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COMPARISON OF WATER ABSORBED DOSE FOR PHOTONS OF LINAC AND TRACEABILITY SYSTEM FOR RADIOTHERAPY IN CHINA*

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Abstract

A water calorimeter is developed as the primary standard of the absorbed dose to water for high-energy photon beams from clinical accelerator, aiming to support the dosimetry calibration for radiotherapy in China. The tissue phantom ratio for 6 and 10 MV photon beams were obtained from the direct measurement and the percentage depth-dose curve separately. The absorbed dose to water of high-energy photon beams from clinical accelerator was reproduced by a water calorimeter with the combined standard uncertainty of 0.35%. The results of the BIPM.RI(I).K6 comparison reported as ratios of the NIM and the BIPM evaluations (and with the combined standard uncertainties given in parentheses), are 0.9917(60) at 6 MV, and 0.9941(59) at 10 MV. The quality correction factors K_Q of commonly-used chambers were measured directly, which were 0.3%~0.7% smaller than the recommended data in the IAEA TRS-398 protocol. The variations are between 0.1% and 0.8% for the results based on the methods recommended in IAEA TRS-398 and the chambers calibrated by megavoltage photons, in terms of the absorbed dose to water for the high-energy photon beams from clinical accelerator.

INTRODUCTION

There are more than 2000 linear accelerators for radiotherapy in China, and the number is increasing annually by 100 in recent years. The quality assurance and quality control of the accelerator is based on the measurement of the absorbed dose to water, accordingly the reproduction of the absorbed dose to water is crucial to the radiotherapy center. In order to provide the calibration service to the radiotherapy centers, a water calorimeter for the primary standard study of the absorbed dose to water of the high energy photons beams and the electron beams is developed by National Institute of Metrology (NIM) in cooperation with National Research Council (NRC) in Canada [1]. After the measurement of absorbed dose to water for 6, 10, and 25 MV photons of accelerator by the water calorimeter, NIM took part in the BIPM.RI(I).K6 comparison with Bureau International des Poids et Mesures (BIPM) in 2016. The results of BIPM.RI(I).K6 comparison prove the equivalence between NIM and other primary laboratories worldwide in terms of the reproduction of the absorbed to water for the high-energy photon beams from clinical accelerator.

The traceability system for radiotherapy in China is based on the standard for air-kerma of ^{60}Co in the past few decades. To verify the consistency between the new traceability system based on the standard for the absorbed dose to water and the existing one, the calibration of clinical accelerator is inter-checked among the IAEA TRS-277 [2], TRS-398 [3], AAPM TG-51 [4] protocols and the accelerator standard for the 6 MV and 10 MV photons. For the calibration of accelerators in radiotherapy centers, the quality correction factor K_Q is determined by measurement.

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APPARATUS

The NIM water calorimeter is designed for horizontal beam delivery, which is in advantageous for primary standard study. As shown in Fig. 1, the calorimeter is composed by three parts, which are a calorimeter core with temperature rise data acquisition unit, a cycling system for the purpose of temperature control, and a water phantom supported by a positioning console. The BIPM graphite calorimeter and pancake chamber in water phantom in the NIM accelerator photon radiation for the comparison is shown in Fig. 2 .

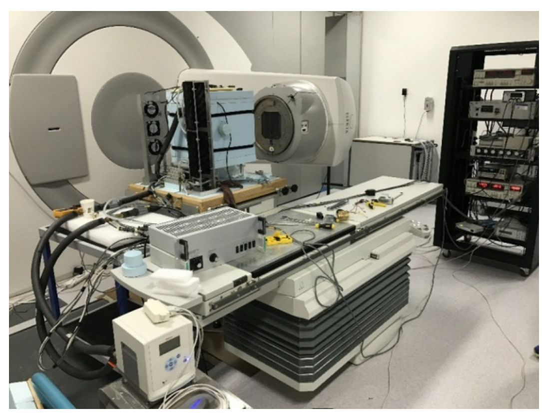

Figure 1: NIM water calorimeter for the primary standard study of absorbed dose to water of the photon beams.

Figure 2: BIPM graphite calorimeter and the pancake chamber in the water phantom for NIM-BIPM comparison.

The PTW 30013 and IBA CC13 ionization chamber with Keithley 6517B electrometer were used for the absolute dose

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measurement and percentage depth-dose curve scanning, respectively. The chamber is oriented with precision better than 0.1 mm by a home-made water phantom system, which is controlled remotely by a LabView platform.

RESULTS

The Tissue-Phantom Ratio

The beam quality index for high-energy photon beam is characterized by the tissue-phantom ratio(TPR_{10}^{20}) in water , which is deduced from the dose at depths of 20 and 10 g/cm^2, on the condition that a Source Chamber Distance(SCD) of 100 cm with a field size of 10 cm×10 cm. Since it is the basic property of photon beam, the TPR_{10}^{20} is crucial for the measurement of absorbed dose to water and comparison. TPR_{10}^{20} measured by definition and calculated by the dose ratio (D_{20}/D_{10}) with the formula in IAEA TRS-398 report are shown in Table 1(6 MV) and Table 2(10 MV). It can be seen that TPR_{10}^{20} measured directly is 0.3% larger than calculated by the dose ratio from percentage depth-dose curves. This is consistent with the Monte Carlo simulation and experimental results by Fonseca [5] *et al*, and the TPR_{10}^{20} for the BIPM.RI(I).K6 comparison is 0.666~0.687 for 6 MV and 0.731~0.748 for 10 MV.

Table 1: Direct Measurement and Calculation by D_{20}/D_{10} of TPR_{10}^{20} for 6 MV Photons

Dose/MU	50	200	400	Average
TPR_{10}^{20}	0.6869	0.6872	0.6868	0.6871
D_{20}/D_{10}	0.5882	0.5881	0.5882	
Calculation	0.6852	0.6851	0.6852	0.6851

Table 2: Direct Measurement and Calculation by D_{20}/D_{10} of TPR_{10}^{20} for 10 MV Photons

Dose/MU	50	200	400	Average
TPR_{10}^{20}	0.7400	0.7398	0.7401	0.7401
D_{20}/D_{10}	0.6298	0.6298	0.6295	
Calculation	0.7379	0.7379	0.7375	0.7378

The Measurement for Absorbed Dose to Water

The absorbed dose to water is measured by water calorimeter with the nominal dose rate of 620 MU from the accelerator. Fig. 3 and Fig. 4 summarize the results for the 6 MV and 10 MV photon beams. The uncertainties shown in Fig. 3 and Fig. 4 only consider the type A standard uncertainty. After calibrating the thermistors and AC bridge separately, absorbed dose to water is absolutely obtained with the combined standard uncertainty of 0.35%. The discrepancy of absorbed dose to water measured separately by N_2-filled and H_2-filled vessel is 0.2% at 10 MV, which is similar to the results obtained by Medin [6] for the measurement of ^{60}Co radiation.

Compare the traceability system for radiotherapy in China, the typical chamber-to-chamber variations of the absorbed dose obtained with the IAEA TRS-277, TRS-398 and AAPM TG-51 are between 0.2% and 1.0% for the different photon beams, as shown in Table 3 . The variations of the dose obtained with IAEA TRS-398 and chambers calibrated directly by megavoltage photons are between 0.1% and 0.8%.

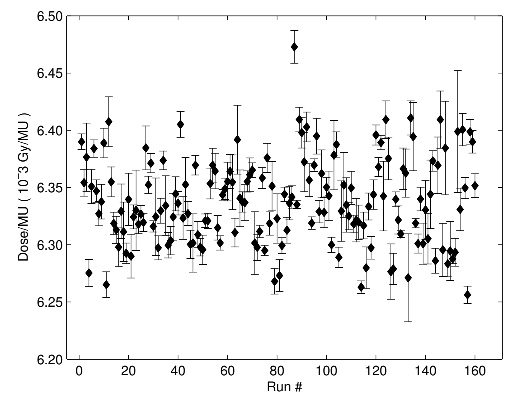

Figure 3: The results of the absorbed dose to water of 6 MV photon beam .

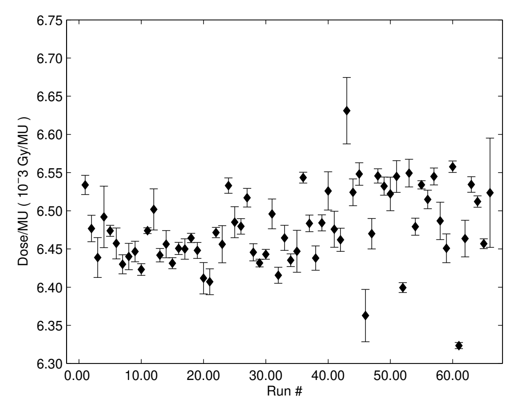

Figure 4: The results of the absorbed dose to water of 10 MV photon beam .

The BIPM.RI.K6 comparison was performed through a transfer chamber, the results reported as ratios of the NIM and the BIPM evaluations (and with the combined standard uncertainties given in parentheses), are 0.9917(60) at 6 MV, and 0.9941(59) at 10 MV [7].

Further experimental results after the comparison show that the NIM water calorimeter can improve the repeatability with a better control of the measurement processes such as the temperature calibration of the thermistor, the voltage calibration of the AC bridge and the temperature monitoring of the transmission ionization chamber during the radiation.

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Table 3: The Discrepancy of Absorbed Dose to Water of 6 MV and 10 MV Photons by Different Formalisms

	$D_{w,6\,\mathrm{MV}}$	discrepancy	$D_{w,10\,\mathrm{MV}}$	discrepancy
TRS-277	1.892	-0.4%	1.923	-0.6%
TRS-398	1.903	0.2%	1.941	0.4%
linac calibration	1.894	-0.3%	1.926	-0.4%
average	1.900		1.934	

The Quality Correction Factor

The quality correction factor K_Q, which is applied to correct the the difference between the responses of an ionization chamber in the actual user beam quality (high-energy photon beams) and in the reference beam quality (^{60}Co) where it is calibrated, is measured directly. The K_Q factors are 0.3%~0.7% smaller than the data in the IAEA TRS-398 and AAPM TG-51 [8] protocols. It is consistent with the comparison report that the K_Q results of NIM are 0.8% (6 MV) and (0.4%) lower than those of BIPM, respectively.

CONCLUSION

The primary standard of absorbed dose to water for high-energy beams of 6 MV, 10 MV and 25 MV is established. The BIPM.RI(I)-K6 comparison was conducted between NIM and BIPM. The new standard presented in this work will enrich and update the current the traceability system and reduce the uncertainty of ion chamber calibrations for accelerator radiotherapy.

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