DUJASE Vol. 5(1 & 2) 75-79, 2020 (January & July)

Experimental Study on Cross-calibrating Ideology for Small Field Dosimetry by High Spatial Resolution Detector

Farzana Hasan Shashi[1], Nafisa Tabassum[1], Md. Khalidur Rahman[2], Md. Faisal Rahman[3], Md. Mahidul Haque Prodhan[3], Zahid Hasan Mahmood[1]

[1]*Department of Electrical and Electronic Engineering, University of Dhaka, Dhaka, Bangladesh*

[2]*Department of Physics, Bangladesh University of Textiles, Dhaka, Bangladesh*

[3]*Department of Nuclear Engineering, University of Dhaka, Dhaka, Bangladesh*

[*]*E-mail: prodhan@du.ac.bd*

Received on 28 October 2019 (revised copy), Accepted for publication on 10 September 2020

ABSTRACT

The study regulates the absorbed dose to water as well as output factors for small fields using IAEA TRS-398 protocol and corrects the results by determining a cross-calibration factor for small fields using German dosimeter standard DIN 6809-8. Herein, we collected several datasets of small-field output factor for two separate values of X-ray energy, 6 MV and 10 MV, from a Varian CLINAC 2100 linear accelerator. The measurements for the datasets had been taken at a depth of 10 cm and varied between 10 × 10 cm² to 2 × 2 cm². Using the Multi-Leaf Collimator (MLC), the fields were outlined and the jaws (secondary) were preserved at 10 × 10 cm². With a PTW TM60012 silicon diode detector, the measurements were made. The volume of this detector is sufficiently small to collect a complete ionization reading for a small-field having a size of 2 × 2 cm². The calibration factors obtained from 4 × 4 cm² were 1.038 (for 6MV X-Ray) and 1.042 (for 10MV X-Ray). This calibration factors can successfully reproduce the institutional output factors from diode detector readings with a variation of maximum 0.6% to minimum 0.1%.

Keywords: Absorbed Dose, Cross-calibration Factor, Multi-Leaf Collimator (MLC), Institutional Output Factor.

1. Introduction

Radiotherapy, a branch of nuclear medicine, is a clinical method that deals with the utilization of ionizing radiation for treatment of various diseases like different types of cancers, tumors etc. [1 - 4]. Radiotherapy utilizes high energy ionizing radiation to contract tumors and destroy cancer cells [5]. Gamma rays, X-rays, and charged particles are some popular types of radiation widely used for cancer treatment [6]. The radiation may be applied by a machine which is placed outside a patient's body (external-beam radiotherapy), or by inserting radioactive material into a patient's body (brachytherapy) [7]. External-beam radiotherapy is often applied in the form of high energy photon beams (either gamma rays or X-rays) [8 - 9]. Systemic radiotherapy utilizes radioactive substances, for example radioactive iodine, that move through blood to eradicate cancer cells. Radiotherapy eradicates cancer cells by causing damage to their DNA [1]. Radiotherapy can either cause damage to DNA directly or can produce charged particles inside the cells that in turn can damage the DNA. A Cancer cell, whose DNA is dented beyond repair, stops getting divided or die. After these cells die, they get fragmented and removed by the body's usual processes. Doses of radiation varies depending upon various types of cancer cells and the radiation can also harm normal cells. This is why doctors study the extent of radiation to which any normal tissue can safely be exposed.

Radiation dosimetry deals with the techniques that quantitatively determine the amount of energy which is being deposited in any particular medium by direct/indirect ionizing radiations. In order to terminate cancer cells, cancer patients are given very precise and targeted amount of radiation during the course of their treatment. To measure the dose, an apparatus is placed in the region of radiation beam and the radiation produces an electrical charge inside that apparatus. The amount of deposited energy can be determined by measuring the corresponding amount of the electric charge or current. In order to convert the measured electrical quantity into a radiation dose, a calibration coefficient is used. The measurement of the electrical quantity can yet vary depending on the nature of the radiation beam (electrons, photons, etc.) and the environmental conditions.

This paper presents small-field output factors that were measured by silicon diode detectors for two different X-ray energies from the **"CLINAC"** linear accelerator by Varian Medical Systems, situated at the Oncology & Radiotherapy Centre, Square Hospitals, Dhaka, Bangladesh. The purpose of this paper is to determine a cross-calibration factor to correct the readings of the diode detectors as diode detector readings tend to deviate from the actual reading.

2. Materials and Methods

The equipment and machines used for setting up the experimental procedures in the present research work have been briefly discussed below. Linear accelerator (LINAC), radiation detectors, electrometer and phantoms play vital role on cross-calibrating small field**.**

2.1 Linear Accelerator (LINAC) [10]

This device is widely used to perform external-beam radiotherapy of the cancer patients. It is capable of delivering high energy X-rays to the locality of the tumor. LINAC accurately produces, monitors, controls and confirms the radiation beam to the target.

Fig. 1. Varian CLINAC 2100 Linear Accelerator at Square Hospitals, Dhaka

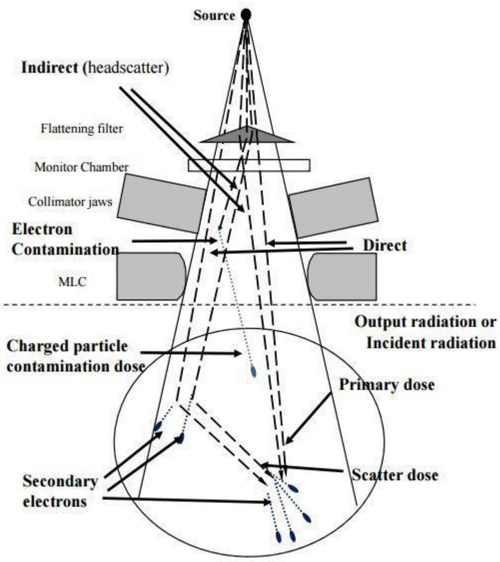

Fig. 2. Internal Construction of LINAC [11]

2.2 Radiation Detectors

A radiation detector, generally called a dosimeter, can provide a reading that indicates the average amount of the absorbed dose which has been deposited on its sensitive volume through ionizing radiation.

2.2.1 Ionization Chambers [12- 16]

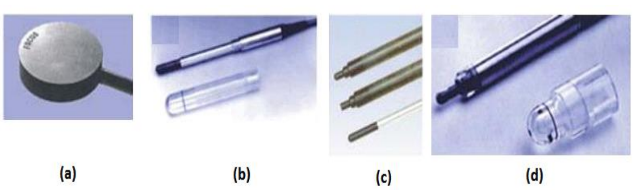

Fig. 3. Examples of some ionization chambers which are used in radiation therapy[12]**:** (a) Parallel plate Roos type electron-beam ionization chamber; (b) Farmer type cylindrical chamber with a Cobult-60 buildup cap; (c) Cylindrical ionization chambers (for relative dosimetry); (d) Pinpoint mini-chamber and Cobult-60 buildup cap.

Ionization chambers are commonly used for the calibration of clinical electron and photon beams. They usually contain three electrodes to define the sensitive air volume. In such ionization chambers, the sensitive air volume is typically in the range of 0.1 to 1 cm^3.

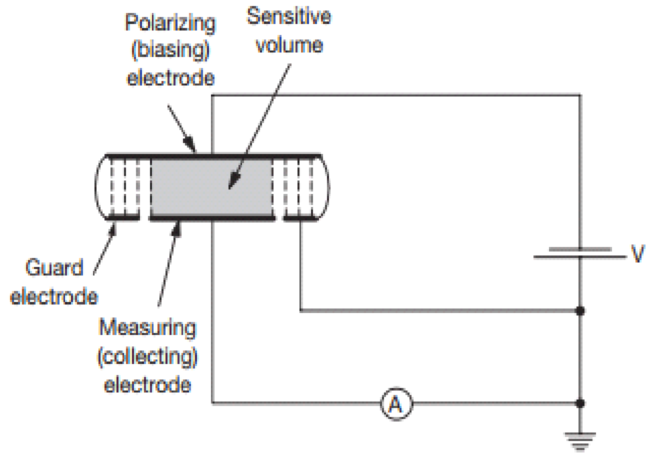

Fig. 4. Circuitry of a dosimetry system which is based on ionization chamber [12]

2.2.2 Silicon Diode Dosimeter System [17 - 18]

A Si diode dosimeter is basically a pn junction diode. To produce a pn junction diode, a p type or an n type silicon base material is taken and the surface is counter-doped. Depending upon the base material, this dosimeter is denoted as a p–Si or an n–Si dosimeter. For radiotherapy dosimetry, only the p–Si type dosimeter is appropriate.

Fig. 5. Silicon Diode Dosimeter (PTW TM60012, S/N 00589)

2.3 Electrometer:

Electrometers are used to measure small currents, typically in the range of 10^{-9} Amp or less. An electrometer which is used in aggregation with an ionization chamber usually contains a negative feedback op-amp with a high gain.

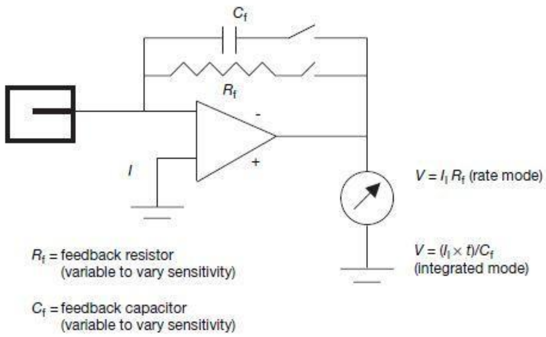

Fig. 6. Electrometer in Feedback Mode of Operation[12]

2.4 Phantoms and Measurement Medium

For dosimetry measurements of electron and photon beams, water is typically used as the standard phantom material.

2.5 Experimental Procedure

At 100 cm (SSD), the multileaf collimator shaped fields have been defined. The point of dimension has been set at a depth of 10cm (effective depth) in water. By tertiary MLC, the sizes of different fields have been well-defined for the CLINAC linear accelerator by Varian Medical Systems, situated at the Oncology & Radiotherapy Centre, Square Hospitals, Dhaka, Bangladesh. Secondary jaws have been kept stable at 10×10 cm^2. This setup offered a convincing MLC/jaw arrangement for IMRT. By maximizing secondary jaw opening to MLC opening ratio, this configuration has also made the most of the effect of MLC modelling within the TPS (treatment planning system). Measurements have been taken for the field dimensions of 10×10, 6×6, 4×4, 3×3 and 2×2 cm^2. Field size dependence output factors have been normalized to the 10×10 cm^2 field value.

3. Data Collection and Calculations

3.1 Output Factor Dataset

Table 1: Un-calibrated Output Factor Dataset for 6 MV X-Ray

Field Size (cm^2)	Meter Reading (nC)	Output Factor	
		Square Hospital	stitution[19]
2x2	79.60	0.766	0.796
3x3	83.60	0.805	0.841
4x4	87.45	0.842	0.874
6x6	94.00	0.905	0.929
10x10	103.90	1	1

Table 2: Un-calibrated Output Factor Dataset for 10 MV X-Ray

Field Size (cm^2)	Meter Reading (nC)	Output Factor	
		Square Hospital	Institution[19]
2x2	88.95	0.796	0.828
3x3	94.15	0.842	0.875
4x4	97.80	0.875	0.912
6x6	103.50	0.926	0.953
10x10	111.80	1	1

3.2 Cross Calibration Factor for Small Field Output Factor

The DIN 6809-8 standard initially determines the calibration factor for the absorbed dose to water measured by a high spatial resolution detector i.e. a silicon diode detector. The same calibration factor calibrates the output factors as well due to the fact that output factor is the ratio of two absorbed doses to water. According to the DIN 6808-9 standard, this calibration factor is measured from the 4cm x 4cm field size data. We can re-write the calibration factor, NCC equation as:

$$\mathrm{NCC} = \frac{\mathrm{OFD}}{\mathrm{OFM}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

where, OFD = Output Factor measured with ionization chamber and OFM = Output Factor measured with high spatial resolution detector

3.2.1 Calibration Factor for 6 MV X-Ray

Here, O_{FD} = 0.874 and OFM = 0.842

So, $N_{CC} = \frac{\mathrm{OFD}}{\mathrm{OFM}} = \frac{0.874}{0.842} = 1.038$

Now, for 3cm x 3cm field,

O_{FM} = 0.805

So, O_{FD} (Experimental) = O_{FM} x N_{CC}

= 0.805 x 1.038

= 0.836

And O_{FD} (Institutional) = 0.841

Percentage of Error $= \frac{0.841-0.836}{0.841}$ x 100%

$= 0.6\ \%$

Again, for 2cm x 2cm field,

O_{FM} = 0.766

So, O_{FD} (Experimental) = O_{FM} x N_{CC}

= 0.766 x 1.038

= 0.795

and O_{FD} (Institutional) = 0.796

Percentage of Error $= \frac{0.796-0.795}{0.796}$ x 100%

$= 0.1\%$

Table 3: Calibrated Output Factor Dataset for 6 MV X-Ray

Field Size (cm^2)	Output Factor	
	Square Hospital	Institution[19]
2x2	0.795	0.796
3x3	0.836	0.841

3.2.2 Calibration Factor for 10 MV X-Ray

Here, O_{FD} = 0.912 and O_{FM} = 0.875

So, $N_{CC} = \frac{\mathrm{OFD}}{\mathrm{OFM}} = \frac{\mathbf{0.912}}{\mathbf{0.875}} = 1.042$

Now, for 3cm x 3cm field, OFM = 0.842

So, O_{FD} (Experimental) = O_{FM} x N_{CC}

= 0.842 x 1.042

= 0.877

and O_{FD} (Institutional) = 0.875

Percentage of Error = $\frac{0.875-0.877}{0.875}$ x 100% = 0.2 %

Again, for 2cm x 2cm field, O_{FM} = 0.796

So, O_{FD} (Experimental) = O_{FM} x N_{CC}

= 0.796 x 1.042

= 0.829

and O_{FD} (Institutional) = 0.828

Percentage of Error = $\frac{0.828-0.829}{0.828}$ x 100%

= 0.1%

Table 4: Calibrated Output Factor Dataset for 10MV X-ray

Field Size (cm^2)	Output Factor	
	Square Hospital	Institution[19]
2x2	0.829	0.828
3x3	0.877	0.875

Hence we can conclude that the calibration factor measured from 4cm x 4cm works for smaller fields with considerable precision.

3.3 Result Analysis

Un-calibrated and calibrated output factor datasets for 6 MV and 10 MV X-rays, measured for CLINAC linear accelerator by Varian Medical systems situated at the Oncology & Radiotherapy Centre of the Square Hospital, Dhaka, Bangladesh and institution [19]. Treatment planning system (TPS) have been shown in Table-1 to Table-4.

For 6MV and 10MV X-rays, small-field output factors have been determined and compared to the TPS calculated values. As expected, measured output factors for the Square hospital's Varian CLINAC 2100 linear accelerator have decreased with decreasing MLC field size. The greatest fall with field size has occurred for the 6 MV beam. Output factors for 6MV beam have found to be considerably smaller. The spread in the Square Hospital measured values (percentage of error) have found to be, on average, 0.35% (ranging from 0.1%–0.6%) for 6 MV beam and on average, 0.15% (ranging from 0.1%–0.2%) for 10 MV beam. For the field size of 2×2 cm^2, the spread in the obtained values has found to be noticeably bigger. This indicates to the difficulty in translating measured data into a modified beam model that deals with very small size fields. It also indicates that for distinct linear accelerators, obtained measurements may often disagree with the calculation for the fields with the smallest sizes. The dissimilarity among the Square Hospital's obtained values and the institution's values has also been shown in following figures (Figure 7 to Figure 10). The average absolute percentage of error has found to be greater for the field with the smallest size along with a lower output factor.

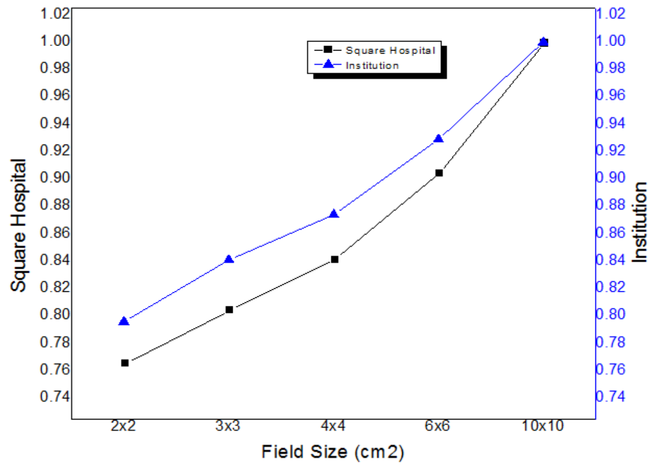

Fig. 7. Un-calibrated Output Factor Dataset for 6 MV X-Ray.

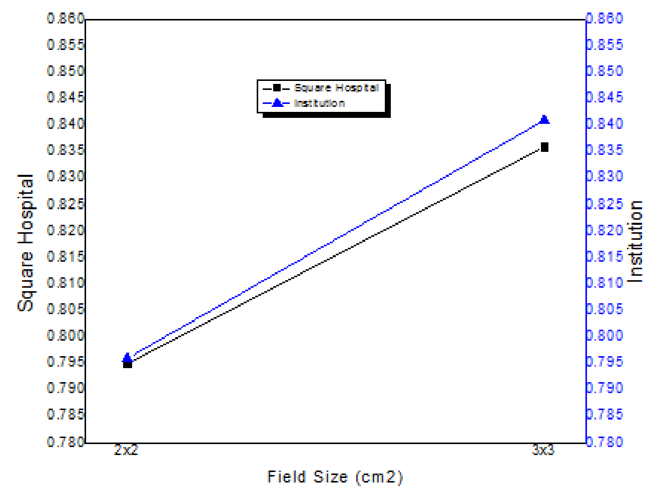

Fig. 8. Calibrated Output Factor Dataset for 6 MV X-Ray.

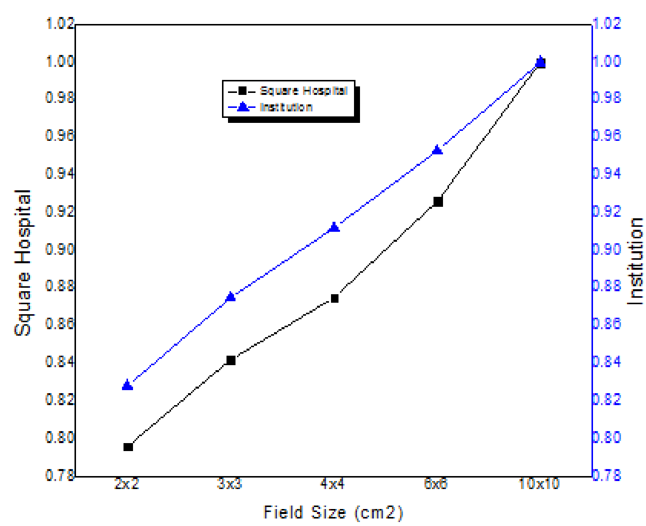

Fig. 9. Un-calibrated Output Factor Dataset for 10 MV X-Ray.

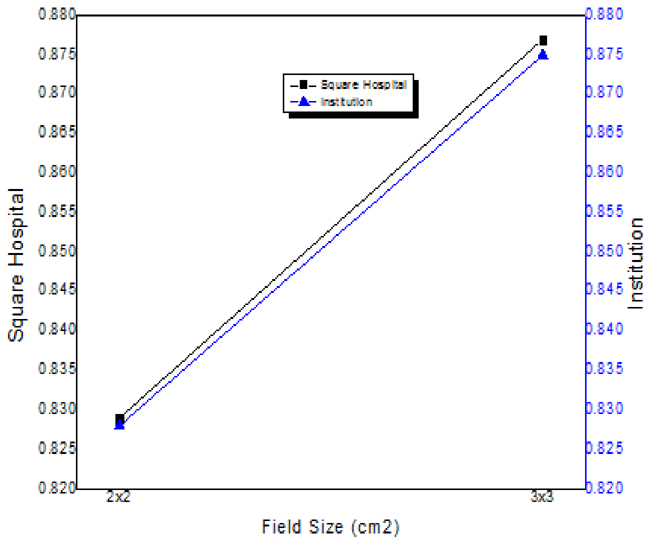

Fig. 10. Calibrated Output Factor Dataset for 10 MV X-Ray.

From the graphs (Fig. 8, Fig. 10), it is evident that the calibrated output factors for both 6 MV and 10 MV X-Ray energies almost similar to the institutional measurements which conclude that these calibration factors can be used to correct the silicon diode detector readings for small fields to produce closely matched results with institutional values.

4. Conclusion

Silicon diode detectors can be constructed with high spatial resolution; hence they are the most suited detectors for small field dosimetry. But diode detectors do not give as precise readings as ionization chambers due to the dependence on environmental parameters and its working principle. This newly proposed formalism of calibrating output factors of small fields measured with high spatial resolution detectors is really beneficial for field sizes much smaller than 4cm x 4cm because ionization chambers fail to determine the correct reading in such small field sizes as their dimension becomes larger than the field sizes. Additionally, it can be used to correct the readings measured with high spatial resolution detectors such as silicon diode with high precision.

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