Dosimetric Verification of Bhabhatron-II Telecobalt Unit at the University College Hospital, Ibadan, Nigeria.

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Abstract: Bhabha Atomic Research Centre, Mumbai, India developed an indigenous Telecobalt unit, Bhabhatron-II, for cancer treatment in the year 2006. The electrical safety of the unit, conducted by the electronics regional test laboratory Thiruvananthapuram, found its compliance with the International Electro-technical Commission (IEC) standards. The radiological safety of Bhabhatron-II was evaluated shortly after its development and also found to comply with the IEC standards. Apart from these tests, there are other tests to which radiation facility must undergo before its acceptance for clinical applications. These include mechanical checks of various parts of the machine and dosimetric measurements of parameters needed for clinical application of the unit on patients. The mechanical check is not discussed in this study. The aim of this study is to verify some dosimetric parameters namely, collimator transmission, wedge transmission, tray factors and Cobalt-60 tissue maximum ratios for square field sizes that are not included in published standard data. This study was carried out during the acceptance testing and commissioning of Bhabhatron-II telecobalt unit newly installed at the University College Hospital, Ibadan, Nigeria. The values of most of the parameters considered in this study agree with values of similar parameters published in literature for Cobalt-60 unit. However, the transmission factors of four out of seven wedge filters have values that are within the values supplied by the Manufacturer. The dosimetric property of Bhabhatron-II telecobalt unit obtained in this study can complement the existing standard data for Cobalt-60 gamma radiation.
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Introduction

Cancer is a major health problem in the world, especially in developing countries where there are acute shortage of radiation treatment facilities due to low income/technical resources. Nearly 12.7 million cancer cases and 7.6 million cancer deaths occurred worldwide. Of these, more than half of the new cases and nearly two thirds of deaths, were in developing countries (IAEA PACT, 2010). The World Health Organization (WHO) stated that a developing country should have at least one teletherapy machine for a population of one million (Jayarajan et al, 2008).

Nigeria has eight Radiotherapy centers distributed by region to a population of 167 million (Zubema 2013). Each center is equipped with one teletherapy machine which means that there is one machine to 21 million. Although, the exact number of people living with cancer is not known but these treatment facilities are not adequate to cater for about 100,000 new cancer cases diagnosed in the country on an annual basis (Elegba, 2005).

The University College Hospital (UCH), Ibadan is one of these Radiotherapy centers and is located in the South-Western region of Nigeria. It was established in the year 1987 with one Telecobalt unit, Theratron 780C manufactured by the Atomic Energy of Canada Ltd (AECL). The average daily workload on this machine was 80 patients in an extended hour of service (8 am – 9 pm). After serving cancer patients within Nigeria and in West African sub-region for about 23 years, it was decommissioned in the year 2011 and replaced with Bhabhatron-II telecobalt unit in the year 2012.

Bhabhatron-II telecobalt unit was manufactured by Bhabha Atomic Research Centre (BARC), Mumbai, India. It is an isocentric external beam radiation therapy machine using radioisotope Cobalt-60 as the source of radiation. The radiological safety of Bhabhatron-II was evaluated shortly after its development and found to comply with the IEC standards (Sahani et al, 2009). Bhabhatron-II unit has capacity (maximum) to load 15 KCi source of radiation and has maximum exposure of 250 Roentgen per minute (RMM) at one meter.

While the radioactive source in the decommissioned Cobalt-60 unit, Theratron 780C, was shielded with depleted Uranium, the radioactive source in Bhabhatron-II unit is shielded with Tungsten, a non- radioactive and high density material. This enhances radiation safety of the unit. During patient treatment, the radioactive source moves from its shielded position to the approved treatment site and radiation beam is focused on this area, after the collimator is set to a desired size, shape and differential attenuation.

The useful square field size (X_{jaw} x Y_{jaw}) of Bhabhatron-II unit ranges from 3 cm x 3 cm (minimum) to 35 cm x 35 cm (maximum). The X_{jaw} is symmetric while the Y_{jaw} is asymmetric. On Bhabhatron-II unit, two treatment techniques, source to skin distance (SSD - 80 cm) and source to axis distance (SAD - 80 cm) are practicable, depending on tumor sites, gantry-couch clearance and decision of Radiation Oncologist. This also applies to radiotherapy simulation on digital simulator unit (Imagin), which accompanied the Indian telecobalt machine.

While the SSD set-up requires central axis percentage depth dose (PDD) data for clinical dosimetry calculations, the SAD set-up requires tissue maximum ratio (TMR) values and inverse square correction factor (if the source calibration is performed in SSD settings). In literature, there are standard tables of PDD for square field size (0 to 45 cm^2) at 80 cm SSD (Aird et al, 1996) and TMR (0 to 20 cm^2) for Cobalt-60 unit (Faiz, 2003).

Since the collimator assembly of Bhabhatron-II unit has capacity for square field sizes beyond 20 cm^2 (for TMR found in literature), it becomes necessary to generate TMR data for other square field sizes (25, 30 and 35 cm^2) which are needed for clinical dosimetry calculations.

In this study we measured some of the dosimetric parameters of Bhabhatron-II unit and compared them with published standard data for Cobalt-60 unit.

Material and Methods

The dosimetric property of Bhabhatron-II telecobalt unit, newly installed at the University College Hospital, Ibadan, Nigeria was considered in this study during its clinical commissioning.

All measurements were carried out using the International Atomic Energy Agency (IAEA) Technical Report Series (TRS 398, 2000). The aspect of this protocol for Cobalt-60 unit involves measurement of absorbed dose at 5 cm depth in water phantom, Field size setting of 10 cm x 10cm at SSD of 80 cm. A calibrated ionization chamber NEL 2571 with serial number 1998 was used with an Electrometer model NE 2570/1 Farmer Dosemeter.

Other devices used for measurement include a water phantom with dimension 30 cm x 30 cm x 30 cm, mercury-in-glass thermometer, analog Barometer and a pocket electronic dosimeter (model DOSIRAD-AL) manufactured by Bombay PVT Ltd, India. The water phantom has a vertical line graduated from 0.5 cm to 20 cm to enhance accurate positioning of ionization chamber with respect to depth in water. The guidelines specified in TRS 398 were used for calibration of radioactive source and measurement of Tissue Maximum Ratios for larger square field sizes (25, 30 and 35 cm^2) which are needed for clinical dosimetry calculations but are not available in standard tables of TMR for Cobalt-60 gamma radiation.

While the depth of TMRs published in standard table for Cobalt-60 ranged from 0.5 cm (d_{max} for Cobalt-60) to 30 cm, the range of depth of TMRs practicable with the dimension of water phantom used (supplied with Bhabhatron-II unit) in this study was from 0.5 cm to 18 cm. For quality assurance purpose, TMR values for square field sizes 10cm^2 and 20cm^2 were also measured and compared with values in standard TMR table for Cobalt-60 unit.

The radiation transmission through the collimator was measured with radiation dosimeter placed at 1 m from the radiation source for 1 min exposure. For this measurement, the collimator jaws were set such that one jaw is at maximum definable field size (35 cm) while the other jaw is fully closed (0 cm). The readings were recorded for two different collimator settings (i) X_{jaw} fully opened and Y_{jaw} fully closed (35 cm x 0 cm) and (ii) X_{jaw} fully closed and Y_{jaw} fully opened (0 cm x 35 cm).

Wedge factors were also determined for seven different (angle and width) wedge filters supplied with Bhabhatron-II unit. Radiation transmission through each of the wedge was determine from ratio of radiation dose with a modifier to that without it. The values (wedge factors) obtained were compared with the values stated by the Manufacturer. Similarly, the transmission factors of trays used to support Lead shielding blocks during treatment was determined. The trays are of four different patterns namely, star, stripes, slotted and plain. The radiation transmission through each of the tray was determined using ratios of radiation dose with the tray to that without the tray. The transmission factor obtained from plain tray was used to normalize transmission factors from other tray patterns.

The ability of Bhabhatron-II to deliver exact radiation dose at the set time on the control console was also investigated. This was carried out by using the most treatment technique on the machine, SAD of 80 cm SAD, in a water phantom with collimator setting of 30 cm x 30 cm. The ionization chamber was placed at 18 cm depth in water. The treatment time (timer setting) needed to deliver radiation dose of say, 1.88 Gy in SAD technique of treatment was calculated manually and input into Bhabhatron-II control unit. During irradiation, charges produced in the air cavity of ionization chamber within the set treatment time were recorded simultaneously and displayed on the Farmer electrometer connected to the Ionization chamber. These charges were converted to absorbed dose using the calibration coefficient of the ionization chamber plus the electrometer and other correction factors specified in TRS 398. The absorbed dose obtained from both methods (direct measurement and calculation) were compared.

Results

The technical specifications of Bhabhatron-II telecobalt unit considered in this study is presented in Table 1. These values were supplied by the Manufacturer.

Table 1: Technical specifications of Bhabhatron-II Telecobalt unit at the University College Hospital, Ibadan

Parameters	Value
Source strength	258 TBq (6971 Ci)*
Source to axis distance	80 cm
Maximum field size at isocentre	35 cm x 35 cm
Minimum field size at isocentre	0 cm x 0 cm
Lower jaw	from 0 cm to 35 cm
Upper jaw	from 0 cm to 35 cm
Optical distance indicator scale	SAD ±20
Minimum couch level above floor	66 cm
Couch horizontal motion	from 0 cm to 89.9 cm
Couch vertical motion	from 66 cm to 139 cm
Lateral motion	from -20 cm to + 20 cm
Rotational motion	from -90^o to + 90^o
Couch material	Carbon fibre
Couch transmission factor	99.89%
Collimator rotational angle	from – 90 to + 90
Wedge filters provided	Manual wedge filters of angles 15^o, 30^o, 45^o and 60^o
Standard shielding block	Shielding blocks of various shapes and sizes provided
Display of set parameters inside the room	TFT monitor
Radiation monitoring device	Treatment room radiation monitor detector (wall mounted)

The Activity of the radioactive Cobalt-60 source as at 24th June, 2013

The activity of radioactive Cobalt-60 source supplied with the machine was 258 TBq as at 24th June 2013 and the machine output (dose-rate) at d_{max} for field size 10 cm x 10 cm at 80 cm SSD was 218.860 cGy/min as at 18th September, 2013. The radiation leakage through the secondary collimator of the unit at two different collimator settings are presented in Table 2. The settings of the collimator is such that the pair of X-jaws is closed while the pair of Y-jaws is closed and vice versa.

Table 2: Leakages through the Collimator (Collimator Transmission)

Collimator Settings	Exposure rate mR/min	Avg. dose-rate (cGy/min) due to radiation leakage	% Rad. leakage*
X- jaws closed while Y- jaws opened	309.85	0.27	0.12
Y- jaws closed while X- jaws open	300.85	0.26	0.12

Radiation leakage w.r.t. the maximum absorbed doserate for a 10 cm x 10 cm radiation field (218.860 cGy/min) measured at source to surface distance of 80 cm; 1 mR = 8.7µGy

The percentage radiation leakage (0.12 %) measured in either settings of the jaws (X_{closed} x Y_{opened} and X_{opened} x Y_{closed}) is the same. This value is within the acceptable tolerance of 2 % (Kutcher et al, 1994) and is smaller than the values obtained from the previous version (Bhabhatron-I) of Bhabhatron telecobalt unit, where the transmission through the X_{jaw} was found to be 2.1 % (Jayarajan, 2008).

The radiation transmission through various wedge filters (width and angles) supplied with Bhabhatron-II unit is presented in Table 3. In addition to these, the values of wedge factors stated by the Manufacturer were also presented for comparison.

Table 3: Wedge Transmission factor

Wedge Filter Angle (deg.)	Wedge Filter Field size cm x cm	Wedge Factor, WF Manufacturer WF (A)	Wedge Factor, WF Measured WF (B)	(%) A/B
15	15W x 20	0.674	0.670	1.0
30	10W x 16	0.580	0.567	2.0
30	15W x 20	0.580	0.566	2.0
45	10W x 16	0.499	0.472	6.0
45	15W x 20	0.444	0.432	3.0
60	10W x 16	0.365	0.372	2.0
60	15W x 20	0.331	0.341	3.0

The transmission factor of each of the tray pattern is presented in Table 4. The values of other tray patterns were compared with that of plain tray and most of them have values that are within the acceptable tolerance of 2% (Kutcher et al, 1994).

Table 4: Tray transmission factor

Tray pattern	Measured Tray Factor	% variation from plain pattern
Star	0.945	2.0
Slotted	0.947	2.0
Stripes	0.975	5.0
Plain	0.930	1.0

The values of TMRs measured for different square field sizes (10, 20, 25, 30 and 35 cm^2) are presented in Table 5a and 5b. While Table 5a shows comparison between measured values and standard TMR values for square field sizes 10 cm^2 and 20 cm^2, Table 5b shows TMR values for larger square field sizes (25, 30 and 35 cm^2) which are not available in standard Cobalt-60 TMR table. The variation between measured and standard TMR values for square field size 10 and 20 cm^2 is within the acceptable tolerance of 2% (Kutcher et al, 1994).

Table 5a: Comparison between measured and published TMR data for Cobalt-60 unit

Depth cm	TMR Published 10 cm x 10 cm (P)	TMR Measured 10 cm x 10 cm (M)	M/P %	Depth cm	TMR Published 20 cm x 20 cm (P)	TMR Measured 20 cm x 20 cm (M)	M/P %
0.5	1.000	1.000	1.0	0.5	1.000	1.000	1.0
1.0	0.994	0.993	1.0	1.0	0.996	0.998	1.0
2.0	0.967	0.967	1.0	2.0	0.975	0.974	1.0
3.0	0.937	0.936	1.0	3.0	0.951	0.946	1.0
4.0	0.905	0.903	1.0	4.0	0.925	0.929	1.0
5.0	0.870	0.867	1.0	5.0	0.898	0.888	1.0
6.0	0.834	0.829	1.0	6.0	0.867	0.868	1.0
7.0	0.796	0.790	1.0	7.0	0.835	0.831	1.0
8.0	0.757	0.752	1.0	8.0	0.804	0.804	1.0
9.0	0.719	0.713	1.0	9.0	0.772	0.774	1.0
10.0	0.682	0.682	1.0	10.0	0.740	0.746	1.0
11.0	0.646	0.645	1.0	11.0	0.709	0.717	1.0
12.0	0.613	0.610	1.0	12.0	0.679	0.685	1.0
13.0	0.581	0.579	1.0	13.0	0.649	0.660	2.0
14.0	0.551	0.547	1.0	14.0	0.621	0.629	1.0
15.0	0.521	0.514	1.0	15.0	0.594	0.602	1.0
16.0	0.493	0.484	2.0	16.0	0.567	0.568	1.0
17.0	0.467	0.457	2.0	17.0	0.541	0.545	1.0
18.0	0.442	0.431	2.0	18.0	0.517	0.517	1.0

Table 5b: Measured TMR for field sizes that are not available in standard TMR data for Cobalt-60 unit

Depth cm	TMR* 25 x 25 cm^2	TMR* 30 x 30 cm^2	TMR* 35 x 35 cm^2
0.5	1.000	1.000	1.000
1.0	0.997	0.999	0.998
2.0	0.981	0.980	0.981
3.0	0.955	0.950	0.952
4.0	0.929	0.936	0.937
5.0	0.902	0.897	0.900
6.0	0.875	0.882	0.886
7.0	0.845	0.844	0.848
8.0	0.814	0.825	0.829
9.0	0.785	0.791	0.796
10.0	0.755	0.768	0.773
11.0	0.727	0.738	0.744
12.0	0.698	0.707	0.713
13.0	0.671	0.685	0.692
14.0	0.639	0.654	0.659
15.0	0.613	0.632	0.640
16.0	0.585	0.603	0.612
17.0	0.556	0.579	0.588
18.0	0.526	0.553	0.561

*Values for this square Field size are not available in standard TMR data for comparison.

The treatment execution in a Tele-cobalt unit requires the calculation of treatment time (timer setting) needed to deliver prescribed dose per fraction to the tumor. The comparison between the absorbed dose per fraction obtained by direct measurement and that obtained by calculation is presented in Table 6.

Table 6: Comparison between absorbed dose obtained by direct measurement and by calculation

Parameter	Values obtained from calculation	Values obtained from measurement
Technique	SAD	IAEA TRS 398
Field size	30 cm x 30 cm	30 cm x 30 cm
Depth	18 cm	18 cm
TMR	-	0.553
Output (Doserate) at dmax for Field size 10 cm x 10 cm at 80 cm SSD	207.46 cGy/min	-
Sc,p (30 cm x 30 cm)	1.1606	-
Inverse square correction	1.013	-
Prescribed dose per fraction	**1.88 Gy**	-
Timer setting to deliver the prescribed dose	1.39 min	-
Charges collected within the timer setting	-	41.80 nC
Calibration coefficient of Ionization chamber and Electrometer	-	4.488 cGy/nC
Conversion of charge to absorbed dose using the calibration coefficient of ionization chamber and electrometer)	-	**187.60 cGy (or 1.88 Gy)**

Discussions

The knowledge of dosimetric performance of high energy Teletherapy unit is highly required before its clinical application on patients. Certain documents from the Manufacturer usually accompany the delivery of the machine and its ancillary accessories to the end users. Some of these documents include specification of the supplied machine, the source calibration certificate (in case of Tele-Cobalt unit), wedge filters' dimension and their stated wedge transmission factors and any other information pertaining to the safety (radiation electrical and mechanical) of the unit.

For the purpose of quality assurance, some of the information supplied by the Manufacturer must be verified through the process of the acceptance testing and commissioning. The Bhabhatron-II Tele-Cobalt machine considered in this study is a new Tele-cobalt product in the market, manufactured in Indian, as compared with the conventional Cobalt-60 unit manufactured in Ontario, Canada (Theratron). Hence, the need to verify its dosimetric parameters and some of the values supplied by its Manufacturer.

The activity (258 TBq) of radioactive source installed in Bhabhatron-II unit was found to be less than the maximum source loading capacity (555 TBq) of the usual Bhabhatron-II Cobalt-60 unit. The reduction in source loading may be attributed to financial constraint and the need to match activity of the source with affordable reinforcement of the shielding capability of the existing bunker at our centre. This agrees with "ALARA" (As Low As Reasonably Achievable) principle of optimizing radiation protection within the available financial resources.

Also, the radiation leakage through the collimator of Bhabhtron-II, especially the X-jaws, was found to be less than the leakages recoded in the earlier model of the unit- Bhabhatron-I (Jayarajan, 2008). The reduction in radiation leakage through the jaws may be attributed to the technological improvement (from the year 2009 – 2012) in the materials used for collimators in this recent batch, Bhabhatron-II unit.

With respect to the measurement performed on the wedge filters, only 4 out of 7 pieces of wedge filters supplied, have values that are similar to the

Manufacturer's stated values and within the acceptable 2% deviation (Kutcher et al, 1994). On the other hand, the Manufacturer did not state values for transmission factors of various pattern of lead shielding trays supplied with the machine. Therefore, the transmission factors obtained for plain tray, being conventional, is used to standardized values obtained for other tray patterns. It was observed that their transmission factors are almost the same, meaning that these trays are only differ by pattern but similar in electron density. The transmission coefficient of a material depends on its electron density and not on the pattern or design inscribed on it. The only exception to this is the tray with stripes pattern, whose deviation from the plain tray is 5%.

Some of the dosimetric quantities needed for clinical application of Cobalt-60 unit are available in published standard data. These include Tissue Air Ratio (TAR), Scatter Maximum Ratios for circular fields, Percentage Depth Dose (PDD) for various source to skin distance, SSD (60, 80 and 100 cm), for square field sizes (0 – 45 cm^2) at various depths (0.5 – 30 cm) (Aird et al, 1996). Other published data for Cobalt-60 unit is the Tissue Maximum Ratio (TMR) for few square field sizes (0 – 20 cm^2) at various depths (0- 30 cm), (Faiz, 2003).

The dosimetric quantities most applicable to our clinical practice are the percentage depth dose and tissue maximum ratio for SSD and SAD techniques respectively on Bhabhatron-II unit. Since the published TMR data is deficient of larger square field sizes (25 – 35 cm^2), which are needed for patients' treatment, it becomes necessary to generate TMR values for larger field sizes from Bhabhatron-II unit.

For comparison with published standard values, TMR of fewer smaller field sizes are also determined. As can be seen in Table 5a and 5b, the variation between measured and standard TMR values for square field size 10 and 20 cm^2 is within the acceptable tolerance of 2% (Kutcher et al, 1994), therefore, the accuracy of TMR values measured for larger field sizes (25 – 35 cm^2) can be assumed.

To substantiate this assumption, the time to deliver a given prescribed dose per fraction was calculated using the measured dosimetric parameter of Bhabhatron-II unit and it can be seen from Table 6 that the value of absorbed dose to water measured with ionization chamber (187.60 cGy) at this calculated time is very close (within 1%) to the prescribed dose (188.00 cGy) used to derive the set time.

In conclusion, most of the values of dosimetric parameters of Bhabhatron-II unit measured in this study agree with values of similar quantities published in literature for Cobalt-60 unit and are within the acceptable tolerance of 2%. The exceptions are wedge transmission factors of three out of seven (3 of 7) wedge filters supplied with the unit and transmission factor of tray (1 of 4) with stripes pattern. Also, the values of TMR for larger square field sizes 25, 30 and 35 cm^2 at depths 0.5 – 18 cm obtained in this study could be used to complement the existing published standard data for Cobalt-60 TMRs.

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