Linac Photon Beam Calibration Using Virtual Simulator Program

Medicine & Physics

Keywords: Radiotherapy, linac, calibration, beam, protocol, virtual simulator program.

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Abstract

In radiotherapy, medical physicists give a major contribution to the safe and effective radiation treatment for patients with cancer. Megavoltage linac photon outputs are determined using the IAEA TRS-398 code of practice or AAPM TG-51 and the results are compared. Beam calibration means: determination of absorbed dose to water per 100 monitor units in a water phantom at reference conditions. The measured dose Dw,Q in water at reference point is a primary parameter for planning the treatment monitor units (MU). Traceability of dose accuracy therefore still depends mainly on the calibration factor of the ion chamber/dosimeter provided by the accredited laboratories. Our data therefore imply that the dosimetry level maintained for clinical use of linear accelerator photon beams are within recommended levels of accuracy, and uncertainties are within reported values. However, in Albania the frequently problem is related to resources with respect to both, qualified teachers and equipment, that are at disposal for teaching and training. The concepts of e-learning methods using different non commercial software, contribute to overcome this problem. In our case, we use an academic education method to practise radiation oncologists and medical physicists for LINAC beam calibration using a virtual simulator program and Matlab. Our group, after some experiences in calculation methods using Matlab, is focused on a PC based program which simulates the required equipment, the measurement set-up, and the measurement itself. All procedures are modelled according to the IAEA Code of Practice, TRS 398.

1. Introduction

After installation of a LINAC, the next procedure is acceptance test and commissioning of linear accelerator for clinical use (Hyka N. et al. 2013) by medical physicists. Since commissioning beam data are treated as a reference and ultimately used by treatment planning systems, it is vitally important that the collected data are of the highest quality to avoid dosimetric and patient treatment errors that may subsequently lead to a poor radiation outcome. IAEA and AAPM (Almond PR, et al. 1999), (IAEA 2000, TRS No. 398) reports and other documents which provide guidelines and recommendations on the proper selection of phantoms and detectors, procedures for acquiring specific photon and electron beam parameters and methods to reduce measurement errors under 1%, beam data processing and detector size convolution. TRS 398, provides a methodology for the determination of absorbed dose to water in the low, medium and high energy photon beams, electron beams, proton beams and heavy ion beams used for external radiation therapy.

2. Materials and Methods

The ranges of radiation qualities covered (IAEA, 2000) in TRS 398 report are given below:

- Low energy X rays with generating potentials up to 100 kV and HVL (half-value layer) of 3 mm Al (the lower limit is determined by the availability of standards);
- Medium energy X rays with generating potentials above 80 kV and HVL of 2 mm Al ^{60}Co gamma radiation;
- High energy photons generated by electrons with energies in the interval 1–50 MeV, with TPR20,10 values between 0.50 and 0.84;
- Electrons in the energy interval 3–50 MeV, with a half-value depth, R_{50}, between 1 and 20 g/cm2;
- Protons in the energy interval 50–250 MeV, with a practical range, R_p, between 0.25 and 25 g/cm2;
- Heavy ions with Z between 2 (He) and 18 (Ar) having a practical range in water, R_p, of 2 to 30 g/cm2 (for carbon ions this corresponds to an energy range of 100 MeV/u to 450 MeV/u, where u is the atomic mass unit).

Main quantities to measure and calculate during a commissioning procedure or periodically checks are:

- $D_{w,Q}$ (Absorbed dose to water at the reference depth, z_{ref}, in a water phantom irradiated by a beam of quality *Q*. The subscript *Q* is omitted when the reference beam quality is ^{60}Co, in gray (Gy).
- *Eo*, *Ez* - mean energy of a photon beam at the phantom surface and at depth *z*, respectively, in MeV.
- k_i - general correction factor used in the formalism to correct for the effect of the difference in the value of an influence quantity between the calibration of a dosimeter under reference conditions in the standards laboratory and the use of the dosimeter in the user facility under different conditions.
- k_{pol} - factor to correct the response of an ionization chamber for the effect of a change in polarity of the polarizing voltage applied to the chamber.
- $k_{Q,Qo}$ - factor to correct for the difference between the response of an ionization chamber in the reference beam quality Q_o used for calibrating the chamber and in the actual user beam quality *Q*. The subscript Q_o is omitted when the reference quality is ^{60}Co gamma radiation (i.e. the reduced notation k_Q always corresponds to the reference quality ^{60}Co).
- $N_{D,w,Qo}$ - calibration factor in terms of absorbed dose to water for a dosimeter at a reference beam quality *Qo*. The product M_{Qo} * $N_{D,w,Qo}$ yields the absorbed dose to water, $D_{w,Qo}$, at the reference depth zref and in the absence of the chamber. The subscript Qo is omitted when the reference quality is a beam of ^{60}Co gamma rays (i.e. $N_{D,w}$ always corresponds to the calibration factor in terms of absorbed dose to water in a ^{60}Co beam). The factor $N_{D,w}$ was called N_D. The

symbol N_D is also used in calibration certificates issued by some standards laboratories and manufacturers instead of $N_{D,w}$.

- $N_{K,Qo}$ - calibration factor in terms of air kerma for a dosimeter at a reference beam quality Q_o, in *Gy/C* or *Gy/rdg*.

The absorbed dose to water at the reference depth z_{ref} in water for a reference beam of quality Q_o and in the absence of the chamber is given by:

$$D_{w,Qo} = M_{Qo} N_{D,w,Qo}$$

where M_{Qo} is the reading of the dosimeter under the reference conditions used in the standards laboratory and $N_{D,w,Qo}$ is the calibration factor in terms of absorbed dose to water of the dosimeter obtained from a standards laboratory. In most clinical situations the measurement conditions do not match the reference conditions used in the standards laboratory. This may affect the response of the dosimeter and it is then necessary to differentiate between the reference conditions used in the standards laboratory and the clinical measurement conditions. The calibration factor for an ionization chamber irradiated under reference conditions is the ratio of the conventional true value of the quantity to be measured to the indicated value. Reference conditions are described by a set of values of influence quantities for which the calibration factor is valid without further correction factors. The reference conditions for calibrations in terms of absorbed dose to water are, for example, the geometrical arrangement (distance and depth), the field size, the material and dimensions of the irradiated phantom, and the ambient temperature, pressure and relative humidity. When a dosimeter is used in a beam of quality Q different from that used in its calibration, Q_o, the absorbed dose to water is given by:

$$D_{w,Q} = M_Q\, N_{D,w,Qo}\, k_{Q,Qo}$$

where the factor $k_{Q,Qo}$ corrects for the effects of the difference between the reference beam quality Q_o and the actual user quality Q, and the dosimeter reading M_Q has been corrected to the reference values of influence quantities, other than beam quality, for which the calibration factor is valid. The beam quality correction factor $k_{Q,Qo}$ is defined as the ratio, at the qualities Q and Q_o, of the calibration factors in terms of absorbed dose to water of the ionization chamber.

$$k_{Q,Qo} = \frac{N_{D,w,Q}}{N_{D,w,Qo}} = \frac{\frac{D_{w,Q}}{M_Q}}{\frac{D_{w,Q0}}{M_{Q0}}}$$

The most common reference quality Q_o used for the calibration of ionization chambers is ^{60}Co gamma radiation, in which case the symbol kQ is used in this TRS 398 for the beam quality correction factor. In some protocols, high energy photon and electron beams are directly used for calibration purposes and the symbol $k_{Q,Qo}$ is used in those cases. In this study, we will calculate these factors to determinate the absorbed dose to water, $D_{w,Q}$, according to the IAEA Code of Practice, TRS 398.

As we described above, to calculate the parameters of a high energy photon beam, it's important to have a set of physical equipments such as: linac, phantom, ionization chambers etc. Best practice to do this is during installation of e new linac machine or measurements for quality control, periodic tests etc, of an already installed machine in a radiotherapy centre. In this case professional software is provided by vendors such is PTW (www.ptw.de). It's very difficult for students to have access in these equipments and to practice. A software that simulate the virtual equipments such as: high energy photon beam (15 MV accelerating potential in our case), ionization chamber (PTW Farmer Type 30013), water phantom, electrometer, thermometer, barometer, is provided to authors by Dr. G. Hartmann[246]. (Hartmann G. H., 2009). A GUI of this software is given in figure 1.

Figure 1- E-training Dose Calibration Program

As is described in user manual and in G. H. Hartmann (2009) publication, this program is structured in three main parts: preparation of measurement, simulation of measurement, calculation and evaluation of parameters. Based on these guidelines, first we set up the measuring equipment.

3. Results and Discussions

To perform measurements with virtual simulator, we followed these steps:

- Preparation of accelerator: we put up the gantry and collimator at zero; we selected the type of radiation and energy 15 MeV and reference field size *10 x 10*.
- Preparation of water phantom: we filled the water phantom and adjust the SSD (source-surface distance) according laser system reference, (figure 2. a). Also we measured virtual temperature and air pressure.

[246] We thank Dr. G. Hartmann EFOMP & German Cancer Research Center (DKFZ), for providing this program to Niko Hyka and Dafina Xhako, students of the "*Training Course on Medical Physics for Radiation Therapy: Dosimetry and Treatment Planning for Basic and Advanced Applications*", organized at ICTP, Trieste Italy.

- Chamber preparation: In our case we used cylindrical chamber, model 30013 Farmer, inner radius of sensitive volume $r = 3.1\ mm$. According PTW user manual calibration factor is $N = 5.233\ Gy/C$ and the voltage to be applied is 400 V. We adjusted to central ray the ionisation chamber; we placed the chamber correctly to zero depth, and arrange the voltage and polarity. (figure 2.b)

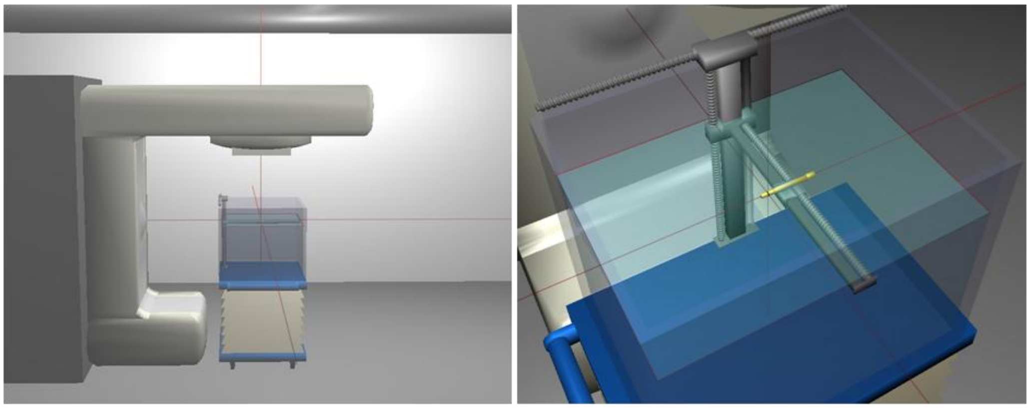

Figure 2 - Virtual simulator positioning of: a) linear accelerator and lasers, b) phantom and ionisation chamber

Table 1. Reference condition parameters.

Reference conditions for 15 MeV photons:	
Field size:	10 cm x 10 cm
SSD (source-surface distance)	99.98 cm
Measurement depth in water:	10 cm (for PDD, 0.5 - 25 cm)
Positioning of chamber:	central electrode at measuring depth
Reference water temperature:	T_0=20°C
Reference air pressure:	P_0=101.325 kPa
Measured water temperature (virtual simulation):	T = 20.6 °C
Measured air pressure (virtual simulation):	P = 98.18 kPa

Measurement under reference conditions (IAEA, 2005): To determine the absorbed dose at z_{max}, for a given beam, we use the central axis percentage depth dose (PDD) data for SSD set-ups and tissue maximum ratios (TMR) for SAD set-ups. Clinical dosimetry requires the measurements of central axis percentage depth dose (PDD) distributions, tissue phantom ratios (TPR) or tissue maximum ratios (TMR), isodose distributions, transverse beam profiles and output factors as a function of field size and shape for both reference and non-reference conditions (figure 3, a).

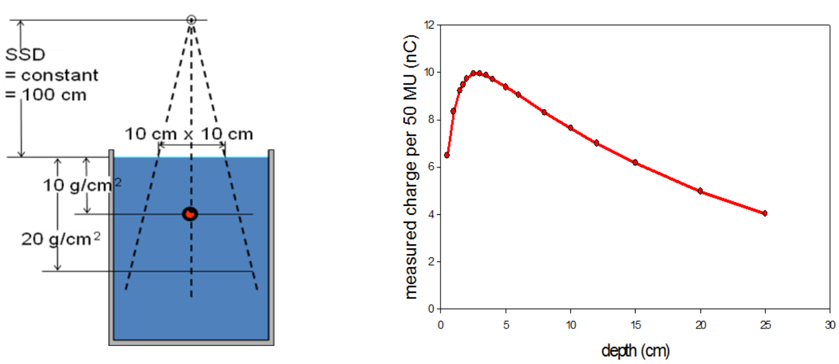

Figure 3 - Example of a depth dose measurement at central ray: a) reference conditions, b) central axis measured charge per 50 MU

Such measurements should be made for all possible combinations of field size and SSD or SAD used for radiotherapy treatment. An example of a depth dose measurement at central ray is shown in figure 3, b). Factor to correct the response of an ionization chamber for the effect of the difference between the standard reference temperature and pressure specified by the standards laboratory and the temperature and pressure of the chamber in the user facility under different environmental conditions. In our case $k_{T,P}$

$$k_{T,P} = \frac{(273.2+T)}{(273.2+T_o)}\frac{P_o}{P} = 1.034$$

Determination of the quality index for high energy photons using the depth dose procedure:

$$M_{10} = 7.745 \text{ nC},$$

$$M_{20} = 5.002 \text{ nC}$$

$$PDD_{20,10} = \frac{M_{20}}{M_{10}} = 0.652$$

For determination of k_Q, is important the reference beam quality for ^{60}Co and the beam quality index Q. TRS 398 calculated values of k_Q for high energy photon beams, for various cylindrical ionization chambers as a function of beam quality $\mathrm{TPR}_{20,10}$ is:

$$\mathrm{TPR}_{20,10} = 1.2661 \cdot PDD_{20,10} - 0.0595, \ \mathrm{TPR}_{20,10} = 0.767$$

Determination of the quality correction factor using interpolation between table values. To determine this value we used linear interpolation in Matlab and found the value 0.973. An example of these measurements is shown in Table 2.

Table 2. Calculated values of k_q for high-energy photon beams, for various cylindrical ionization chambers as a function of beam quality $\mathrm{TPR}_{20,10}$

Quality index	0.74	0.76	0.767	0.78	0.80
PTW 30006/30013	0.98	0.975	?	0.968	0.960

Determination of charge under reference conditions: measure charge, apply correction factors (Table 3).

Table 3. Measure charge under identical conditions with the lower voltage of 100 V:

Voltage	Charge in *nC*
400.0	7.674
100.0	7.587

where reference saturation is 100% and used polarizing potential is 400 V positive. From quadratic fit coefficients, for the calculation of k_s by the two voltage technique in pulsed and pulsed–scanned radiation, as a function of the voltage ratio *V1/V2*, we found:

$$k_s = a_o + a_1\left(\frac{M_1}{M_2}\right) + a_2\left(\frac{M_1}{M_2}\right)^2 = 1.004 .$$

Used polarizing potential +400 V, the polarity effect for photon beams usually is very small. In such a case where no information on the polarity used at calibration is given, it is better not to perform any correction. It may be a wrong correction.

Determination of corrected charge, M_Q: Chamber reading in beam of quality *Q* corrected for influence quantities to the reference conditions:

$$M_Q = 7.674 \cdot 1.034 \cdot 1.004 = 7.967 \text{ [nC/50 MU]}$$

where: k_s = 1.004 and $k_{T,P}$ =1.034.

Determination of $N_{D,W,Q}$ is based on calibration certificate of ionisation chamber. In our case we used absorbed dose to water calibration factor $N_{D,W,Q}$ *= 5.233 x 107 Gy/C* for beam quality ^{60}Co.

Using the formalism:

$$D_{w,Q} = M_Q\, N_{D,w,Q_o}\, k_{Q,Q_o}\ ,\ M_Q = 7.967 \text{ nC/50 MU},$$

$$D_{w,Q_o} = 5.233 \times 10^7 \text{ Gy/C},$$

$$k_{Q,Q_o} = 0.973,$$

we can calculate: $D_{w,15MV} = 0.812$ Gy/100 MU. Our ionization chamber reads 100 MU when an absorbed dose of 0.812 Gray is delivered to a point at the depth of maximum dose in a water-equivalent phantom whose surface is at the isocentre of the machine at 100 cm from the source and with a field size at the surface of *10x10* cm^2 for 15 MeV energy photons.

4. Conclusions

In this work we described, a different way to calculate the output dose of high energy photons in a linear accelerator according to the IAEA Code of Practice, TRS 398. This dosimetry application tool and protocol gives the basic concepts of e-learning methods using different non commercial software (Hyka N. et al. 2013). This academic education method is a good tool to practise radiation oncologists and medical physicists for linac beam calibration. Also, this application gives to the users good skills in cross check of hand calculation of dosses (Hyka N. et al. 2013). The most recent dosimetry protocols or codes of practice, based on the calibration of ionization chambers in terms of absorbed dose to water, use a photon beam quality specified in terms of $TPR_{20,10}$. However, there are more practical problems with measuring PDD than with $TPR_{20,10}$, and errors in determining the beam quality index may have in general more adverse consequences with PDD than with $TPR_{20,10}$. The accuracy of dose estimation would be more with the protocols based on the water calibration procedures, as no conversion quantities are involved for conversion from air to water. For this reason, this application tool cannot be used for clinical proposes. PTW – Unisoft IAEA 398 is the most popular professional software for acceptance tests, commissioning and QA procedures. It's always recommended a double calculation procedure for more accuracy.

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