Monte Carlo Conversion for the Australian Primary Standard of Absorbed Dose to Water in High Energy Photon Beams

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ABSTRACT

Radiotherapy treatment entails the delivery of large radiation doses to malignant tissues in the human body. These doses must be accurate in order to balance tumour control and damage to healthy tissues. The first step in accurate dosimetry is the calibration of radiation dosemeters by the national primary standards laboratory. Any uncertainties in this fundamental step will be passed on to every radiotherapy patient in Australia. Absorbed dose to water is the quantity used for the calibration of linear accelerator (linac) beams and many treatment planning systems. The work in this thesis is devoted to the establishment of the Australian primary standard of absorbed dose with clinically used high energy photon beams, and in particular to the Monte Carlo methods employed.

The work described occurs in three stages: modelling of the accelerator head, modelling of the graphite calorimeter and water phantom in order to determine absorbed dose to water, and validation of the Australian primary standard of absorbed dose to water by comparison with international primary standards laboratories.

The EGSnrc user codes BEAMnrc and DOSXYZnrc have been used for this work. The linac model is built using BEAMnrc component modules to match the components inside the real linac head. Validation of the linac model is performed by comparison of modelled PDDs and profiles with their measured counterparts.

The ARPANSA measurement of absorbed dose to water is the basis for all absorbed dose calibrations performed in Australia. The determination of absorbed dose to water by ARPANSA begins with a measurement of absorbed dose to graphite. A graphite calorimeter is used to measure the heating caused by irradiation in order to determine the absorbed dose to graphite. The measured dose to graphite is converted to absorbed dose to water by a factor evaluated by Monte Carlo calculations. The conversion factor is calculated as the ratio of two components: the modelled dose to water at the reference depth in the absence of an ionisation chamber and the modelled dose to the core (the sensitive element) of the calorimeter. The calorimeter is modelled to replicate the device used with all Mylar coatings and air and vacuum gaps included. The physical calorimeter geometry is confirmed by kilovoltage imaging and gap corrections are calculated and

compared to similar calorimeters in the literature for added confidence in the calorimeter model.

The final stage of method validation involves comparisons with measurements performed by other researchers. Primarily this is done by comparing the determination of absorbed dose to water with other primary standards laboratories. This thesis presents a direct comparison performed in the ARPANSA linac beams and two indirect comparisons with measurements by the other participants completed at their respective laboratories. In all cases the ARPANSA measurement was lower than comparison participant. The difference between the ARPANSA measurement and that of the other participant was 0.02 to 0.46% at 6 MV, 0.41 to 0.76% at 10 MV and 0.68 to 0.80% at 18 MV. All results for the 6 MV beam agreed within 1σ. At 10 MV one measurement agreed within 1σ. The remaining 10 MV comparisons and all comparisons at 18 MV differed by between 1σ and 2σ. In addition to the validation methods, a detailed assessment of the uncertainties in the Monte Carlo conversion factor and the resulting calibration of an ionisation chamber are presented. The uncertainty in the calibration coefficient of an ionisation chamber after interpolation to the clinical beam energy is between 0.6 and 0.7%.

The resulting quantity of absorbed dose to water is used to determine the calibration factor, $N_{\mathrm{D,w}}$, of an ionisation chamber. The ratio of calibration factors measured in a linac beam and in ^{60}Co is the measured energy correction factor, k_Q, at the linac beam quality. In addition to comparisons of absorbed dose to water, the measured k_Q values for commonly used ionisation chambers have been compared to measured and modelled values of k_Q published elsewhere.

An important consideration in changing from using the IAEA k_Q values published in the TRS-398 Code of Practice to directly measured k_Q values at megavoltage energies is the shift caused in chamber $N_{\mathrm{D,w}}$ factors. This varies with chamber type and beam quality. In this thesis four chamber types were considered: the NE 2571 Farmer chamber, and the NE 2611A, PTW 30013 and IBA FC65-G Farmer-type chambers. At 6 MV the expected shift in $N_{\mathrm{D,w}}$ ranges from -0.2% to -0.9% across the four chamber types. For the 10 MV beam quality the expected shift is -0.8% to -1.3% and at 18 MV -1.1% to -1.4% is expected. The reason for these differences is twofold. The IAEA k_Q values are typically higher than measured k_Q values published by many authors. In addition to this, the ARPANSA measured k_Q values tend to be low compared to the average of many measured k_Q values. Regardless of the reasons, the shift has an impact on the beam calibration of clinical linacs and the implications of this effect are discussed.

DECLARATION

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint award of this degree.

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Date

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LIST OF ABBREVIATIONS

AAPM	American Association of Physicists in Medicine
ACPSEM	Australasian College of Physical Scientists and Engineers in Medicine
ANSTO	Australian Nuclear Science and Technology Organisation
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
BIPM	Bureau International des Poids et Mesures
DVM	Digital volt meter
ECUT	Electron cut off energy
ENEA-INMRI	Ente per le Nuove Tecnologie, l'Energia e l'Ambiente – Istituto Nazionale di Metrologia delle Radiazioni Ionizzanti (Italy)
EPOM	Effective point of measurement
ESDM	Estimated standard deviation of the mean
FWHM	Full-width half-maximum
IAEA	International Atomic Energy Agency
IMRT	Intensity-modulated radiation therapy
K6	Key comparison BIPM.RI(I)-K6
KCDB	Key comparison database
k_Q	Energy correction factor
KRISS	Korea Research Institute of Standards and Science (Korea)
Linac	Linear accelerator
LNE-LNHB	Laboratoire National de Métrologie et d'Essais – Laboratoire National Henri Becquerel (France)
MC	Monte Carlo
METAS	Swiss Federal Office of Metrology and Accreditation (Switzerland)
$N_{\mathrm{D,w}}$	Calibration coefficient for the absorbed dose to water
NIST	National Institute of Standards and Technology (USA)

NMI	National measurement institute
NMIJ	National Metrology Institute of Japan
NPL	National Physical Laboratory (UK)
NRC	National Research Council (Canada)
PCUT	Photon cut off energy
PDD	Percentage depth dose
PDI	Percentage depth ionisation
PTB	Physikalisch-Technische Bundesanstalt (Germany)
QA	Quality assurance
SSD	Source-to-surface distance
TG-51	AAPM’s TG-51 protocol for clinical reference dosimetry of high-energy photon and electron beams
TRS-398	IAEA Code of Practice for absorbed dose determination in external beam radiotherapy (Technical Report Series No. 398)
XCOM	NIST photon cross-section database