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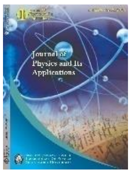

Five-Year Analysis of Measured and Calculated Dose Rates from Co^{60} Teletherapy Machine at Centre for Nuclear Medicine and Radiotherapy (CENAR) Quetta, Pakistan: A Comprehensive Assessment

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ABSTRACT

This study assesses the dosimetry of a Cobalt-60 (Co^{60}) teletherapy unit at the Centre for Nuclear Medicine and Radiotherapy (CENAR), Quetta, to ensure consistent radiation doses for cancer management. Dosimetry measurements were compared against expected outputs derived from the International Atomic Energy Agency's TRS-398 protocol and decay calculations. The current investigation demonstrates uniformity in average output (dose rate) between the actual dosimetry values and the anticipated output values obtained through the International Atomic Energy Agency's TRS-398 (2000) protocol and decay method respectively. The actual dosimetry values fall within a range of ±2% of the estimated values. The difference in measurements acquired through the two approaches falls within acceptable limits as per recommended protocols. Consequently, our study reveals a steady pattern in dose rate, ensuring improved patient dose distribution and minimizing the risk of over or under-dosage.

1. Introduction

The stable form of cobalt was discovered by Georg Brandt in 1735 [1]. The only stable isotope of cobalt (Co) that is found naturally is 59Co. There are 22 classified radioisotopes among which 60Co, 57Co, 56Co, and 58Co have the lengthiest half-lives (5.2714 years, 271.79 days, 77.27 days, and 70.86 days, respectively). Radioactive isotopes that remain entirely intact have half-lives of less than 18 hours, with the majority lasting less than 1 second. Moreover, this element has 4 Meta states with half-lives under 15 minutes. Atomic weights of cobalt isotopes span from 50 u (50Co) to 73 u. (73Co).

Beta decay is the main method of decay for isotopes with atomic mass units larger than 59, while electron capture is the main mode of decay for isotopes with atomic mass units smaller than the most common stable isotope, 59Co. Element 26 (iron) isotopes are the principal decay products before 59Co, and element 28 (nickel) isotopes are the primary decay products after [2].

The world's top commercial radioisotope in terms of revenue production is cobalt-60, with a half-life of 5.27 years. The majority of its present applications are in the sector of sterilization, mainly for medical products meant for human consumption [3].

By hitting cobalt-59 with neutrons, cobalt-60 (also known as 60Co) may be created in predictable quantities and with high activity, making it a useful gamma-ray source. Nickel-60, (60Ni28), is produced when cobalt-60 decays into a beta particle. Two gamma-ray photons with energies of 1.17 MeV and 1.33 MeV are released by the activated nickel nucleus, giving rise to an average beam energy of 1.25 MeV. These gamma rays' energy is utilized in radiotherapy to treat diseases like cancer. Radiation therapy serves as a significant modality in cancer treatment, employed either independently or in combination with other therapeutic approaches [4].

The primary objective of radiotherapy is to optimize the radiation dose delivered to tumor cells, minimizing the exposure of surrounding normal tissues to the greatest extent possible [5]. Diverse radiation types, such as photons, electrons, protons, and heavy ions, are employed in modern cancer treatment. High-energy photon beams from linear accelerators and Co-60 teletherapy units are utilized to eradicate malignant cells through ionizing radiation [6]. The objective of radiotherapy is twofold: treating cancer and minimizing complications in normal tissues. Achieving this goal relies entirely on precise radiation doses, which are determined by measuring the dose rate from the radiation source [4]. The measurement of dose rates or dosimetry for radiation-emitting devices/sources is a crucial component of a quality assurance (QA) program. This program encompasses all systematic or planned actions essential to ensure that specified requirements for quality healthcare services are met [7].

A tolerance of ±2% is specified for source dose rate measurements following protocols, and this same tolerance has received endorsement from other authors [8]. Dosimetry plays a vital role in ensuring the quality assurance of radiation-producing machines and sources. It constitutes a systematic and planned set of actions necessary to deliver high-quality healthcare services [9]. This investigation was carried out using a Co-60 radiotherapy machine to determine its depth doses in a water phantom at 80 cm source-to-surface distance (SSD) and a depth of 5 cm, following the protocols established by the International Atomic Energy Agency (IAEA) [10].

Absorbed dose is influenced by factors such as photon energy, Source-to-surface distance (SSD), field size, and depth. By varying any of these values, one can observe changes in the absorbed dose [11]. Because it is not feasible to measure dose rates directly in real patients, water phantoms or equivalent mediums have been utilized since the inception of radioisotope treatments for patients. These measurements are then applied in the calculation of treatment for actual patients [12].

CENAR Cancer Hospital Quetta is a fully equipped healthcare facility specializing in the diagnosis, treatment, and research of malignant tumors. Established to incorporate the latest research methodologies in cancer management, the hospital's radiotherapy department utilizes a cobalt-60 teletherapy machine for external beam radiotherapy in various cancer treatments. This study seeks to analyze and compare the absolute output dose of the Co-60 teletherapy machine over five years at the CENAR Quetta Institute, examining both measured and calculated values.

2. Method

The Centre for Nuclear Medicine and Radiotherapy (CENAR) Quetta, Pakistan has been equipped with the Best Theratronics teletherapy machine since 2017. The Secondary Standard Dosimetry Laboratory Pakistan (SSDL) conducts beam output measurements every year following the regulations set by the Pakistan Nuclear Regulatory Authority (PNRA). Dose verification is conducted every month as part of routine procedures since the installation. In monthly dose measurements, a PTW 0.6 cm3 ion chamber (Model 30013) was employed in conjunction with a PTW Unidoselectrometer. Radiation dose measurements were conducted in a water phantom of dimensions 30×30×30 cm^3 at a source-to-surface distance (SSD) of 80 cm and a depth of 5 cm, using a field size of 10 x 10 cm^2. Absolute dosimetry is conducted following the TRS-398 protocol established by the International Atomic Energy Agency (IAEA) [13]. The ionization chamber and electrometer assembly undergo calibration every two years at the Secondary Standard Dosimetry Laboratory (SSDL) PINSTECH Islamabad, utilizing +400 V polarity voltages, 1013.25 kPa pressure, and 20°C temperatures. These identical parameters are also applied for dosimetry. The dose rate at the reference depth was determined using the formula specified in the International Atomic Energy Agency's TRS-398 (2000) protocol [14].

$$\text{Output: } M_R \times K_{Pol} \times K_S \times K_Q \times N_{DW} \times K_{TP} \qquad (1)$$

M_R : Electrometer Reading

K_{Pol} : $(M_+ + M_-)/2M$

K_{Pol} : Polarity Correction Factor

K_S : Ion Recombination Factor

K_{Pol} & K_S : the change in the polarity factor and ion recombination factor taken as 1, because the polarity factor and applied voltage were kept same according to parameters on which the chamber was calibrated.

K_Q : Quality Factor taken as 1 for gamma rays.

N_{DW} : NDW represents the calibration factor specific to the electrometer and thimble chamber for measuring absorbed water dose.

K_{TP} : Temperature and pressure correction factor.

K_{TP} : $(273.2+T \times P_o)/(273.2+T_o \times P)$

T_o & P_o : reference values for pressure and temperature, with standardized values set at 101.3 kPa (kilopascal) and 20 °C (Celsius), respectively.

Since the chamber was maintained at a reference depth of 5 cm, the result derived from the aforementioned equation corresponds to a depth of 5 cm. To obtain the output at D_{max}, the acquired output results were divided by the percentage depth dose at a depth of 5 cm.

$$D_{cal} : D_0 e^{-0.693t} / T_{1/2} \qquad (2)$$

D_{cal} : Current Dose Rate of Cobalt-60 Source

D_0 : Previous Dose Rate of Cobalt-60 Source

t : the time gap (in days) between two dose rate measurements.

$T_{1/2}$: Half-Life of the source and for Co-60 Source it's about 1925 days (5.27 years).

The equation used to calculate the percentage error for the dosimetry procedure is as follows:

$$\text{Percentage Error: } (D_{measured} - D_{cal}) \times 100 / D_{cal} \qquad (3)$$

Percentage error in radiation dosimetry directly affects the correction factors, such as K_{TP} (temperature-pressure correction) and K_{Pol} (polarity correction). Deviations in these factors, measured by percentage error, can significantly influence the accuracy and reliability of dose measurements in clinical settings. Dose measurement data has been documented over the past five years, starting from 2018. The current study involves the analysis of data ranging from year 2018 to 2022.

3. Results and Discussion

The measured output and estimated output (calculated through the decay method) from 2018 to 2022 are presented in Tables 1-6 and Figures 1-5. The tabulated and graphical data consistently indicate that the percentage error calculated each year has consistently remained below ±2%, demonstrating reliability according to established protocols the graphical data also show a linear downward trend due to Radioactive decay: Co-60 is a radioactive isotope, which means it breaks down over time into a more stable form. This process is called radioactive decay. As Co-60 decays, there are fewer radioactive atoms left to emit radiation. This results in a decrease in the dose rate over time. It is crucial to ensure that the radiation dose administered to the patient aligns with the prescribed dose. The most reliable method to verify this alignment is through regular measurements of the absorbed dose. According to AAPM TG40 guidelines, monthly dose verification is recommended for Cobalt-60 machines, with an acceptable dose difference of within ±2% from the calculated dose [8].

Figure 6 demonstrates the discrepancy ranges between the measured and calculated outputs of the reported results over the five years. Inaccuracies in dosimetry setup, variations in temperature and pressure conditions, placement of beam dosimeters, and disparities in calibration collectively contribute to these justified errors on a small scale.

Baba M.H. et al. documented a range of dose differences, with a minimum of -1.65% and a maximum of +0.66% [4]. SA Memon reported a minimum dose difference of 2.08% and a maximum of +2.48%, both slightly higher values for the same machine model that was mentioned in Baba M.H, et al [15,4]. In another study conducted by Acharya NP, the minimum and maximum output rates were reported as -1.34% and 1.78%, respectively [16].

Table 1. Measured output, calculated output & %age Error of C0-60 machine for the year 2018 (CENAR, Quetta)

Year	Month	Calculated Dose Rate D_{cal} (cGy/min)	Measured Dose Rate $D_{measured}$ (cGy/min)	Percentage Error	Yearly Average Error
2018	January	217.3	217	0.14	1.88
	February	214.5	215.2	-0.33	
	March	212.6	212.2	0.19	
	April	210.3	209.7	0.29	
	May	208	209.1	-0.53	
	June	205.7	206	-0.15	
	July	203.5	203.1	0.20	
	August	201.3	200	0.65	
	September	199.1	199.7	-0.30	
	October	196.9	195	0.96	
	November	194.7	194.9	-0.10	
	December	192.6	192.4	0.10	

Table 2. Measured output, calculated output & %age Error of C0-60 machine for the year 2019 (CENAR, Quetta)

Year	Month	Calculated Dose Rate D_{cal} (cGy/min)	Measured Dose Rate $D_{measured}$ (cGy/min)	Percentage Error	Yearly Average Error
2019	January	191	190.2	0.42	-1.11
	February	188.6	188.2	0.21	
	March	186.4	186.7	-0.16	
	April	184.4	184	0.22	
	May	182.4	182.1	0.16	
	June	180.4	181	-0.33	
	July	173.6	174	-0.23	
	August	177.1	177.8	-0.40	
	September	175.2	175	0.11	
	October	173.3	173.9	-0.35	
	November	171.4	170.9	0.29	
	December	169.2	170.5	-0.77	

Table 3. Measured output, calculated output & %age Error of C0-60 machine for the year 2020 (CENAR, Quetta)

Year	Month	Calculated Dose Rate D_{cal} (cGy/min)	Measured Dose Rate $D_{measured}$ (cGy/min)	Percentage Error	Yearly Average Error
2020	January	168.8	168.7	0.06	1.5
	February	167.1	166.8	0.18	
	March	163.9	163.5	0.24	
	April	163.4	163	0.24	
	May	160.5	161	-0.31	
	June	160.1	160	0.06	
	July	158.5	158.2	0.19	
	August	157	156.8	0.13	
	September	153.5	154	-0.33	
	October	153	153.3	-0.20	
	November	151	151.7	-0.46	
	December	150	149.7	0.20	

Table 4. Measured output, calculated output & %age Error of C0-60 machine for the year of 2021(CENAR, Quetta)

Year	Month	Calculated Dose Rate D_{cal} (cGy/min)	Measured Dose Rate $D_{measured}$ (cGy/min)	Percentage Error	Yearly Average Error
2021	January	147.7	147	0.47	-1.33
	February	148.5	148.7	-0.13	
	March	147	145	1.36	
	April	145	143.7	0.90	
	May	141.2	140	0.85	
	June	139	140.3	-0.94	
	July	139.5	138.9	0.43	
	August	135.6	136.1	-0.37	
	September	133.8	134.5	-0.52	
	October	132.9	133.3	-0.30	
	November	131.5	132.1	-0.46	
	December	127	127.4	-0.31	

Table 5. Measured output, calculated output & %age Error of C0-60 machine for the year of 2022(CENAR, Quetta)

Year	Month	Calculated Dose Rate D_{cal} (cGy/min)	Measured Dose Rate $D_{measured}$ (cGy/min)	Percentage Error	Yearly Average Error
2022	January	128.6	129.3	-0.54	1.20
	February	126.2	127	-0.63	
	March	125.4	126.3	-0.72	
	April	124.7	124.4	0.24	
	May	123.4	123	0.32	
	June	122.9	122.5	0.33	
	July	119.9	120.4	-0.42	
	August	119	119.7	-0.59	
	September	118.4	117.8	0.51	
	October	116.2	117	-0.69	
	November	115.1	115.4	-0.26	
	December	114	113.5	0.44	

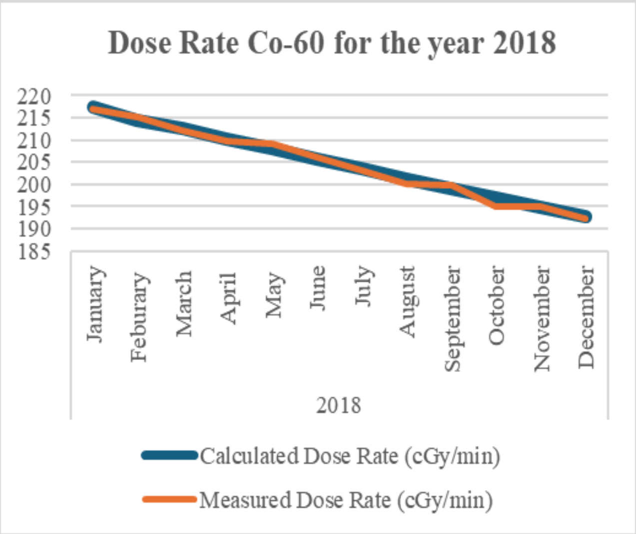

Fig. 1: Measured output vs. calculated output of C0-60 machine for the year 2018 (CENAR, Quetta)

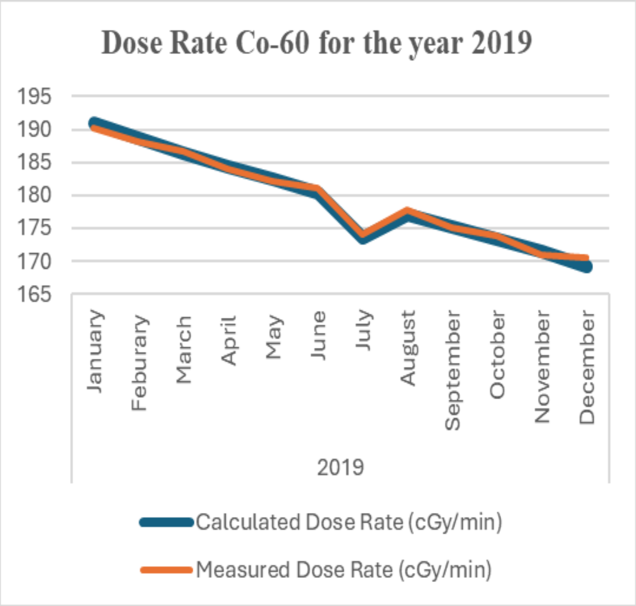

Fig. 2: Measured output vs. calculated output of C0-60 machine for the year 2019 (CENAR, Quetta)

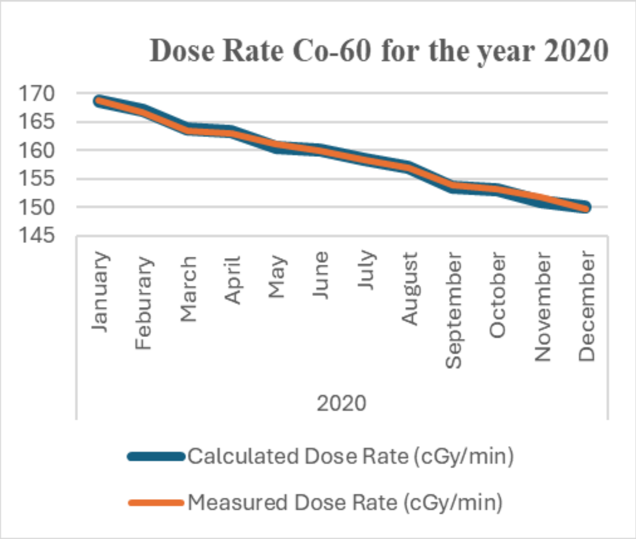

Fig. 3: Measured output vs. calculated output of C0-60 machine for the year 2020 (CENAR, Quetta)

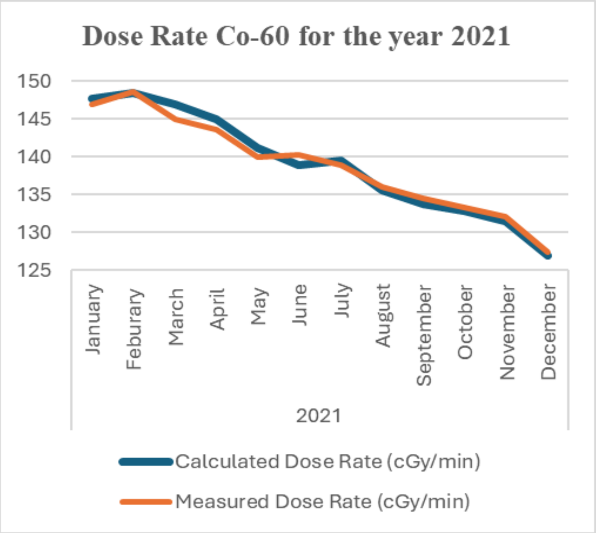

Fig. 4: Measured output vs. calculated output of C0-60 machine for the year 2021 (CENAR, Quetta)

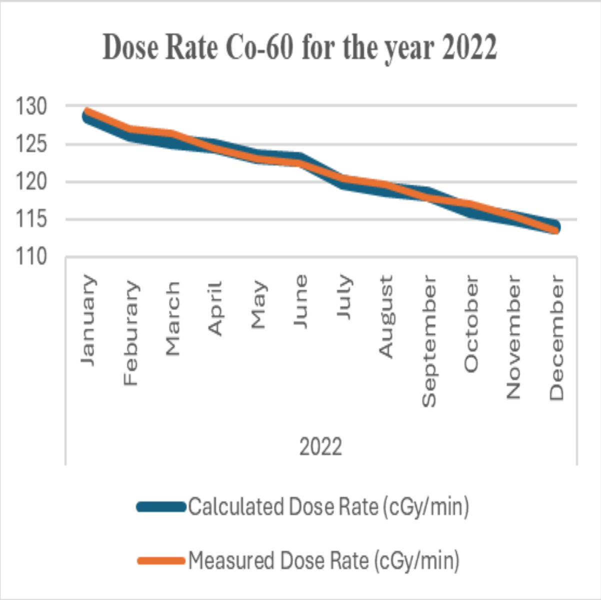

Fig. 5: Measured output vs. calculated output of C0-60 machine for the year 2022 (CENAR, Quetta)

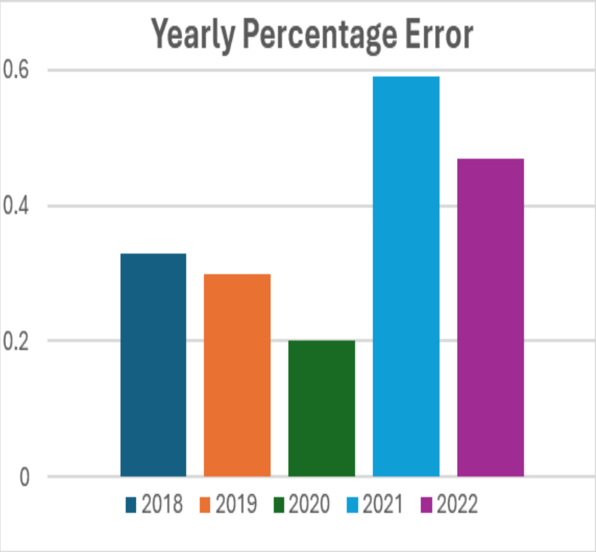

Fig. 6: Yearly Percentage Error of C0-60 machine from the year 2018 to 2022 (CENAR, Quetta)

4. Conclusion

The output obtained through actual dosimetry from 2018 to 2022, when compared to the expected output, demonstrates a deviation within acceptable limits, specifically within ±2% annually. This underscores the consistency in measured output over the 5 years, reflecting the precision in dose calculation. The conducted study reveals an ongoing trend towards uniformity, and the review process has proven effective in identifying any deficiencies and implementing necessary corrections.

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