

Validating dose rate calibration of radiotherapy photon beams through IAEA/WHO postal audit dosimetry service

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Abstract

In external beam radiation therapy (EBRT), the quality assurance (QA) of the radiation beam is crucial to the accurate delivery of the prescribed dose to the patient. One of the dosimetric parameters that require monitoring is the beam output, specified as the dose rate on the central axis under reference conditions. The aim of this project was to validate dose rate calibration of megavoltage photon beams using the International Atomic Energy Agency (IAEA)/World Health Organisation (WHO) postal audit dosimetry service. Three photon beams were audited: a 6 MV beam from the low-energy linac and 6 and 18 MV beams from a dual high-energy linac. The agreement between our stated doses and the IAEA results was within 1% for the two 6 MV beams and within 2% for the 18 MV beam. The IAEA/WHO postal audit dosimetry service provides an independent verification of dose rate calibration protocol by an international facility.

Keywords: Radiation, EBRT, Photon beams.

Introduction

External beam radiation therapy (EBRT) using megavoltage photon beams from linear accelerators is the most widely used treatment modality in the treatment of cancer. The accurate delivery of prescribed dose to the patient requires vigilant and on-going quality assurance (QA) of radiation beam dosimetry.¹⁻⁴ One of the dosimetric parameters that require monitoring is the beam output, specified as the dose rate on the central axis under reference conditions.

The Aga Khan University Hospital (AKUH) radiation oncology centre in Karachi, Pakistan, has two Varian Clinac® linear accelerators: a 6 MV and a 6/18 MV dual-energy machines. The beam outputs of these modalities are monitored on a daily basis using the PTW-QCPlus® commercial tool as part of the morning pre-treatment QA. The daily readings are referenced to the monthly calibrations in solid water using a Farmer chamber with a calibration factor traceable to the IAEA/WHO network of Secondary Standards Dosimetry Laboratory (SSDL) in Islamabad, Pakistan.^{5,6} The absolute in-water calibrations are performed

yearly, following a scheduled annual QA, using the AAPM TG 51 Protocol.⁷ The absolute calibrations may be prone to errors arising from an incorrect experimental setup and/or incorrect interpretation/application of the dose measurement protocol. Hence, it would be reassuring to have it verified by an independent external facility.

Thermoluminescent dosimetry (TLD) remains a proven and accepted methodology for postal dose audit service.⁸⁻¹⁰ Unlike other in-vivo dosimeters such as diodes, MOSFET and other solid state detectors, TLDs are small, rugged and re-usable;^{11,12} they require no connection to an external electrometer. Hence, they are cost-effective and ideally suited for remote dose audits. The time delay between the irradiation and the readout is a necessary consequence of postal audit system, but this is not an issue.

Materials and Methods

The IAEA/WHO offers a free postal TLD service to participating institutions to audit dose rate calibrations of clinical teletherapy photon beams from Cobalt-60 and megavoltage linear accelerators. Their service can be requested by correspondence.¹³ The postal audit service¹⁴ is a three-step process (Table-1): the IAEA mails the irradiation kit and the instructions to the participating institution; the institution performs the irradiation within a stated timeframe and mails back the package for readout; and the results of the audit are mailed back to the participant.

If the results are within the IAEA acceptance limit of $\pm 5\%$, a subsequent audit is recommended within two years. If the results are outside the acceptance limit, the IAEA mails out a second irradiation package for an immediate repeat procedure. If the repeat audit does not resolve the discrepancy, the IAEA recommends an expert's visit to the institution. In addition to the bi-annual service, the IAEA also considers individual requests under special circumstances such as new installations, major repairs or any unusual clinical considerations.

The IAEA/WHO package consists of a tripod stand, a hollow plastic holder that attaches to the tripod base plate, TL capsules and instruction sheets. The TL dosimeter consists of

Table-1: Summary of the postal audit activities and timelines.

Activities	Timelines
Explored the venue: “IAEA/WHO Postal Dose Audit Service”. Requested IAEA/WHO to include AKUH as participant. IAEA/WHO confirmed AKUH registration.	August-October 2009
TL dosimeter received from IAEA along with the irradiation protocol.	November-09
TL dosimeter irradiated as per IAEA/WHO instruction, subsequent to our annual QA TL dosimeters sent back to IAEA/WHO	December-09
Receipt of results	April-10

Table-2: Summary of the IAEA TLD Audit results for the photon beams at AKUH.

Photon Beams	TLD Capsule	IAEA Dose (Gy)		User Stated Dose** (Gy)	IAEA Mean User Dose
		Measured*	Mean		
Varian Clinac® 600 C/D – 6 MV PDD10 = 67.0%	10462-1	1.94	1.94	1.96	0.99
Varian Clinac® 2300 C/D – 6 MV PDD10 = 67.0%	10462-2	1.94	1.97	1.96	0.99
	10463-1	1.96		1.98	
Varian Clinac® 2300 C/D – 18 MV PDD10 = 80.0%	10463-2	1.97	1.95	1.98	0.98
	10464-1	1.94		1.98	
	10464-2	1.95		1.98	

*: Mean of four readings from each TL capsule. The combined uncertainty in TLD measurement of dose is 1.6% (1 standard deviation).¹⁶

** : The combined uncertainty is 1.9%; based on the uncertainty in the user Co-60 calibration factor (1.25%)⁶ and user high energy photon beam (1.4%).¹⁷

~165 mg of LiF powder in a watertight polyethylene 3mm x 20mm cylindrical capsule that allows four readings to be made from each sample.¹⁵ The irradiation kit was assembled as per the instructions, placed in a water bath (plastic container) with its top surface in line with the water level and positioned in such a way that the TL capsule in the holder was aligned with the central axis of the beam at a depth of 10 cm (Figure-1). A fixed source-axis distance (SAD) of 100cm and a 10cm x 10cm field size were used. The irradiation geometry is shown by the schematic diagram in Figure-2.

Three photon beams were audited: a 6 MV beam from the low-energy linac and 6 and 18 MV beams from a dual high-energy linac. Each capsule (two per beam) was irradiated with 200 monitor units (MU) and the dose delivered, based on our in-house calibration, was noted. Subsequent to the irradiation, the TLD capsules were re-packaged and mailed back to the IAEA for readout.

Results

The agreement between our stated doses and the IAEA/WHO results was within 1% for the 6 MV beam and within 2% for the 18 MV beam (Table-2).

The monthly QA results of the dose calibrations for the

three photon beams are shown in Figure-3. If the monthly reading exceeds the tolerance level of $\pm 2\%$, the output is tuned to bring back to its nominal value of 1.0 cGy/MU. The mean and standard deviations of the results are $0.993 \pm 1\%$ for the 6 MV low-energy linac and $1.008 \pm 0.5\%$ for 6 and 18 MV beams from the dual-energy linac. It is interesting to note that the

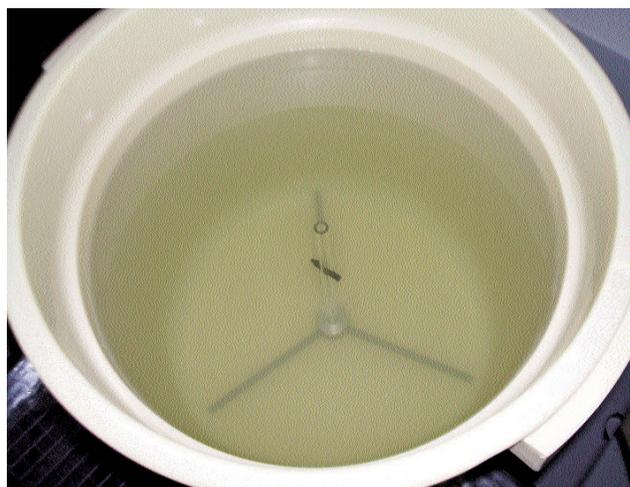


Figure-1: Irradiation Setup; tripod stand placed in the water container.

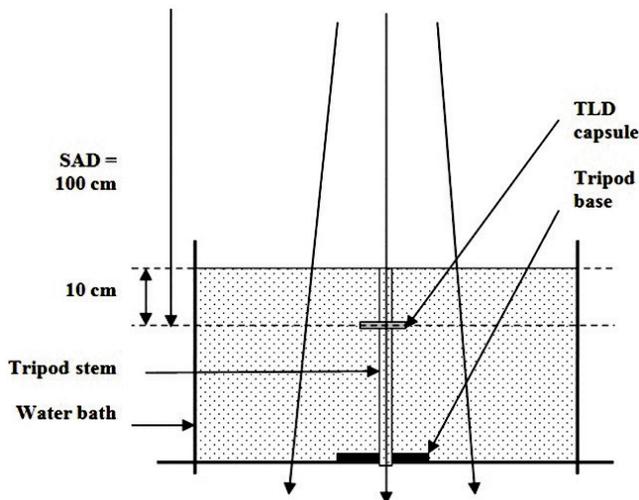


Figure 2: Schematic diagram showing the TLD irradiation geometry.

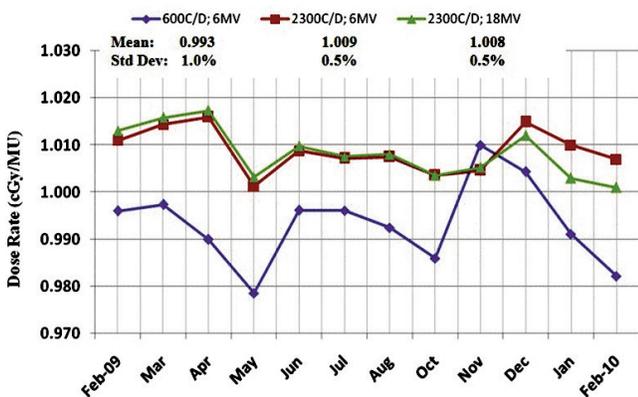


Figure 3: Monthly dose rate calibrations: February 2009 - February 2010.

magnitude of standard deviations speak well for the stability of the linacs over a one-year period. In fact, the same trend has been observed over a period of four years for both linacs.

Discussion

The decision to participate in the IAEA/WHO external audit was taken at the departmental level, involving the Operational Group consisting of radiation oncologists, medical physicists, radiation therapists and the Chair of Quality Improvement Committee. The project was undertaken as an effort in Continuing Quality Improvement (CQI) of the department's core process. The reporting back of the audit results to the Operation Group and a follow-up, if necessary, was an inherent part of the process. The results of the audit for all three photon energies at the institution are well within the IAEA/WHO acceptance limit of $\pm 5\%$. Had it been otherwise, an appropriate follow-up, in concert with and as recommended by IAEA/WHO, would have been deemed

mandatory; namely, an immediate re-audit and, if necessary, a visit from the IAEA/WHO experts to resolve the discrepancy.

Izewska et. al.¹⁶ have carried out an analysis of the uncertainties in the IAEA/WHO postal audit system. The absorbed dose determined from the TLD measurements is expressed as:

$$DTLD = M * N * f_1 * f_2 * f_3 * f_4 \quad (1)$$

where M is the mean of the four TLD readings from each capsule and N is the TLD calibration factor. The remaining factors in Eq. (1) are the TL correction factors for fading (decrease of TL response due to loss of charge between irradiation and readout), the influence of the holder (perturbation effect), energy dependence (due to neutron contamination in high energy photon beams) and dose response non-linearity (above 12 Gy), respectively. They estimate the combined relative standard uncertainty in the DTLD with high-energy X-rays to be 1.6% (1 standard deviation).

The corresponding combined uncertainty in our user-stated doses is estimated to be 1.9%. This is based on the uncertainty in the Co-60 calibration factor (1.25%) for the Farmer chamber, as stated by the SSDL6; and the uncertainty in the conversion of the chamber reading to determine the absorbed dose to water for high-energy photon beams (1.4%).¹⁶ Hence, an agreement between the user-stated dose and that determined by IAEA/WHO within 2.5% ($\sqrt{[1.6^2+1.9^2]}$) would be reasonable. This is in line with the results of our efforts.

The calibration of megavoltage beams from linear accelerators has three essential requirements: (i) the use of an ion chamber with a calibration traceable to an SSDL; (ii) an accurate experimental setup; and, (iii) the correct interpretation of the dosimetry protocol to determine and correctly apply the factors to convert the charge reading to the absorbed dose in water at the calibration point.

The Pakistan Nuclear Regulatory Authority (PNRA) requires that the ion chamber used for absolute dose measurements be calibrated at SSDL every two years. Our institution has been in compliance with this requirement since its inception in February 2006. However, absolute dose calibrations may still be prone to errors arising from an incorrect setup and/or incorrect interpretation/application of the dose measurement protocol. Hence, it would be reassuring to have them verified by an independent external facility. The IAEA/WHO TLD Audit Service provides just such an opportunity.

Conclusion

Based on our experience, we recommend that all cancer centres in Pakistan shall participate in the IAEA/WHO-sponsored service to ensure an external validation of their photon beam outputs.

Acknowledgements

The authors thankfully acknowledge the assistance of the Medical Physics staff, radiation Oncology at the Aga Khan University Hospital, Karachi.

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