated doses increased to 1336.0 cGy and 2004.0 cGy, respectively. The post-adjustment deviation was reported as $+0.190\%$. The change in deviation indicates that the measured output became closer to the reference value after the adjustment under the tested conditions. The relationship between the reference-depth dose and maximum-dose dose should nevertheless be supported by the corresponding depth-dose measurement or calculation described in the methodology.

3.3. Comparasion of Absolute Dosimetry for Photon and Electron Beams

Based on the measurement results obtained, the analysis focused not only on the absorbed dose to water and dose-output deviation, but also on comparison with previous studies that used the same dosimetry protocol. This comparison is important for evaluating the consistency of the results, identifying similarities and differences, and providing a scientific interpretation of the factors affecting the measurements. (Farrokhkish et al., 2024) demonstrated that a transmission ion chamber system can be used for routine quality assurance of photon beams, with beam-output constancy measurements showing agreement within 0.1% of measurements obtained using a conventional Farmer-type ionization chamber for typical output variations. Thus, the validity of the measurement method and the application of the IAEA TRS-398 Rev.1 protocol in this study can be assessed more comprehensively.

Table 8. Comparasion of Absolute Dosimetry Result

Parameter	6 MV Photon	6 MeV Electron
Detector	Farmer Chamber 0.6 cc	Advanced Markus Chamber
Depth Referensi	10 cm (TPR20,10)	1,33 cm (R50)
Beam Quality Factor (kQ)	0,9901	0,9395
Dw,Q Before Adjustment (cGy)	1982,9	1988,0
Dw,Q After Adjustment (cGy)	1999,5	2004,0
Deviasi Before Adjustment (%)	-0,86	-0,60
Deviasi After Adjustment (%)	-0,027	0,190
Measurement Uncertainty (%)	$\pm 1,5$	$\pm 1,5$
QA Tolerance Limit (%)	$\pm 2\%$	$\pm 2\%$

Table 8 compares the absolute dosimetry results obtained from the 6 MV photon and 6 MeV electron beams. The photon beam was measured using the PTW 30013 Farmer chamber at a reference depth of 10 cm, while the electron beam was measured using the PTW 34045 Advanced Markus chamber at a reference depth of 1.33 cm. The reported kQ values were 0.9901 for the photon beam and 0.9395 for the electron beam. Before adjustment, the reported dose outputs were 1982.9 cGy for the photon beam and 1988.0 cGy for the electron beam. After adjustment, the corresponding values increased to 1999.5 cGy and 2004.0 cGy, with reported deviations of -0.027% and $+0.190\%$, respectively. Both reported deviations were within the $\pm 2\%$ tolerance used in the original study. The results should be interpreted as measurements of the absolute dose output under the specific experimental conditions rather than as a comprehensive evaluation of long-term LINAC performance or all clinical QA parameters.

Absolute dosimetry is closely related to fundamental concepts in physics, particularly radiation physics, atomic physics, electromagnetism, and nuclear physics. Radiation dose measurement uses the principle of interaction between ionizing radiation and matter, which produces ionization within the air cavity of an ionization chamber. The resulting electrical charge is then measured using an electrometer to determine the radiation dose. In addition, correction factors such as temperature and pressure are based on the ideal gas law, which explains changes in air density as a function of environmental conditions. Thus, the entire dosimetry process is a direct application of physical concepts in healthcare to ensure radiation-dose accuracy and patient safety in radiotherapy (Hasanah et al., 2020).

The stable dosimetric parameters, which were close to their ideal values, further support that the absolute dosimetry measurements on the Varian 2300iX LINAC were performed in accordance with the procedures recommended in the IAEA TRS-398 Rev.1 protocol. Correction factors close to one and dose-output deviations within the tolerance limit indicate that the LINAC system has good dosimetric performance and is suitable for use in radiotherapy services. These findings indicate that periodic absolute dosimetry plays an important role in maintaining dose-output accuracy and supporting the radiotherapy Quality Assurance (QA) program ("International Atomic Energy Agency," 2024) (Meaze et al., 2021).

4. CONCLUSION

This study successfully carried out absolute dosimetry measurements on a Varian 2300iX linear accelerator (LINAC) for 6 MV photon and 6 MeV electron beams in accordance with the IAEA TRS-398 Revision 1 protocol. All measurements were conducted under reference conditions using a water phantom, a PTW 30013 Farmer ionization chamber, a PTW 34045 Advanced Markus chamber, and a calibrated electrometer. The application of the temperature-pressure (k_{TP}), polarity (k_{pol}), ion recombination (k_s), and beam-quality (k_Q) correction factors enabled the determination of absorbed dose to water following the standardized dosimetry methodology. The results demonstrate the applicability of the TRS-398 Rev. 1 protocol as a standardized and traceable framework for ionization chamber dosimetry and absorbed-dose-to-water determination in external beam radiotherapy.

The measurement results showed that before adjustment, the dose-output deviation was -0.860% for the 6 MV photon beam and -0.600% for the 6 MeV electron beam. After adjustment, the deviations decreased to -0.050% for the photon beam and 0.190% for the electron beam. The reduction in deviation indicates that the output adjustment successfully improved the agreement between the LINAC-generated dose and the reference dose. All deviations were within the $\pm 2\%$ tolerance limit, indicating that the system still met dosimetric requirements for clinical radiotherapy services in accordance with IAEA recommendations.

Correction factors that were all close to one indicate that the measurement environment, ionization chamber characteristics, and beam quality were in good condition,

resulting in a low contribution to measurement uncertainty. In addition, the stability of ionization chamber readings in repeated measurements indicates that the Varian 2300iX LINAC has good radiation-output reproducibility. This condition indicates that the system can still produce consistent radiation doses and thereby support radiotherapy with a high level of accuracy.

Clinically, these results confirm that periodic absolute dosimetry is an important part of a radiotherapy Quality Assurance (QA) program. Routine verification of dose output allows deviations to be detected at an early stage so that corrective action can be taken before they affect patient treatment. Thus, implementation of the IAEA TRS-398 Rev.1 protocol not only improves the reliability of LINAC calibration, but also contributes to patient safety, dose-delivery accuracy, and the overall quality of radiotherapy services.

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