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Research Article

Practically Achievable Accuracy and Uncertainties Estimation in Radiation Dose Measurement with Different Protocols

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Abstract

Aims: This study aimed to determine the degrees of accuracy that are practically achievable in dose measurement with reference to the international protocols and estimated the associated uncertainties.

Material and Method: Experiments were performed on Varian linac with 5 photon energies; 6, 10, 15 MV, and 6, 10, MV Flattening Filter Free. Tissue phantom ratio (TPR20,10), percent depth dose (%DD) were measured and calculated, while beam profile was only measured. Measurements for range of field sizes and depths were carried out in water with Farmer and Semiflex chambers.

Results: The measured $TPR_{20,10}$ values were in agreement with calculations, where percentage error was found to be < 0.6% for all energies. The absorbed dose to water (D_w,Q) at z_{max} according to Task Group (TG)-51, and Technical Reports Series (TRS)-398 protocols was in good agreement with an average discrepancy of <0.2%. The observed discrepancies were thought to be associated with procedures and equipment used. The percentage difference between monitor units (MUs) delivered by linac and MUs calculated by Treatment Planning System (TPS) at 5 and 10 cm depths for various field sizes were found to be within ± 5% tolerance limit. The measured %DD are consistent with calculations from TPS. The relative standard uncertainty of $D_{w,Q}$ at reference depth in water, was also found as ±<2.0%.

Conclusion: Overall, the results of measured parameters were in acceptable agreement as per recommended protocols, and measurements are consistent with calculations from TPS. This assisted to move forward with beam modelling of the TPS.

Keywords: Accuracy; Uncertainties; Photon; Dosimetry; Protocols

Introduction

Radiotherapy aims to precisely deliver a high dose of ionizing radiation to tumour while minimizing the dose to surrounding normal tissues, thereby improving the likelihood of survival and quality of patient's life. However, errors and uncertainties may affect the accuracy and precision of the entire treatment outcome. It is therefore recommended to minimize all expected inaccuracies, and clinical impact of dose-and treatment-related uncertainties as low as possible and professionals involved must know quantitatively the magnitude of existing uncertainties [1-5]. Furthermore, dosimetric accuracy must be maintained because the treatment outcome depends on the radiation dose delivered to patients. The recommendations by the international commission on radiological units and measurements (ICRU) insists on dose delivered to primary target to be within ±5% of prescribed value [6-9]. The aim of this study was to evaluate the degrees of practically achievable accuracy for external photon beam dosimetry and to estimate the associated uncertainties.

Materials and Methods

The study considered 5 high energy photon beams (6, 10, and 15 MV, 6 & 10 MV FFF), generated by the TrueBeam linear accelerator (Varian Medical Systems, Palo Alta, CA, USA). The measurements were performed in a BeamScan 3D water scanning system (PTW, Freiburg Germany), with the farmer-type ionization chamber TM30013 (PTW, Freiburg, Germany) for the determination of absorbed dose in water. For absolute dose measurement, 100 MUs were delivered for all beam energies with the same setup, and the absolute dose was calculated by following the American Association of Medical Physicists (AAPM) Task Group (TG)-51 [10] and International Atomic Energy Agency (IAEA) Technical Reports Series (TRS)-398 [11]. The percentage discrepancies in dose measurement between two protocols at the depth of z_{max} were obtained for various beam energies.

The two PTW waterproof Semiflex-3D ionisation chambers TM31021, SN: 142869 and SN: 142869 were used for relative dosimetry. The SN: 142869 was used as a reference chamber, while the SN: 142856 was used as a field chamber for the measurement of %DD, profile and output factors. The PDD data scanning was done on the beam central axis, with a chamber position step size of 0.1 mm at various depths and field sizes. For beam profiles, the scanning was done perpendicularly to the central axis, at various depths ranging from 16 mm to 300 mm and the horizontal beam scanning was done from -82.4 mm to 82.4 mm, with a positional step size of 0.30 mm. The relative measurements were analysed and evaluated with the Data Analyser module of the PTW BEAMSCAN® Software (version 4.3.2). This analysis was done following the AAPM TG-51, IAEA TRS-398, DeutschesInstitutfürNormung (DIN) 6800-2 [12], and British Institute of Physics and Engineering in Medicine (IPEM) [13] protocols that are included in the Data Analyser module.

For absolute dose measurement, the Farmer type (PTW, Freiburg, Germany) ionization chamber was coupled to a PTW-UNIDOS-E electrometer which measured the charge collected during irradiation.

In this study, the beam quality was measured following the IAEA-TRS-398 protocol, in which the $TPR_{20,10}$ is the recommended beam quality specifier. For assessing the consistency of beam quality measurements, the$TPR_{20,10}$ was also calculated using the empirical relationship (Equation 1) suggested in TRS-398 [14].

$TPR_{20,10}=1.2661*PDD_{20,10}-0.0595$ -----Eq. 1

Where, $PDD_{20,10}$ is the ratio of dose at 20 cm 10 cm depth, respectively.

For the determination of the absorbed dose in water, for respective photon beam, having the dosimeter reading M at the point of measurement m, the Equation 2 was generally applied following the codes of practice for high energy photon beam dose measurement listed in the IAEA TRS-398 and AAPM TG-51 protocols [10,11].

$$D_{m,Q} = M_Q . N_{m,Q} M_Q = M . K_{TP} . K_s$$ ---- Eq.2

Where, is the calibration factor of the reference chamber, determined in a standard laboratory for a beam of quality Q; and are the corrected and uncorrected meter readings, respectively; and are the corrections related to the air density and ionic recombination, respectively. Furthermore, the percentage discrepancies in absolute dose measurement between two protocols (TRS-398 and TG-51) at z_{max} were measured with respect to all considered photon beams.

$$MU = \frac{100 \text{ x Dose}}{\text{Machine output x OF x PDD}}$$ ----- Eq. 3

Where, OF is the machine's output factor, while PDD is the percentage depth dose.

The relative standard uncertainties were mentioned according to the source of each uncertainty. The uncertainty in the calibration of an ionization chamber shown on the chamber calibration certificate was combined with other sources of uncertainty, such as uncertainty in the calibration certificate, Temperature and pressure correction k_{TP}, Humidity correction k_h, Recombination correction k_s, Polarity correction k_{pol}, Deviation of chamber position (depth) in phantom, beam quality correction factor k_Q and stability of the instrument. The total relative standard uncertainty was calculated using the quadrature summation [Equation 4] [15]

$$U^2=\sum_{i=1}^{N} u_i^2$$ ---- Eq. 4

Where; U is the overall combined standard uncertainty and u_i, is the contribution of the input uncertainty quantities. Both type A and B uncertainties were measured. Type A was measured by the mean and standard deviation obtained from a series of readings (at least ten readings were taken), while type B uncertainties were obtained using non-statistical methods such as the uncertainties stated in calibration certificates, uncertainties and tolerances stated in specifications given by the manufacturer, etc.

Results

Beam quality index ($TPR_{20,10}$)

The measured and calculated values for the $TPR_{20,10}$ are shown in Figure 1. The differences were negligible for all photon energies.

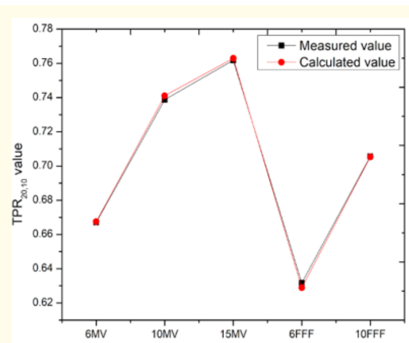


Figure 1: The measured and calculated values of TPR20,10 as a function of photon energies at 10x10 cm² field size.

Absolute dosimetry

The results for absorbed dose at z_{max} for considered photon beams in this study are shown in Figure 2.

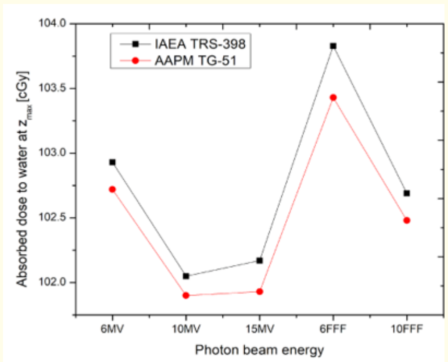
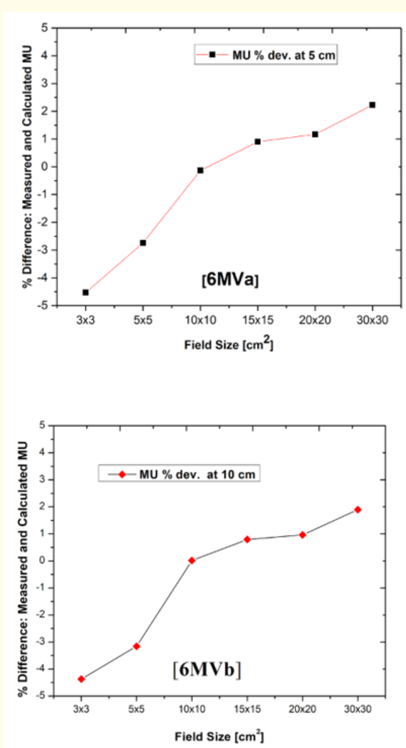


Figure 2: The absorbed dose to water at zmax as a function of photon beam energy, following the TRS-398 and TG-51 protocols at 10x10 cm^2 field size.

Monitor units (MUs) verification

The percentage difference between MUs delivered by linear accelerator and MUs calculated by TPS at 5 cm and 10 cm depths in water is shown in Figure 3. The 5% tolerance limit is maintained for all considered photon beams, and depths [Figured 3].



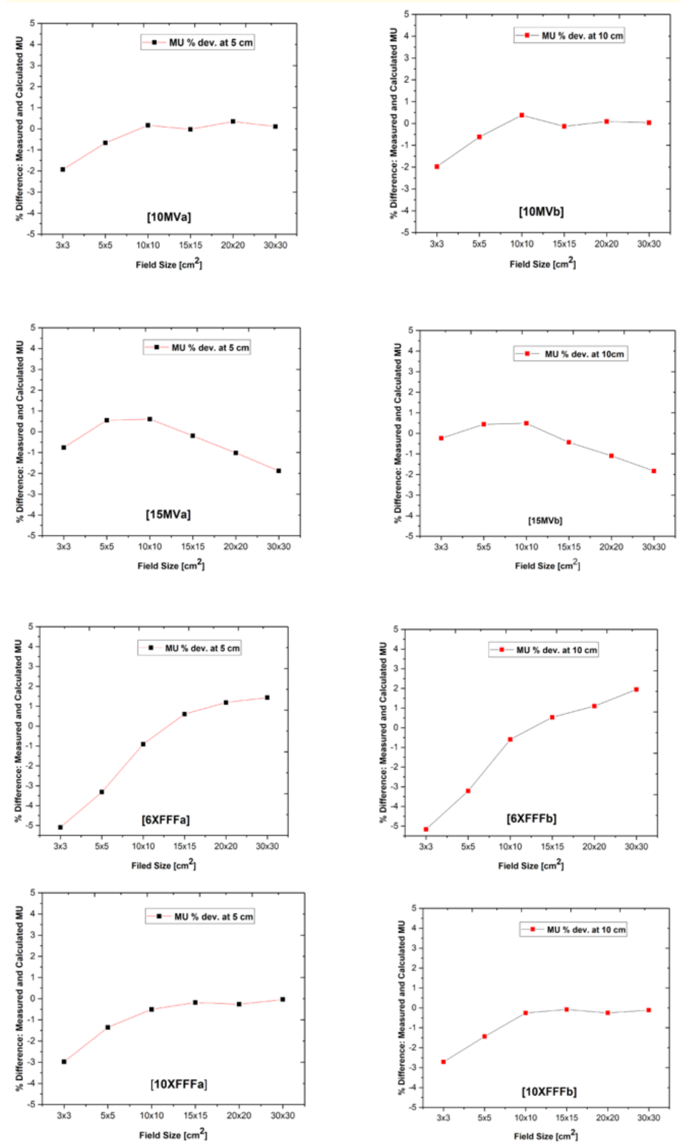


Figure 3: The percentage difference between MUs delivered by Linac and MUs calculated by TPS at 5 cm (a) and 10 cm (b) depths for 6, 10, 15 MV and 6, 10 MV FFF photon beams. Measured MU refers to MU values delivered by Linac, while Calculated MU refers to MU calculated by TPS.

Relative dosimetry: percentage dose distribution (%DD)

The measured and calculated %DD distribution curves in water at 10x10 cm^2 field size for 6, 10, 15 MV, are shown in Figure 4.

The depths of maximum dose (z_{max}) and %DD values at 10 cm depths ($\%DD_{10}$) as function of considered protocols at 10x10 cm^2 field size are shown in Figure 5.

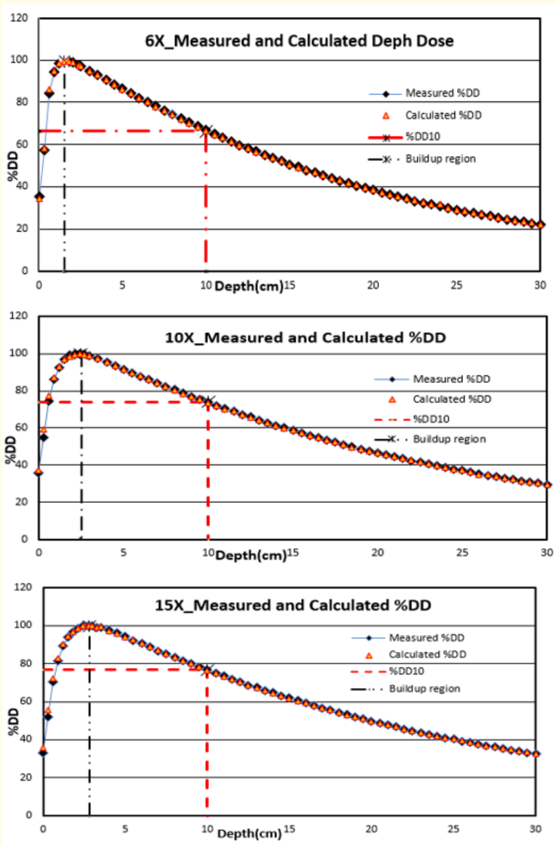


Figure 4: Measured and calculated %DD curves in water at 10 × 10 cm^2 field size for 6, 10, 15 MV photon beams.

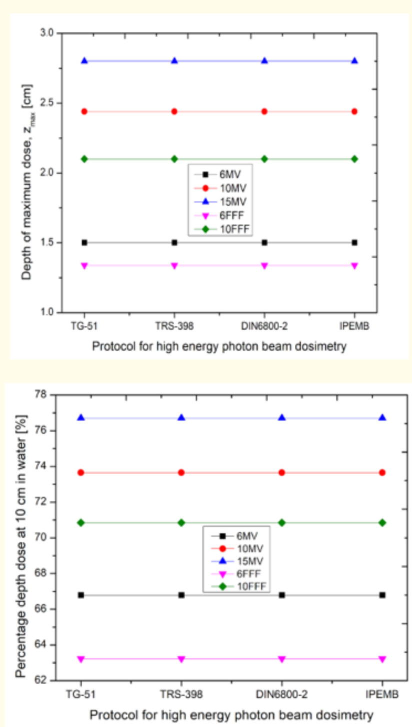


Figure 5: The depth of maximum dose (z_{max}) and %DD at 10 cm depths (%DD10) for various photon beam energies, according to different protocols.

In order to assess the variation in central axis dose distribution parameters with different field sizes, the %DD data were measured with various field sizes ranging from 3x3 cm^2 to 40x40 cm^2. The obtained results at 10 cm depth are presented in Figure 6.

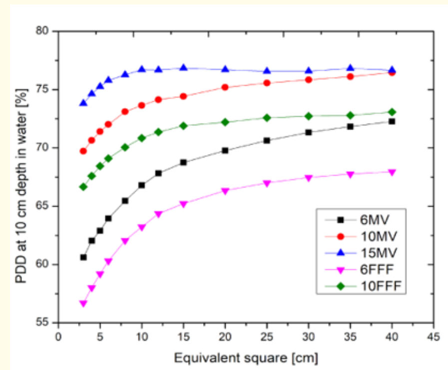


Figure 6: The %DD at 10 cm depth (%DD10) versus field size for different photon energies.

Relative dosimetry: beam profile

The measured beam profiles at 10x10 cm^2 field size are shown in Figure 7. Moreover, the beam symmetry and flatness results for different photon beams considered in this study at various field sizes obtained with Data Analyser module are shown in Table 1.

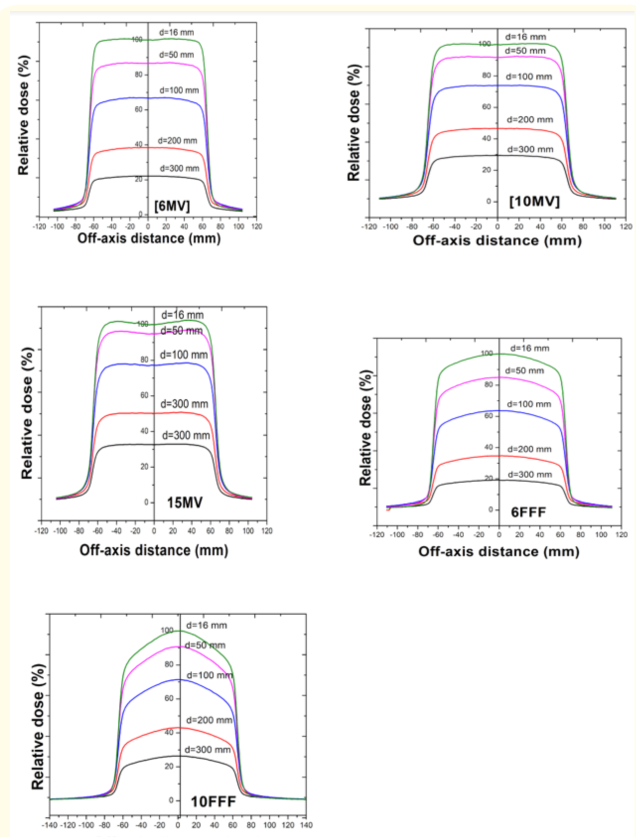


Figure 7: The 10x10 cm^2 beam profile for various photon beam energies; 6, 10, 15 MV, 6 and 10 MV FFF.

Energy	z_{max}[mm]	Profile Data [%]	3x3	4x4	5x5	6x6	8x8	10x10	12x12	15x15	20x20	25x25
6 MV	14	Flatness	6.66	3.59	2.16	1.56	1.05	0.74	0.55	0.91	1.35	1.73
		Symmetry	1.21	0.62	0.25	0.26	0.23	0.22	0.22	0.23	0.45	0.44
10 MV	25	Flatness	8.34	5.55	3.71	2.83	1.55	1.03	0.61	1.02	1.48	1.78
		Symmetry	1.17	0.86	0.40	0.48	0.21	0.44	0.32	0.34	0.30	0.29
15 MV	30	Flatness	8.51	5.91	4.06	2.91	1.67	1.34	1.50	1.87	2.14	2.24
		Symmetry	1.11	0.83	0.58	0.41	0.54	0.98	0.86	0.81	0.77	0.60
6 FFF	14	Unflatness	1.02	1.02	1.02	1.02	1.03	1.097	1.123	1.168	1.1250	1.338
		Symmetry	0.26	0.18	0.12	0.13	0.24	0.31	0.33	0.33	0.41	0.42
10 FFF	24	Unflatness	1.05	1.04	1.04	1.05	1.08	1.198	1.2	1.33	1.48	1.64
		Symmetry	0.30	0.27	0.31	0.34	0.47	0.32	0.56	0.61	0.51	0.57

Table 1: The beam profile data analysis for various field sizes (3x3cm^2 to 25x25 cm^2). The analysis was done at the 100% isodose line and z_{max} of the correspondent beam energy.

Output factor

The output factors for all photon beams considered are shown in Figure 8.

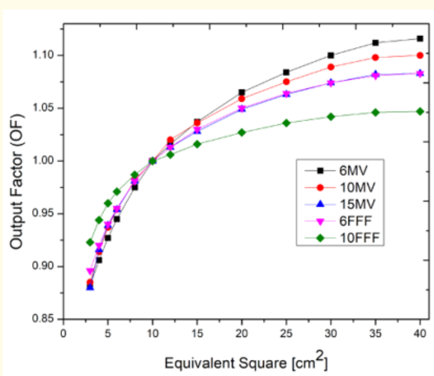


Figure 8: The in/cross plane output factor at cm^2 vs field size for various photon beam energies.

Uncertainties estimation

The results of total relative standard uncertainty in quadrature summation are shown in Table 2.

Discussion

Several dosimetric parameters such as beam quality index, %DD, beam profile, and output factors were obtained for 5 photon energies. Practically achievable accuracy was evaluated by checking the consistency of the measurements with the calculated values, and with respect to different international protocols for dose measurements. The measurements for beam quality index ($TPR_{20,10}$) were in agreement with calculated values, where the minimum and maximum percentage error were found to be 0.035% and 0.57%, respectively [Figure 1]. This error is practically negligible and doesn't cause a net effect on the final dose to water calculation. The absorbed dose to water at z_{max} according to TG-51

Input quantity x_i/Source of uncertainty	Uncertainty Type	Uncertainty distribution	Relative standard (expanded) uncertainty
			U_i [%]
Calibration coefficient, $N_{D,w}$			
Uncertainty in the calibration certificate	B	Normal	1.1
Dosimeter reading corrected for leakage, M			
Repeatability	A	Normal	0.10
Maximum response deviation, Resolution	B	Rectangular	0.50
Temperature and Pressure correction, k_{TP}			
Uncertainty in air density correction factor	B	Rectangular	0.10
Humidity correction kh			
Deviation from reference condition of 50%	B	Rectangular	-
Recombination correction ks			
Uncertainty in the recombination correction factor	B	Normal	0.10
Polarity correction kpol			

Uncertainty in the polarity correction factor	B	Normal	0.10
Depth positioning ionisation chamber in phantom			
Uncertainty due to deviation from ref. condition: z_{ref}, SSD	B	Normal	0.10
Beam quality correction factor kQ			
Uncertainty in the quality correction factor (TRS-398)	B	Normal	1.0
Total uncertainty according to IAEA TRS-398 (2000)			1.58

Table 2: Uncertainty estimation for the determination of absorbed dose to water, $D_{w,Q}$. All individual uncertainty contributions are summed in quadrature and the combined standard uncertainty was obtained.

and TRS-398 protocols were in good agreement, where the average discrepancies in the determination of absorbed dose to water among the two protocols were 0.19% for all photon beams [Figure 2]. The small dose discrepancies observed are thought to be associated with dose measurement procedures and equipment used. The MUs delivered by Linac were consistent with TPS calculations [Figure 3], where the percentage deviation falls within ±5%, which is the internationally recommended accuracy by ICRU [6].

The measured and calculated %DD were found to be in good agreement [Figure 4], the %DD parameters such as depths of dose maximum (z_{max}), $\%DD_{10}$ were found to be in good agreement according to different international protocols [Figure 5]. The measured depth of maximum dose (d_{max}) are 1.5 cm, 2.4 cm, 2.8 cm, 1.3 cm, and 2.1 cm for 6, 10, 15MV, 6 and 10 MV FFF photon beams respectively, and their %DD at 10 cm depth ($\%DD_{10}$) are 66.79%, 73.65% ,76.71%, 63.23% and 70.85%, respectively [Figure 4]. The measured central axis dose distribution parameters are within the limit of IEC recommendations [16]. Moreover, the $\%DD_{10}$ versus field size curves [Figure 6], indicates that %DD increases with the field size, which is broadly thought to be associated with scattering radiation contribution, which is significant at higher field sizes.

The beam profile symmetry and flatness at 10x10 cm^2 field size, [Figure 7], were evaluated and the results are summarized in Table 1. The symmetry was 0.22%, 0.44%, 0.98%, 0.31%, and 0.32% for 6, 10, 15MV, 6 and 10 MV FFF, respectively, while flatness was 0.74%, 1.03%, 1.34% for 6, 10, 15MV, respectively. The beam flatness and symmetry are in the IEC60976 recommended range, 3% and 2%, respectively. However, the flatness for 6, 10, and 10 MV at lower field sizes (<10x10 cm^2) was found to be out of the recommended range [Table 1]. This is associated with the loss of lateral charged particle equilibrium, the finite source size, steep dose gradient, detector size, and volume averaging effect, which are observed significantly at lower field sizes.

It was also found that the output factors in respective beam energy increase with field size [Figure 8]. The increase in output factor with field size may be attributed to the radiation scattered from the primary collimator and flattening filter in the treatment unit head [17]. The relative uncertainty values associated with different physical quantities or procedures that contribute.d to the absorbed dose determination are presented in Table 2. The overall estimated relative standard uncertainty of $D_{w,Q}$ at the reference depth in water, was found to be within +/-1.58%, which is the recommended tolerance value for high energy photon beams as per TRS-398 [11].

Conclusion

This research offered an introduction to radiotherapy treatment and basic background in dosimetry. The protocols followed in this study are self-contained and are all based on standards of absorbed dose to water. In this study, different factors affecting the accuracy of radiation dose measurement and the existing magnitude of the uncertainties for megavoltage photon beams were exhaustively investigated. Overall, the measurements obtained are in excellent agreement with calculated data, which confirmed proceeding with the next steps of beam modelling of TPS.

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