Installation, Commissioning And Quality Assurance Tests Of First Indian Made Tele-Therapy Cobalt Machine (Bhabhatron- II) At Sher-I-Kashmir Institute Of Medical Sciences, Srinagar, Jammu And Kashmir.

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Abstract:
Cancer is a major health problem all over the world. Like other developing countries, in India, the disease is showing increasing trend and in next 15 years, the incidence is expected to double. Most of the cancer patients need radiotherapy during the course of treatment. However, due to the high cost of imported radiotherapy machines,there is an acute shortage of radiotherapy facilities in India and other developing countries. To meet the demand of an affordable radiotherapy machine, Bhabha Atomic Research Center(BARC) made first indigenous tele-cobalt machine in India called Bhabhatron-II. The major advantage of this machine is its lower cost without any compromise on the quality of treatment. Sher-i-kashmir institute of medical sciences (SKIMS), Srinagar, procured this indigenous cobalt-60 unit in 2012-13. Before the machine is practically used forpatient treatment, it is mandatory to conduct the quality assurance and commissioning tests of the radiation emitting equipment so as to ensure the consistency and accuracy in dose delivery of prescribed dose, minimal radiation dose to normal tissue, minimal exposure to occupational radiation workers, adequate patient monitoring and mechanical/electrical safety. In this paper, the results pertaining to quality assurance and commissioning tests of first Indian made teletherapy cobalt machine (Bhabhatron-II) installed at SKIMS are reported. The various tests were carried out as per requirements of AERB standards and acceptance criteria. The results obtained thereof are in coherence with the international regulations.

Key Words: Teletherapy, Bhabhatron-II, quality assurance, BARC, cancer treatment, cobalt-60

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Introduction

The global burden of cancer continues to increase largely because of aging and growth of the world population alongside an increasing adoption of cancer causing behaviors. In this regard, the International Agency for Research on Cancer (IARC), the specialized cancer agency of the World Health Organization published data on cancer incidence, mortality and prevalence worldwide.[1,2,3] According to IARC, an estimated 14.1 million new cancer cases and 8.2 million cancer related deaths occurred in 2012, compared with 12.7 million and 7.6 million in 2008 respectively. Further, more than half of all cancers and cancer deaths occurred in less developed regions of the world and these proportions will increase further by 2025.[4,5]

In India, like other developing countries, cancer is a major health problem. There are about 25 lakh cancer patients in the country. Every year, about eight lakh new cases are detected and more than five lakh patients die due to this dreaded disease. Moreover, the cancer incidence in the country is expected to double in next 15 years.[6,7] Established methods of cancer treatment are radiotherapy, surgery and chemotherapy during the course of treatment. Being the most cost effective, teletherapy using cobalt-60 is the most relevant method of cancer treatment in a developing country like India. The tele-cobalt units are preferred over medical linear accelerator because of i) low cost, ii) Low maintenance cost iii) lower power requirement and iv) less down time.[8] However, It is well recognized that medical linear accelerators also has some advantage over tele-cobalt machines such as variable dose rate, multi energy photon and electron beams and smaller beam penumbra.[8]

At present, there are only 399 teletherapy units (280 tele-cobalt units and 119 linear accelerators) in India. Out of the 280 tele-cobalt units, almost all are imported. The imported tele-cobalt units are quite expensive, which is a major hindrance for establishing radiotherapy centers in rural India.It is worth mentioning that in Indiamost of the cancer treatment facilities are located in urban areas, while the vast rural areas remain untouched. Many states and most of the districts in India do not have any teletherapy machine. Although more than two-third of cancer patients need radiation therapy, only about one –third of them receive it, due to the shortage of teletherapy units and urban-centric distribution of radiotherapy centers. This alarming shortage is due to the lack of affordable tele-cobalt machines.On the basis of data pertaining to cancer incidence in India, it is estimated that more than 1000 teletherapy units will be required in the near future.[8]

In view of this, Bhabha Atomic Research Center, Mumbai India has designed and developed a prototype tele-cobalt unit, which has been named Bhabhatron-I. After receiving feedback on the operation of this unit, a modified model,Bhabhatron-II was developed having a maximum source capacity of 555 TBq of Co-60.[9] The machine was further modified by introducing asymmetric motion of collimator jaws and motorized wedge. This machine is known as Bhabhatron-II-TAW.Efforts are in progress to upgradethese tele-cobalt units with advanced technology such a multi-leaf collimators (MLCs).[10,11]

Cobalt-60 is a radionuclide produced in a nuclear reactor by activating Co-59 withneutrons. Cobalt-60 is a primary beta emitter, which decays into an excited state of Ni-60 with a half-life of 5.27 years. The excited nucleus of Ni-60 gives up it excess energy by emitting two gamma photons with energies of 1.17 MeV and 1.33 MeV, the average energy being 1.25 MeV. The radiation from a Cobalt unit is usually considered to be mono energetic (1.25 MeV).[12,13]

In radiotherapy the goal of the treatment is to deliver the required dose the target safely.Before a teletherapy unit could be used for treating patients, a set of performance tests need to be performed on the machine, which is commonly known as the Quality Assurance Programme of the equipment.The programme is accepted world-wide and can be seen in various IAEA, AAPM, ACPM, ICE,ICRU, ICRP & AERB rules and reports.[14-20]

In India, the atomic energy regulatory board (AERB) ensures that the unit complies with national/ international standards before it is used for clinical applications. It shall comply with the various standards of electrical, mechanical, dosimetric and radiation safety. Therefore, in this paper, the results pertaining electrical, mechanical, dosimetric and radiation safety tests of the first India made tele-cobalt unit Bhabhatron- II-TAW installed in a tertiary care hospital (SKIMS) are reported.

Material and Methods:

The department of radiological physics of SKIMS is facilitated with well-equipped dosimetry and radiation safety laboratories, where all the latest equipment related to quality assurance of radiation generating machines are available.Cobalt therapy machine under trade name Bhabhatron-II-TAW with head number 029, source drawer number 34/11-T, source type cobalt-60 and maximum capacity of source head equal to 555TBq (15000 Ci) supplied by Panacea Medical Technologies Pvt. Ltd was used for present investigation. The source strength measured was 212.07 RMM. The dosimetry was performed byusing the following equipment.

- Calibrated Farmer Electrometer*, Model: 2570 A/613
- Full scatter water phantom (30x30x20)
- Calibrated Aneroid Barometer
- Calibrated 2571 Thimble Chamber (Ion Chamber type with 0.6cc volume)
- Calibrated Thermometer

*Farmer Electrometer 2570 A/613along with 2571 thimble shaped Ion Chambers used for dose measurements istimely calibrated from secondary standarddosimeters laboratory at Bhabha Atomic ResearchCentre (BARC).

For radiation safety measurements the detectors used were Ion chamber based Fluke Biomedical System (Model: 451) and Geiger-Muller based Inovision-190 survey meters. Both these detectors are timely calibrated. For the mechanical tests like iso-center accuracy, SSD verification, Field size verification and collimator jaw parallelism and orthogonality etc.,the tools used were graph paper, mechanical front pointer, iso-align tool,

The methodology used consisted of:

a) For mechanical tests, a field size of $10x10cm^2$ was drawn on a graph paper and the centre of the field was marked. The paper was placed on the treatment table (Couch) and the iso-centre was adjusted at 80 cm SSD. It was observed that the optical field coincided perfectly with the field marked on the graph paper. Now the table was moved vertically and brought to the extreme positions. A shift was observed in the position of the iso-centre with this vertical motion of the table. To see the shift in the position of the iso-centre with the rotational motion of the gantry mechanically, a needle with a sharp tip was fixed alongside the table with its tip at the position of the iso-centre. The gantry was rotated through ± 180^0.Again a shift was observed in the position of the iso-centre with the rotational motion of the gantry.

b) The measurement of doses (output) for SSD and SAD techniques is done by following the TRS-398 protocol for absorbed dose measurement in External Beam Radiotherapy (EBRT).[21] The calibrated thimble chamber was placed at the reference depth of 10 cm in a 30 x 30x 30 cm^3 water phantom. For SSD measurements the surface of water was kept at 80 cm, such that source to chamber distance was 90 cm. Then five readings were taken each for 1 minute, for reference field size of 10 x10 cm^2. For SAD measurements water surface was kept at 70 cm, so that source to chamber distance was 80 cm. Here again five readings were taken each for one minute for reference field size $10x10cm^2$.

The absorbed dose rate to water (output) at reference depth was obtained by using the following formula:[22]

$D_W = M_R \times K_{Pol} \times K_S \times K_Q \times N_{DW} \times K_{TP}$……………………..…(1)

Where

M_R = Average electrometer reading obtained.

K_{Pol} = Polarization correction factor and is given as

$$K_{Pol} = \frac{M^+ + M^-}{2M} \qquad ………..…(2)$$

where M^+ = Meter reading at +V volts

M^- = Meter reading at –V volts

K_S=Recombination correction factor[23] and is desc ribed as

$$K_S = \frac{\left(\frac{V_1}{V_2}\right)^2 - 1}{\left(\frac{V_1}{V_2}\right)^2 - \left(\frac{M_1}{M_2}\right)} \qquad ………..…(3)$$

Where M_1 and M_2 are the collected charges at the polarizing voltages V_1 and V_2 respectively with $V_1=2V_2$.

K_Q = Beam energy correction factor and for Co-60 is taken as 1.

N_{DW} = Combined electrometer and ionchamber calibration factor.

K_{TP} = Temperature and Pressure correction factor and is defined as

$$K_{TP} = \frac{(273.15+T)}{(273.15+T_0)} \times \frac{P_0}{P} \qquad ………..…(4)$$

where P_o and T_o are the reference values of pressure and temperature respectively.

Since the chamber was kept atreference depth of 10cm, the outputobtained from the above equationwould be at 10cm depth. In order toobtain the output at d_{max}as a functionof field size the above formula wasdivided by percentage depth dose value corresponding to 10 cm depthfor SSD technique and tissue air ratioin case ofSAD technique.

For the shutter timer error, the centre of the thimble chamber with build-up cap of the secondary standard dosimeter was placed at normal treatment distance. Now a time of T seconds was selected and accordingly 5 exposures each of T seconds were given to calculate the average reading R1. Next, two consecutive exposures of T/2 seconds were given and the reading was taken at the end of T/2 + T/2. Again 5 sets of such readings were taken to get the average reading R2. The shutter timer error was then calculated as

$$\delta t = \frac{(R2-R1)\times T}{2R1-R2} \qquad ………..…(5)$$

Results and Discussion:

After the successful installation of equipment, following quality assurance tests were performed for its commissioning.

1. Electrical tests.

The equipment passed all the electrical tests including interlocks, source head displays, control console displays and control console functions like beam ON switch, beam OFF switch, emergency switch, timer switch, treatment mode selection switch and machine rotation switch etc.

2. Mechanical tests

2.1 Couch: The minimum couch level above the floor was found as 68 cm and the shift in optical field due to vertical motion from minimum to maximum position, that is, -20 to +20 cmwas 1mm. Similarly the shift in optical field due to rotational motion from -90 to +90º was 2mm. Both these shifts were within the tolerance limit of ≤2mm.

2.2 Collimators: The results of mechanical tests of collimators are shown in table.1.From table 1, it can be observed that all the tests performed are within the tolerance limits as prescribed by regulatory agency of India. The minimum field size available of the machine is 0x0 cm^2which means the collimator jaws of this machine can be

Table 1. Collimator parameters.

Parameter	Observed value	Tolerance
Rotational angle	94.1 to 267.7	---
Field size available Lower Jaw Upper Jaw	 0 to 35 cm 0 to 35 cm	---
Distance from iso-centre	33.9 cm	---
Optical beam and Collimator axis coincidence	1.0 mm	= 1.0 mm
Parallelism of jaws Lower Jaw Upper Jaw	 < 1.0 mm < 1.0 mm	 mm 1.0 mm
Orthogonality of adjacent jaws	90 ± 0.5º	90 ± 1º
Symmetry of jaws	< 1.0 mm	= 1.0 mm
Optical field overlap 0 to 180 90 to 270	 Not available < 1.0 mm	 = 1.0 mm

Table 2. Read-out accuracy

Parameter	Stated value (cm)	Observed value (cm)
Mechanical front pointer	80	79.9
Optical distance indicator	80	80
Laser beam indicator	80	80

Table 3.Field size (Fs) definition.

Set optical field size (cm x cm)	Measured optical Field size at gantry position (cm x cm)				Tolerance
	0º	90º	180º	270º	
5 x 5	5 x 5	5 x 5	5 x 5	5 x 5	For Fs= 10cm x 10cm = 1mm
10 x 10	10 x 10	10 x 10	10 x 10	10 x 10	
15 x 15	15 x 15	15 x 15.1	15 x 15	15 x 15.1	For Fs = 10cm x 10cm = 2mm
20 x 20	20 x 20.1	20 x 20.1	20 x 20.1	20 x 20.1	
30 x 30	30 x 30.1	30 x 30.1	30 x 30.1	30 x 30.1	
35 x 35	34.8 x 35.1	34.8 x 35.1	34.8 x 35.1	34.8 x 35.1	

completely closed. This is a huge advantage as compared to the Theratron machines where the minimum available field size is 4x4 cm^2. The maximum field sizeavailable is 35 x 35 cm^2.

2.3 Gantry: The mechanical tests performed on the gantry showed that it has a fixed type rotation with one rotation per minute (1RPM) and the mechanical iso-centre was obtained as 2mm in diameter which is well within the tolerance limit of 4mm diameter sphere. The important observation during this test was that the gantry of this machine (Bhabhatron) rotates by an angle of +180º to -180º unlike Theratron machines where the gantry rotation is fully 360º, that is, the gantry can make several rotations in one direction. This is a drawback to Bhabhatron-II machine.

2.4 Read-out Accuracy

2.4.1. SSD and SAD verification: the stated and measured values of mechanical front pointer, optical distance indicator and laser beam indicator for the verification of source to surface distance and source to axis distance are shown in table 2. The tolerance limit for these quantities is ≤ ± 1.5 cm. from the table it is clear that all these parameters are within the tolerance.

2.4.2. Field Size (Fs) verification: Field size is defined as the opening of (x,y) jaws measured at the normal treatment distance, that is, 80 cm in the present case. Table 3 refers to the stated and measured field sizes. All the observed values are within the tolerance limits.

2.4.3. ODI scale verification: All the optical distance indicator readings from the normal treatment distance (80 cm from radiation source) to ± 20 cm are within tolerance limit of 1.5 mm.

3. Radiation Checks

3.1. Congruence between optical and radiation fields: To know if the radiation field is exactly overlapping with defined optical field, a paper

Table. 4. Shutter Timer error.

S. No	1	2	3	4	5	Average	Time (T)
R1	240.2	243.0	243.2	243.2	243.2	243.16	1 min.
R2	246.7	246.7	246.7	246.7	246.7	246.7	1min.

Table 5. Output factors.

Field Size cm^2	Meter Reading (nC/min)				PDD/100	Corrected Output at D_{max} (SSD + 0.5cm) in Gy/min	Corrected output in R/min	NOF
	a	b	c	average				
5 x5	25.35	25.35	25.35	25.35	0.507	2.70	281.50	0.93
10x10	30.05	30.05	30.05	30.05	0.556	2.92	304.27	1.00
15x15	32.55	32.60	32.60	32.58	0.584	3.02	314.08	1.03
20x20	34.15	34.15	34.15	34.15	0.602	3.07	319.37	1.05
25x25	35.15	35.15	35.15	35.15	0.602	3.16	328.73	1.08
30x30	35.65	35.65	35.65	35.65	0.602	3.20	333.41	1.09
35x35	35.80	35.80	35.80	35.80	0.602	3.21	334.80	1.10

Table 6. Wedge transmission factors.

S. No	Wedge Filter		Wedge Factor (WF)	
	Angle	Field Size (cm^2)	Measured	Specified by Manufacturer
1	15^o	15W x 20	0.674	0.674
2	30^o	10W x 16	0.564	0.580
		15W x 20	0.562	0.580
3	45^o	10W x 16	0.474	0.499
		15W x 20	0.430	0.444
4	60^o	10W x 16	0.374	0.365
		15W x 20	0.343	0.331

packed therapy verification film (model: Kodak EDR2) fixed in an iso-align tool for proper build-up was placed at the normal treatment distance. The edges and cross wire positions of the optical field were marked by radio opaque markers. The film was exposed to a dose of 100 rads to get an optical density of nearly one. After development, the densities were measured by using 1 mm hole densitometer and the results are shown in fig.1. From fig. 1, it can be observed that the radiation field measured at 50 % density width in two orthogonal directions are 10.1 cm (along left to right) and 10.2 cm (along gantry to front), which are within the tolerance limit of ≤2mm.

3.2 Output calibration

3.2.1 Shutter timer error: This parameter being an estimate of radiation dose during the transit time of radiation source from OFF to ON position and then back from ON to OFF position has been evaluated by double exposure technique. The results of 5 sets of exposures are presented in table 4. Using equation (2), the value of shutter timer error has been determined as 0.015.

3.2.2Normalized Output Factor (NOF): Since the output (dose rate) varies with field size, it is important to find the normalized output factor. Using equation (1), the output was determined for several fields and the results of normalized output factor defined as the ratio of output of a given field size to the output of 10 x 10 cm^2 field size are shown in table 5. The values of $K_{Pol,}$ K_S and K_Q were taken as 1 for cobalt energy. The value of combined chamber electrometer calibration factor N_{DW} was taken as 4.531 × 10^7Gy/C. Similarly the value of $K_{T,P}$ depending on environmental conditions was found as 1.1929. From the table it can be seen that NOF varies from 0.93 to 1.10 lying close to the prescribed range of 0.96 to 1.08.

3.3 Wedge Factor: The iso-dose distribution for a defined radiation field is often changed by introducing a special absorbing device inside the field to suit a particular situation. The most commonly used beam modification device in radiotherapy is the wedge filter. The main goal for its usage is to achieve uniform dose in the target volume in the case of oblique fields. The wedge filter reduces the dose along the central axis by a factor known as wedge factor (WF), which is to be taken care of during the dose calculations. The WF is defined as

$$WF = \frac{\text{Exposure in presence of wedge filter}}{\text{Exposure under identical conditions in absence of wedge filter}}$$

Table 6 presents the measured wedge factor and the wedge factor values specified by manufacturer for different wedge angles and filed sizes.

4. Radiation Protection Survey

Radiation protection involves protection of patients, technical staff handling the radiation generating equipment, hospital personnel in general and the public in particular. Radiation safety depends on the equipment design/construction, room shielding, staff training, working procedures and practicing of safety rules. Based on this, the head leakage of the machine was measured during both ON and OFF condition of source following the international protocol.

The OFF condition leakage was measured at 25 cm from the source (at the surface of head) and 1meter distance from source respectively. At 25 cm distance, the maximum exposure rate measured around the machine head was 1.0 mR/hr, which is less than the tolerance limit of 20.0 mR/hr when unit is loaded with maximum capacity source. At 1 meter distance, the maximum exposure rate measured was 0.11 mR/hr much less than the tolerance limit of 1.0 mR/hr when unit is loaded with maximum capacity source. Similarly the ON condition leakage was measured with collimators completely closed and the average value of leakage was 0.011% of RMM, which was much less than the tolerance limit of 0.1% of RMM (Roentgen per minute at 1 meter distance) of the loaded source. To find the adequacy of primary and secondary walls for room shielding, radiation survey was carried out at different locations around the bunker with radiation ON and collimators wide open and beam directed towards a particular direction. It was found that both primary and secondary walls were adequate for protection. Further the safety integrity of areas occupied by radiation workers, non-radiation workers and public members was found satisfactory.

Conclusion

From our systematic study of various parameters of first Indian made tele-cobalt machine namely Bhabhatron-II-TAW following the international protocol (TRS-398), it has been concluded that this radiation generating equipment is fit for the radiotherapy treatment of cancer. All the electrical, mechanical, radiation and safety tests performed lie within the tolerance limits as prescribed by AERB and IAEA. The big advantage of this machine is that unlike other tele-cobalt machines, the field size could be reduced to 0x0 cm^2 size. This could be of great use during an emergency of radiation source stuck. However the drawback of the machine is in its gantry rotation, which rotates by an angle of +180º to -180º unlike Theratron machines where the gantry rotation is fully 360º. This as such would result in more time consumption for multiple field treatments. Moreover, the Bhabhatron-II machine is much cost effective than the Theratron machines and hence could be a good choice for developing countries like India, without compromising on the quality of treatment.

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