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Dosimetric Consistency of Telecobalt and Brachytherapy Installations over a period of thirteen years: An Institutional Study

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Abstract
Introduction: *The use of radionuclides in telecobalt and brachytherapy machines demands safe handling of the equipment and accurate measurement of source activity to ensure safety of the patients, workers and public. This paper reports dosimetric consistency of few Quality Assurance parameters of Theratron Phoenix Telecobalt and micro Selectron HDR Brachytherapy machines performed for a period of thirteen years from 2007 to 2019.*
Materials and Method: *The output of the telecobalt unit for both SSD and SAD techniques and the source strength of the HDR Brachytherapy unit in terms of RAKR were measured as per national and international guidelines. The percentage variations between measured and theoretically calculated values were obtained for the thirteen years period. Timer error, error in Timer linearity and variations in TPS vs. manually calculated treatment times were calculated for the HDR unit after each source replacements.*
Results: *The results obtained from the measurements done all over the thirteen years period were found to be well within the stipulated values specified by competent authority. The results were shown in graphical and tabulated form.*
Conclusion: *The results show that the parameters measured were well within tolerance limits for a long period of thirteen years. Hence, this study establishes the consistency and accuracy in the dosimetric parameters of the Theratron Phoenix and micro Selectron HDR Brachytherapy machines.*
Keywords: *Telecobalt, Brachytherapy, Reference Air Kerma Rate, Timer Error and Linearity, Dosimetric Consistency, TPS.*

Introduction

With the introduction of Telecobalt radiotherapy machines in the 1950s, many state-of-the-art teletherapy machines viz. Linear accelerators, Gamma Knife, Tomotherapy, and Heavy Ion Therapy etc. have been in use to treat cancers. However, telecobalt radiotherapy machines are still used in the "resource limited" developing and middle/lower middle income countries and play an important role in the field of Radiation

Oncology[1,2]. Brachytherapy, used alone or in combination with external beam radiotherapy (EBRT),is a vital component of a radiotherapy clinic. High Dose Rate (HDR) brachytherapy machines are now commonly used worldwide. The use of radionuclides in the telecobalt and brachytherapy machines demands safe handling of the equipment and accurate measurement of activity of sources associated with it to ensure safety of the patients, radiation workers and public.

Functions of radiation generating equipment are complex and involve sophisticated technologies. Electronic failure, component failure or mechanical breakdown can suddenly change the functioning of radiotherapy equipment which may inadvertently affect the dose delivery. The functional performance can also change with the aging of the radiotherapy equipment. Therefore, delivery of treatment with the Radiation Generating Equipment requires extensive and periodic Quality Control (QC) program to ensure safety to the public, patients and staff. Several international guidelines have been published to describe the procedures and conditions for acceptance and commissioning of radiation therapy equipment. These guidelines should be followed to verify the performance characteristics of the equipment with manufacture's specifications and to establish baseline performance values. Once the baseline standards have been established, a protocol for Quality Assurance (QA) test should be developed for the purpose of monitoring the reference performance values[3-7].

In our Institute, we have been using Telecobalt and HDR Brachytherapy machines for decades. We have done the commissioning and performance evaluation of the machines complying with the regulations prescribed by the competent authority – Atomic Energy Regulatory Board (AERB) of India. Subsequently, all the periodic QA procedures have been performed following national and international guidelines. In this paper, we are going to report the various parameters related to the Quality Assurance (QA) of the Theratron Phoenix (Theratronics, Kanata, Ontario, Canada) and microSelectron HDRV2 (Nucletron, Mallinckrodt Medical B.V., The Netherland) Brachytherapy machines performed for a period of thirteen years from 2007 to 2019.

Materials and Method

The Theratron Phoenix Telecobalt unit is an isocentric telecobalt unit with source to surface distance (SSD) of 80 cm. The unit has ^{60}Co radioisotope of size 23.3mm in diameter and 36.7mm of length with average gamma photon energy of 1.25 MeV. The source housing capacity of the unit is 200 RMM (Roentgen per minute at one meter). The collimator system of the unit comprises with symmetric jaws and having field size ranging from 4 x 4 cm^2 to 35 x 35 cm^2.

Themicro Selectron HDR Brachytherapy unit, having ^{192}Ir source, has maximum source loading capacity of 10Ci(370GBq). The unit requires frequent source replacement after every 4-5 months as the half-life of the source is too short (73.8days). The source has capsule dimension of 0.9mm diameter, 4.5mm length and source pellet dimension of 0.6mm in diameter, 3.5mm of length with energy 0.38MeV. This miniature source is in wire form and encapsulated in a stainless steel capsule.

Output Measurement of telecobalt unit

Treatment Time required to deliver the prescribed dose to patient is calculated from the output of the telecobalt machine using some other dosimetric parameters like percentage depth dose (PDD), tissue maximum ratio (TMR), Wedge Factor (WF), Tray Factor (TF) etc. As the activity of the^{60} Cosource decays day by day with monthly decay factor ≈1.1%, the output also decreases accordingly. Hence, we need to measure the output in monthly basis to maintain accurate dose delivery to patients and to avoid any over dosage or under dosage. We have done the output measurements in monthly basis since the installation of the unitas per IAEA TRS-398

(International Atomic Energy Agency Technical Report Series No. 398) guidelines for both SSD and SAD (Source to Axis Distance) setups [8].We used 0.6cc Cylindrical Ion Chamber (SN: TN30013-007071, PTW, Germany) with electrometer (PTW UNIDOS E T10008/80060, PTW, Germany) in a water phantom (30 cm x 30 cm x 30 cm) with a waterproof sleeve to measure the dose rate at 10cm depth. Measured PDD and TMR values were applied to calculate the dose rate at depth of dose maximum (d_{max}) using the following formulae [8]:

For SSD Setup : Dose Rate in water, $D_w = \frac{M_R \times N_{DW} \times K_{TP} \times K_Q \times K_S \times K_P}{(T+\delta t) \times PDD}$ ..... (1)

For SAD Setup : Dose Rate in water, $D_w = \frac{M_R \times N_{DW} \times K_{TP} \times K_Q \times K_S \times K_P}{(T+\delta t) \times TMR}$ .....(2)

-where M_R, T, δt and $N_{D,W}$ represent the average electrometer reading, irradiation time, shutter timer error and ion chamber calibration factor (in Gy/C) respectively. The terms $K_{T,P}$, K_Q, K_S and K_P represent temperature-pressure correction factor, beam quality factor, ion recombination correction factor and polarity correction factor respectively as defined in IAEA TRS-398 guidelines [8]. The shutter timer error was calculated using the following formula:

$$\delta t = (R_2 - R_1)\, t / (2R_1 - R_2) \quad \ldots\ldots (3)$$

- where t=2minutes, R_1 is the meter reading for irradiation of 2minutes and R_2 is the meter reading for 2minutes with an interruption at 1minute.

The output or absorbed dose rate obtained for the reference field size (10x10 cm^2) is then compared with the output theoretically calculated from the reference output (output on the day of source loading) using decay correction method. Then the percentage variation between measured and theoretically calculated values for every month was calculated. The same was then calculated for thirteen years period(from 2007 to 2019) and plotted in graph.

The equipment used for the QA measurements in HDR Brachytherapy unit were re- entrant well-type ion chamber of nominal volume 200cc (Nucletron SDS REF 077094/25317, The Netherland) with electrometer (PTW UNIDOS E T10008/80060, PTW, Germany), coaxial cable, source holder and calibrated thermometer and barometer. The QA tests were performed following AERB guidelines[9].

Source Strength verification of HDR Brachytherapy unit

After the every installation of the new source in the micro Selectron HDR after loading system, the re- entrant chamber electrometer system was used in a scatter- free environment to compute the air kerma rate (AKR) at one- meter distance in the air. A gynecological transfer tube was used to connect the source holder that was kept inside the well of the ion chamber with the first index of the HDR unit. After adequate warm up of the dosimetry system, the maximum response position (position 21) of the chamber was found out. The micro Selectron HDR was programmed at that position i.e., 21 position for about 60 Sec and the average was taken from the three sets of electrometer readings in Nano Ampere (nA).

The source strength was then calculated in terms of Reference Air Kerma Rate (RAKR) using the following formula:

$$RAKR\ (mGy/h\ at\ 1m) = M_R \times N_{RAKR} \times K_{ion} \times K_{TP} \times K_P \quad \ldots\ldots (4)$$

- where M_R and N_{RAKR} are the average electrometer reading in nA and ion chamber calibration factor in $Gym^2h^{-1}A^{-1}$provided by National Standard Dosimetry Laboratory (NSDL),

Radiation Standards Section, BARC, Mumbai respectively. K_{ion}, K_{TP} and K_P are the correction factors forion recombination, temperature-pressure and polarity[10]. The manufacture's quoted RAKR value was corrected for decay and the percentage variation with the measured value was calculated.

Temporal Accuracy

A treatment system achieves temporal accuracy if each source sequence or single source dwell position remains at its intended position for the length of time specified by the treatment program. The dwell time of the remote after loader brachytherapy unit is controlled by an electronic timer. Test of timer accuracy is required when the machine timer is used to control treatment delivery duration and to integrate charge measurements during source-strength calibration. In addition, the influence of transit dose on dose delivery accuracy must be evaluated and corrected for, if necessary. Transit dose is the additional dose delivered while the source is in motion[7].

Timer Error

Timer Error and Percent Timer Error were calculated using the following formulae:

$$\text{Timer Error (sec)} = (R_2 - R_1)\, t / (2R_1 - R_2) \quad \ldots\ldots (5)$$

$$\%\ \text{Timer Error} = \{\text{Timer Error (sec)}/60\} \times 100 \quad \ldots\ldots (6)$$

-where R_1 is the is the meter reading for irradiation of 60 seconds and R_2 is the meter reading for 60 seconds with an interruption at 30seconds.

Timer Linearity:

Three sets of electrometer readings (nC) were taken for 300sec (T) and average reading (Q_{avg}) was used to calculate $I_{corrected}$ which is equal to Q_{avg}/T. Now the electrometer readings for set times (T_{set}) 60sec, 120 sec, 180 sec, 240 sec, and 300 sec were noted and average of each was divided by $I_{corrected}$ to obtain the corresponding measured times (T_{meas}).The percent linearity error was then calculated using the following formula:

$$\%\ \text{Linearity Error} = \left[1 - \frac{\text{Tmeas Max (T1)} - \text{Tmeas Min (T2)}}{\text{Tset corresponding to T1} - \text{Tset corresponding to T2}}\right] \times 100 \quad \ldots\ldots (7)$$

Verification of treatment time

Nucletron 3D Plato Treatment Planning System (TPS) was used for both single source loading and multiple-source loading at the prescription point to find the agreement between TPS and manual calculation.

For single source loading, a single catheter was created in TPS with a source exactly at the center of the catheter and dose of 1000 cGy was prescribed to the prescription point at 1cm from the source along the transverse axis. For multiple-source loading, a single catheter with three source positions each at 2cm apart was created in the TPS and dose of 1000 cGy was prescribed to a point at 1cm from the center of the central source position. For both the cases, the TPS calculated treatment times were compared with the manually calculated treatment times and percentage deviations were calculated.

$$\text{Treatment time at each dwell position} = \frac{\text{Prescribed Dose}}{\text{Total Dose Rate}} \quad \ldots\ldots (8)$$

Results

The percentage variations in the measured and theoretically calculated output for both SSD and SAD setups are shown in figure1. It is seen from the figure that the deviations were in the range from -1.96 to 1.99 and -1.61 to 1.82 for SSD and

SAD techniques respectively. The mean deviations were 0.54 and 0.40 for the two techniques respectively over the period of thirteen years. This implies that the variations were always within ±2% which fulfilled the criteria prescribed by the National Competent Authority.

The timer error values, timer linearity error, variation in measured and calculated RAKR values and variation in TPS and manually calculated treatment times (for both single and multiple source loading) of the 23 micro Selectron HDR V2 sources are shown in table1. The average values of timer error and timer linearity error of the HDR unit were found to be 0.6877% and -0.079% respectively. The percentage variation in TPS calculated and manually calculated times were in the range of -1.59 to 0.26, average being -0.20 for single source loading, and for multiple source loading, the variation was found in the range of -1.24 to 0.64 with average value of 0.02. The percentage variations in the measured and theoretically calculated RAKR values were found in the range from -1.91to 1.99 with average value -0.11.

Table 1: Percentage variations in measurements of RAKR, Timer Error, Timer Linearity Error and TPS vs. Manual Calculated Treatment Times.

Source No.	RAKR			Timer Error (%)	Timer Linearity Error (%)	Single Source loading			Multiple Source loading		
	Measured (mGy/h)	Quoted (corrected for Decay) (mGy/h)	Variation (%)			TPS Calculated Time	Manual Calculated Time	Variation (%)	TPS Calculated Time	Manual Calculated Time	Variation (%)
1	36.590	36.577	-0.04	0.80	-0.32	92.40	92.35	-0.05	67.70	68.01	0.46
2	38.481	38.185	-0.78	0.76	0.07	86.70	86.72	0.02	63.60	63.72	0.19
3	41.800	41.018	-1.91	0.83	0.08	81.20	81.32	0.15	59.60	59.76	0.27
4	38.901	38.374	-1.37	0.68	-0.10	88.00	87.80	-0.22	64.50	64.66	0.24
5	38.263	39.041	1.99	0.62	-0.23	84.10	83.87	-0.28	61.70	61.77	0.11
6	38.794	39.021	0.58	0.73	-0.60	84.40	84.61	0.25	62.00	62.32	0.51
7	41.141	41.100	-0.10	0.71	0.20	81.30	81.14	-0.20	59.60	59.76	0.27
8	37.784	38.050	0.70	0.69	-0.90	90.00	89.97	-0.03	66.00	66.24	0.36
9	38.258	38.053	-0.54	0.73	0.10	87.80	87.25	-0.63	64.40	64.08	-0.50
10	38.278	38.039	-0.63	0.85	0.30	87.80	87.24	-0.64	64.40	64.08	-0.50
11	34.200	34.511	0.90	0.69	0.30	98.00	97.48	-0.53	72.20	71.78	-0.59
12	35.730	35.590	-0.39	0.74	-0.10	93.90	93.31	-0.63	68.90	68.72	-0.26
13	33.786	33.606	-0.54	0.73	-0.20	100.30	99.59	-0.71	73.60	73.35	-0.34
14	30.865	30.919	0.17	0.73	0.20	106.31	106.31	0.00	78.30	78.29	-0.01
15	33.574	33.298	-0.83	0.50	-0.60	101.10	99.51	-1.59	74.20	73.29	-1.24
16	34.005	34.085	0.24	0.78	0.02	98.00	98.26	0.26	71.90	72.36	0.64
17	41.167	41.196	0.07	0.61	0.10	98.00	98.26	0.26	71.90	72.36	0.64
18	37.179	37.340	0.43	0.67	0.43	88.21	88.26	0.06	65.02	65.00	-0.03
19	37.171	37.463	0.78	0.36	-0.30	91.60	91.55	-0.05	67.20	67.32	0.18
20	35.727	36.094	1.02	0.66	-0.54	91.80	91.82	0.02	67.61	67.62	0.01
21	24.507	24.082	-1.77	0.67	0.31	133.82	133.85	0.02	97.71	97.74	0.03
22	36.169	36.499	0.91	0.78	-0.83	92.35	92.37	0.02	68.00	68.03	0.04
23	37.674	37.123	-1.48	0.51	0.80	86.11	86.12	0.01	63.40	63.42	0.03

RAKR=Reference Air Kerma Rate TPS=Treatment Planning System

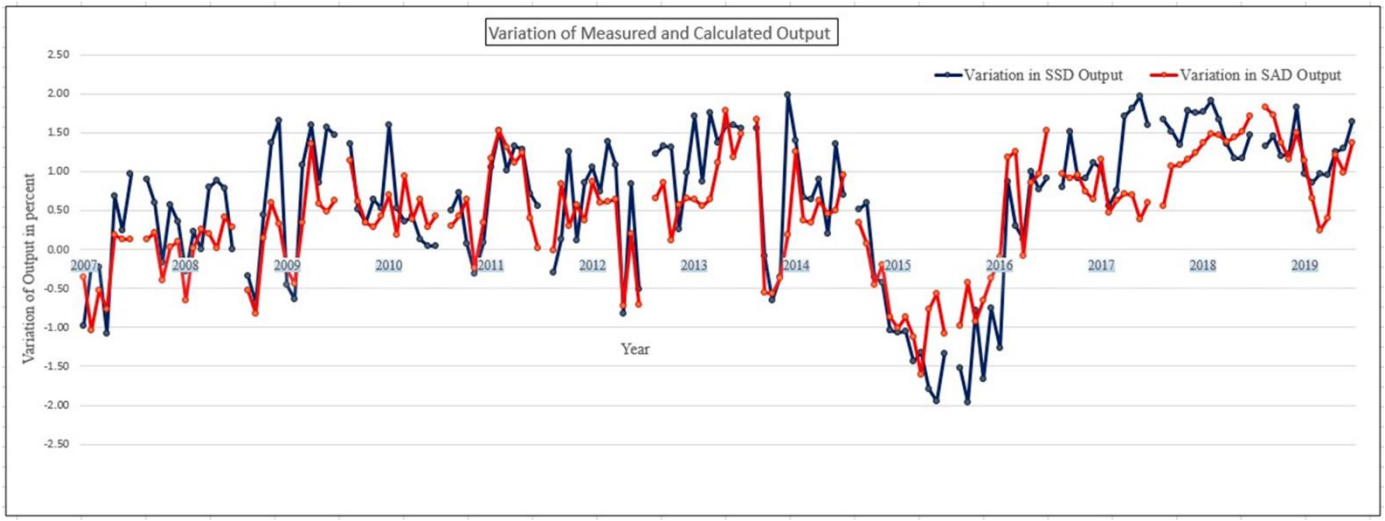

Figure 1: Variations of measured and calculated output in percentage for SSD and SAD techniques of the Theratron Phoenix Telecobalt unit for the period 2007-2019.

Discussion

The accuracy of dose delivery depends upon the dose measuring device, proper calibration of the device, measurement set- up, the correction factors used in the dose calculation formalism etc. The ion chamber used for measurements should have calibration factor directly traceable to NSDL as per national regulations. Periodic re-calibration of the chamber is essential as the calibration factor supplied by NSDL comes with a validity of 3 years. Cross calibrated chambers, however, are also used in dosimetry[8,11]. In the output measurement procedure of telecobalt machine, the depth of measurement, field size, reference point of measurement on the ion chamber, SSD/SAD etc. were followed as prescribed by IAEA TRS-398 protocols.

Specification of source strength of brachytherapy sources has been discussed in the AAPM Report No. 21 (American Association of Physicists in Medicine Task Group No.32) which recommends that the brachytherapy source should be specified in terms of air kerma strength (AKS) in μGym^2h^{-1} defined as "the product of air kerma rate in free space and the square of the distance of the calibration point from the source center along the perpendicular bisector" ; the distance between the detector and source should be large enough so that the source can be treated as a point source and the detector can be treated as a point detector[12]. International Commission on Radiation Units and Measurements (ICRU) recommended RAKR as source specification defined as the air-kerma rate at a specified distance (usually 1m) along the perpendicular bisector of the line source[13]. AKS and RAKR both have the same numerical value but defined differently.

Before clinical use, a set of QA procedures was performed after each and every replacement of new sources of the remote after loader unit. Measurement and verification of strength of the ^{192}Ir source is a major part of quality assurance program. The ^{192}Ir sources used in the HDR unit were supplied by the vendor with calibration certificates where the RAKR in $mGyh^{-1}$ at 1 m with the uncertainty of ±5% was mentioned with the date and time of measurement. The quoted RAKR should be corrected for decay on the day of loading/QA to compare with the measured RAKR values. The sources of uncertainty in the measurement may arise from the chamber, electrometer, positioning error, variations in temperature and pressure, humidity and primary calibration of the chamber[14]. After measurements, correct entry of measured RAKR in the treatment console station (TCS) as well as treatment planning system (TPS) is very important to ensure accurate dose delivery to brachytherapy patients and should be done with care.

Timer error for both telecobalt and brachytherapy leads to excess dose to patient and hence this needs to be taken into account in dose calculation. This is attributed to the exposure during transition of the source from OFF to ON position and vice versa. The linearity of the timer of the TCS should be verified with an independent timer. The temporal accuracy should be well within the tolerance limit of ± 1% as prescribed by AERB. After the entry of all parameters in the TPS and TCS, the treatment time calculated by TPS must be verified by manual calculation.

Conclusion

The QA of telecobalt and HDR brachytherapy machines includes various mechanical, electrical, radiation and dosimetry tests, survey of installation, TPS QA etc. However, in this study, we have reported the output of telecobaltmachine, source strength verification, timer error, timer linearity and verification of TPS calculated time with manual calculation of HDR Brachytherapy machine. Uncertainties in the measurements of dosimetric parameters lead to inaccurate dose calculation and treatment delivery. To minimize the uncertainties, stringent radiation safety protocols prescribed by the competent authority should be followed right from commissioning of the machines to patient treatment. Apart from the QA tests stated in this study, the source OFF and ON conditions of the machines were surveyed in timely manner in and around the machine room. All other QA tests e.g., mechanical, electrical, leakage and contamination tests, source position accuracy of brachytherapy unit etc. were performed over the stated time period and passed with good agreement with prescribed criteria. From this retrospective study, we conclude that the measured output of Phoenix telecobalt unit and the measured source strength of HDR brachytherapy source were within the acceptable limit when compared with the theoretically calculated values (within ±2%). Timer error and Timer Linearity error of the HDR unit were consistent and within tolerance limits over the thirteen years period and TPS calculated times for both single and multiple source loading were in good agreement with the manually calculated times. Hence, this study establishes the consistency and accuracy in the treatment with the Phoenix telecobalt and the microSelectron HDR units.

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