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QUALITY CONTROL AND DOSIMETRIC ACCURACY ASSESSMENT OF COBALT-60 TELETHERAPY UNIT AT SSDL, BANGLADESH

MD. ABDUL AZIZ[1], SANTUNU PUROHIT[1], TANJIM SIDDIQUA[2], MD. SHAKILUR RAHMAN[2] and AKM MOINUL HAQUE MEAZE[1]*

[1] Department of Physics, University of Chittagong, Chittagong- 4331, Bangladesh
[2]Secondary Standard Dosimetry Laboratory, Institute of Nuclear Science & Technology, Bangladesh Atomic Energy Commission, Savar- 1100, Bangladesh

**Corresponding author e-mail: meaze@cu.ac.bd*

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ABSTRACT

External beam radiotherapy, often known as teletherapy, is one of the most efficient ways to treat cancer since it targets harmful cells with radiation. Dosimetric accuracy of a recently installed Cobalt-60 teletherapy unit (Theratron Equinox100#2149, Initial Activity: 12000 Ci) at the Bangladesh Atomic Energy Commission's Secondary Standard Dosimetry Laboratory (SSDL), Savar, Dhaka, has been the main focus of this work. Several measurements are made that are necessary to ensure the accuracy of the Cobalt-60 teletherapy unit in terms of dosimetric level, specifically the accuracy of absolute and relative dosimetry. These measurements include the following dosimetric parameters: absorbed dose to water, percentage depth dose (PDD), beam profile, inter-chamber comparison (to ensure the highest level of dosimetry accuracy), and comparison of absorbed doses using two protocols named IAEA TRS-277 and IAEA TRS-398. The absorbed dose rate at reference field size (10×10 cm^2) was found to be 1.548 Gy/min with an uncertainty of ±0.020. In the case of the inter-chamber comparison, the maximum deviation among values of absorbed dose to water for four Farmer chambers was 0.27% for $D_w(Z_{ref})$ and 0.26% for $D_w(Z_{max})$. The resultant output of this study may contribute to developing the treatment planning system in the realm of cancer treatment.

Keywords: *Quality Control, Co-60 teletherapy, IAEA TRS 277 and 298*

1. INTRODUCTION

Cancer was considered a western disease in the past, but now cancer is affecting and killing more people in the developing world than in the industrialized nations [1]. In 2012, about 65% of all deaths that occurred globally due to cancer were in the low- and middle-income countries (LMICs) [2, 3]. Because of relatively low awareness, late diagnosis, and the lack of access to affordable curative services, patients with cancer in the LMICs have a poorer prognosis about the diseases [4, 5]. According to research, in 2018, about 9.8 million cancer deaths happened, and an estimated 18.1 million people had been diagnosed with cancer [2, 6]. As per the WHO estimation, the annual cancer-related deaths will reach 16.5 million, and the annual number of new cancer diagnoses will reach 29.5 million by 2040 [4]. As per the current world scenario, one of the most prominent treatments for cancer is 'radiation therapy,' as more than 50% of all cancer patients across the world required radiation therapy during their course of illness [7, 8]. The therapeutic treatment of cancer refers to the use of ionizing radiation for killing the malignant cells. However, the main purpose of killing the tumor cells is to protect the vital cells from infections [9, 10]. But the main constraint to strengthen access to cancer care in LMICs is the high cost of modern radiotherapy machines [11]. Cobalt-60 teletherapy machines are the cheapest among all the external-beam radiotherapy machines available in the current world. Besides being comparatively cheap, the Cobalt-60 teletherapy machine has some other advantages, such as low cost, low maintenance cost, lower power need, less machine downtime, constancy of beam quality, etc. Due to these reasons, Cobalt-60 machines are suitable for treatments of commonly encountered types of cancers in LMICs [11]. Dosimetry is an essential component of QA, which is done in order to ensure that dose output and several factors useful in QA are within an acceptable limit according to the recommendation of the American Association of Physics in Medicine [12].

The main responsibility of a Secondary Standard Dosimetry Laboratory (SSDL) is to bridge the gap between the Primary Standard Dosimetry Laboratory (PSDL) and the users of ionizing radiation by enabling the transfer of dosimeter calibrations from the primary standard to the user instrument [13]. One of the principle goals of SSDL, Bangladesh (situated at Ganakbari, Savar, Dhaka) in the field of radiotherapy dosimetry is to guarantee that the dose delivered to patients undergoing radiotherapy treatment is within internationally accepted levels of accuracy [14]. According to ICRU, the dose should be within ±5% of the prescribed dose [15]. There are three basic methods that are currently used for the absolute determination of absorbed dose to water: calorimetry, chemical dosimetry, and ionization dosimetry. At present, these are the only methods that are sufficiently accurate in order to form the basis of primary standards for measurements of absorbed dose to water [16]. Comparisons of primary standards of absorbed dose to water have been carried out over the past decade [17, 18]. On the other hand, comparisons of air-kerma primary standards have a much longer history. Results of comparisons at the International Bureau of Weights and Measures (BIPM) in terms of absorbed dose to water for ^{60}Co gamma radiation are given in Ref. [19]. However, the air-kerma primary standards of all PSDLs are graphite cavity ionization chambers, and the conversion and correction factors used are strongly correlated. The standards for radiation oncology prescribed by the American College of Radiology [20-22] specify a QA program including patient chart review [23-28]. The purpose of this study is to determine the accuracy of absolute and relative dosimetry, which are essential measurements for ensuring the Cobalt-60 teletherapy unit's dosimetric level. The following dosimetric characteristics are included in these measurements: beam profile, absorbed dose to water, percentage depth dose (PDD), inter-chamber comparison (to ensure the highest degree of dosimetry accuracy), and comparison of absorbed doses using two protocols, which are IAEA TRS-277 and IAEA TRS-398.

2. MATERALS AND METHODS

The Secondary Standard Dosimetry Laboratory of the Bangladesh Atomic Energy Commission is facilitated with well-equipped dosimetry and radiation safety equipment. A Cobalt-60 teletherapy machine under the trade name EQUINOX-100 with teletherapy source number S-6356, source type Cobalt-60, and a maximum capacity of source head equal to 445.0 TBq (12,026 Ci) supplied by Best Theratronix Ltd. was used for the present investigation.

Two water phantoms were used in the dosimetry, such as the IAEA phantom (30 cm × 30 cm × 30 cm) and the CNMC phantom (40 cm × 38 cm × 38 cm). IAEA phantom was used for dose calculation, and CNMC phantom was used for measurement of PDD (Percentage Depth Dose) and beam profile. A calibrated FC65-G (serial no. 4324) chamber (ion chamber type with 0.65 cm^3 volume), a calibrated electrometer Dose1 (serial number 27889), a calibrated barometer, a calibrated thermometer, and some other particular instruments were used in the whole dosimetry.

Before going to the dosimetry part, it's very important to check various mechanical parameters regarding the Co-60 teletherapy unit. For ensuring the accuracy of mechanical parameters, some crucial checks like the parameters of optical field size verifications, accuracy of alignment lasers, optical distance indicator (ODI) accuracy, mechanical isocenter with respect to the rotation of gantry and collimators, collimator and gantry angle accuracy, parallelism and orthogonality of jaws, movements of couch (treatment table) in various directions, etc. were checked for their specified tolerance prescribed by IAEA.

The output factor may be determined as the ratio of corrected dosimeter readings measured under a given set of non-reference conditions to those measured under reference conditions. These measurements are typically done at the depth of maximum dose or at the reference depth and corrected to the depth of maximum dose using percentage depth-dose data (or TMR). When output factors are measured in open as well as wedged beams, special attention should be given to the uniformity of the radiation fluence over the chamber cavity. In wedged beams, the radiation intensity varies strongly in the direction of the wedge. For output measurements in such beams, the detector dimension in the wedge direction should be as small as possible. Small thimble chambers aligned with their axis perpendicular to the wedge direction are recommended. The coincidence of the central axes of the beam, the collimator, and the wedge should be ensured prior to making the output measurements.

The measurement of dose (output) for SSD (source to surface distance) techniques is done by following the TRS-398 protocol for absorbed dose measurement in External Beam Radiotherapy (EBRT) [14]. The calibrated Farmer chamber (FC65-G #4324) was placed at the reference depth of 10 cm in the 30×30×30 cm^3 water phantom. For SSD measurements, the surface of water was kept at 100 cm, such that the source to chamber distance was 110 cm. then five readings were taken each for 1 minute for different field sizes ranging from 5×5 cm^2 to 20×20 cm^2.

The absorbed dose rate to water (output) at reference depth was obtained by using the following formula [29]:

$$Dw = M_R \times K_{Pol} \times K_S \times K_Q \times N_{DW} \times K_{TP} \quad (1)$$

Where,

M_R = Average Electrometer reading obtained
K_{Pol} = Polarization correction factor
K_S = Recombination correction factor [30]
K_Q = Beam energy correction factor
N_{DW} = Combined Electrometer and ion chamber calibration factor [31]
K_{TP} = Temperature and Pressure correction factor

As the ionization chamber was kept at a reference depth of 10 cm, the output obtained from the above equation would be at 10 cm depth. In order to obtain the output at d_{max} as a function of field size, the above formula was divided by the percentage depth dose value corresponding to 10 cm depth for the SSD technique [31].

The outputs for different fields were obtained, and the output factors for the individual fields were calculated.

PDDs were mainly calculated from two basic data points: depth and dose. The FC65-G ionizing chamber was placed in several depths of water from the surface. Then the accumulated charges were measured by the Dose1 #27889 Electrometer. Several readings were taken from which the average value for charges was determined. Then the charges provided us with the amount of dose. Thus, depth and dose were determined for measuring the PDD by plotting a graph (shown in Figure. 1).

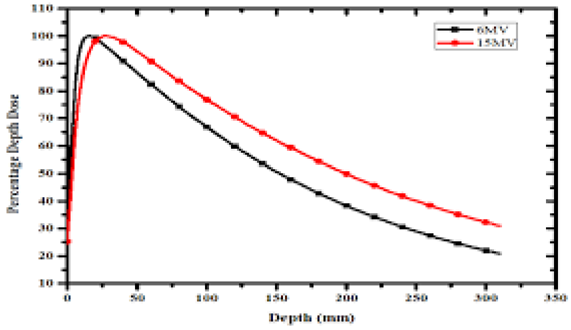

Fig. 1. Conceptual diagram of PDD (percentage Depth Dose)

Beam profiles were also generated by almost the same procedure. The only different procedure was that in this case, the distances were considered on the X-axis instead of depth on the Y-axis. Then the accumulated charges were calculated in the same way. Then corresponding graphs were generated by putting the distance in the X-axis and the dose (shown in Figure. 2).

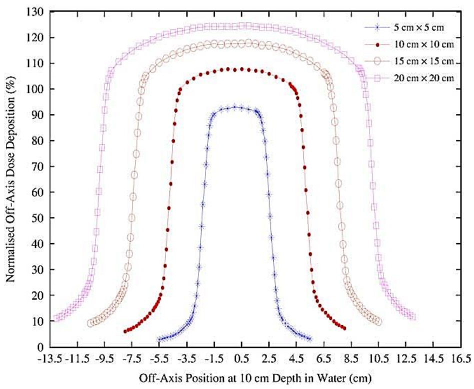

Fig. 2. Conceptual diagram of beam profiles

For ensuring the maximum accuracy in the dosimetry, an inter-chamber comparison was also done. For comparison among the four Farmer-types ionizing chambers (IBA FC65-G #4324, PTW 30013 #011153, EXRADIN A19 #XAQ110103, NE 257 #1205), the dose in 5 cm depth in water was calculated for each chamber by the Cobalt-60 teletherapy unit. Considering FC65-G as the reference chamber, the deviations of $D_W(Z_{ref})$ and $D_W(Z_{max})$ from the FC65-G were calculated for the rest three ionizing chambers.

3. RESULTS

3.1 Dose measurement

The dose measurement process was performed with an ionization chamber (FC65-G #4324) and an electrometer (Dose 1 #27889). The SSD was 100 cm while performing the whole dose measurement process. The IAEA water phantom (30×30×30 cm^3) was used for these measurements. The data of accumulated charge were collected from the electrometer reading throughout these measurements, and then they were used in the measurement of absorbed dose according to the IAEA TRS-398 protocol. Some uncertainty was present here, which is shown later. The resulting value of absorbed dose for different sizes of field is shown in Table. 1.

Table. 1 Dose for different field sizes

Field size (cm × cm)	**Absorbed Dose, $D_w(Z_{max})$ Gy/min**	**Output factors**
5 × 5	1.459	0.942
6 × 6	1.493	0.964
7 × 7	1.510	0.975
8 × 8	1.524	0.984
9 × 9	1.539	0.994
10 × 10	1.548	1.000
12 × 12	1.576	1.018
14 × 14	1.599	1.032
15 × 15	1.610	1.039
16 × 16	1.619	1.046
18 × 18	1.637	1.057
20 × 20	1.654	1.068

Output factors are calculated as the ratio of dose in a particular field to dose in the reference field. Here, the reference field size is 10 × 10 cm^2.

3.2 Percentage depth dose (PDD)

The PDD measurement process is performed with a Farmer chamber (FC65-G #4324) and an electrometer (Dose 1 #27889). All the measurements were taken at 100 cm SSD. CNMC water phantom was used for this procedure. The PDD curves for several field sizes (10 × 10, 15 × 15, and 20 × 20 cm^2) are shown in Fig. 3.

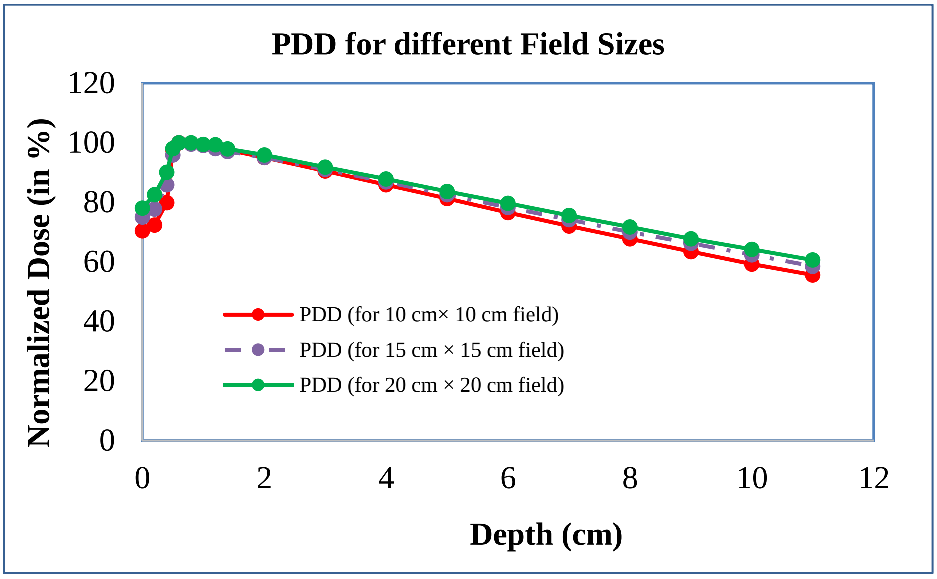

Fig. 3. Percentage Depth Doses (PDD) at 100 cm SSD for different fields

3.3 Beam profile

The procedure of generating the beam profile is performed with a Farmer chamber (FC65-G #4324) and an electrometer (Dose 1 #27889). All the measurements were taken at 100 cm SSD. The resultant beam profiles for several field sizes (10 × 10, 15 × 15, and 20 × 20 cm^2) are given in Fig. 4.

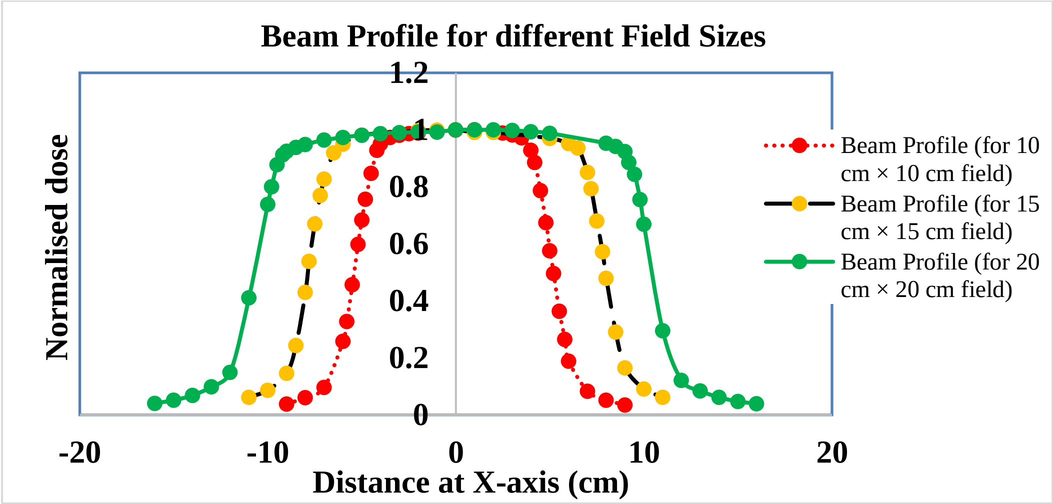

Fig. 4: Beam Profile for different Field Sizes at 100 cm SSD of the Co-60 teletherapy unit

3.4 Inter-chamber comparison

Inter-chamber comparison is performed with four different types of ionizing chambers using TRS-398 and TRS-277. SSD was 100 cm for every chamber. The different values for different Farmer chambers are shown in Table. 2.

Table. 2 Inter-chamber comparison

Farmer chambers	**$D_w(Z_{ref})$ (Gy/min)**	**$D_w(Z_{max})$ (Gy/min)**	**Deviation of $D_w(Z_{ref})$ From IBA chamber (%)**	**Deviation of $D_w(Z_{max})$ from IBA chamber (%)**
IBA FC65G(#4324)	1.195	1.486	0	0
PTW 30013(#011153)	1.198	1.489	0.226	0.222
EXRADIN A19(#XAQ110103)	1.195	1.486	0.017	0.020
NE 2571(#1205)	1.198	1.490	0.268	0.262

3.5 Measurement of uncertainty in dosimetric level

The uncertainty of the scale reading can be estimated by taking n measurements (at least 10) and calculating the mean value and the standard deviation of the mean (type A uncertainty). The uncertainty in dosimetric level is given in Table. 3.

Table. 3 Calculation of uncertainty in dosimetry for different field sizes

Field Size (cm × cm)	**Type-A Uncertainty (%)**	**Type-B Uncertainty (%)**	**Combined Uncertainty (%)**	**Corrected value of absorbed dose, $D_w(Z_{max})$ Gy/min**
5 × 5	0.332	1.136	1.184	1.459 ± 0.017
6 × 6	0.331	1.136	1.183	1.493 ± 0.018
7 × 7	0	1.136	1.136	1.510 ± 0.017
8 × 8	0.330	1.136	1.182	1.524 ± 0.018
9 × 9	0.328	1.136	1.182	1.539 ± 0.018
10 × 10	0.611	1.136	1.290	1.548 ± 0.020
12 × 12	0.615	1.136	1.292	1.576 ± 0.020
14 × 14	0.621	1.136	1.295	1.599 ± 0.021
15 × 15	0.312	1.136	1.388	1.610 ± 0.022
16 × 16	0.629	1.136	1.299	1.619 ± 0.021
18 × 18	0.324	1.136	1.181	1.637 ± 0.019
20 × 20	0.325	1.136	1.182	1.654 0.020

4. DISCUSSION

Generally, the accuracy of treatment for a cancer patient is very much dependent on the accuracy of the measurement of different dosimetric parameters of the Cobalt-60 teletherapy unit. Measured values of absorbed dose, output factor, PDD, and beam profile for different field sizes were in an acceptable range as per the IAEA TRS-398 protocol. The measured values of absorbed dose for different field sizes had uncertainty of 1.136%-1.388% due to some technical and manual errors. Also, some mechanical errors were responsible for these deviations and uncertainty. The maximum dose was found at 0.6 cm depth from the PDD curve for different field sizes. The expected or standard value of the depth of the maximum dose is 0.5 cm. This slight deviation in value has occurred because of the uncertainty of the effective volume of the ionization chamber. Similarly, some deviations in linearity and symmetry of beam profile were also present. This might occur because of uncertainty in positioning the chamber, uncertainty in measuring the SSD, etc. Four different types of Farmer chambers were used for comparing among the measured absorbed doses by respective chambers. Basically, three Farmer chambers (PTW, EXRADIN, NE) were compared with the IBA Farmer chamber to find out the accuracy of measurements and to find out the deviations among them. The values for absorbed dose to water at 5 cm depth for PTW, EXRADIN, and NE Farmer chambers had 0.226%, 0.017%, and 0.268% deviations, respectively, from the IBA Farmer chamber. The values for maximum absorbed doses to water for PTW, EXRADIN, and NE Farmer chambers had 0.222%, 0.020%, and 0.262% deviations, respectively, from the IBA Farmer chamber. These deviations might occur due to the mechanical errors in the teletherapy unit, errors in positioning the chambers, etc. Overall, the uncertainty in several measurements of this work was found within the acceptable range. The uncertainty and deviations could be reduced more by determining the wedge factor and tray transmission factor.

5. CONCLUSIONS

Bangladesh has around 13 to 15 lakh cancer patients, with approximately 2 lakh new cases diagnosed each year. The radiotherapy treatment of this large number of cancer patients is performed by several cancer hospitals with several equipment. The accuracy of this radiotherapy treatment depends on several factors; one of them is accuracy in calibration of the equipment. SSDL, BAEC provides this calibration facility to the cancer hospitals in Bangladesh. According to this study, the absorbed dose was increasing in a remarkable ratio while increasing the sizes of the field, which means the measured doses for different field sizes were in a good pattern. The value of uncertainty in the dosimetric level is nearly 1.1 to 1.4%, which is a good indication of accuracy. The PDD curve for three different normal fields gave a good indication about the accuracy of dosimetry as they were in a desired acceptable range. The beam profiles for three different normal fields were found to be in a good level of accuracy since the linearity, penumbra, and other parameters were in an acceptable range. This is an indication of maximum accuracy. In the case of the inter-chamber comparison, the maximum deviation among values of absorbed dose to water for four Farmer chambers was 0.27% for $D_w(Z_{ref})$ and 0.26% for $D_w(Z_{max})$, which indicates a good sign of accuracy in the measurements.

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