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Determination of Timer Error and Evaluation of Its Effect on Dose for OB6, GammaBeam X200 and X-Ray Irradiators at the Secondary Standard Dosimetry Laboratory in Nigeria

Olumide Olaife Akerele, Samuel Mofolorunsho Oyeyemi, David Olakanmi Olaniyi, Francis Adole Agada, Bamidele Musbau Adeniran, Latifat Ronke Owoade

National Institute of Radiation Protection and Research, University of Ibadan, Ibadan, Nigeria
Email: akereleolu@yahoo.com

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Abstract

Timer error as well as its convention is very important for dose accuracy during irradiation. This paper determines the timer error of irradiators at Secondary Standard Dosimetry Laboratory (SSDL) in Nigeria. The irradiators are Cs-137 OB6 irradiator and X-ray irradiators at the Protection level SSDL; and Co-60 irradiator at the Therapy Level SSDL. PTW UNIDOS electrometer and LS01 Ionization chamber were used at the Protection Level to obtain doses for both Cs-137 OB6 and X-ray irradiators while an IBA farmer type ionization chamber and an IBA DOSE 1 electrometer were used at the Protection Level SSDL. Single/multiple exposure method and graphical method were used in the determination of the timer error for the three irradiators. The timer error obtained for Cs-137 OB6 irradiator was 0.48 ± 0.01 s, the timer error for the X-ray irradiator was 0.09 ± 0.01 s while the timer error obtained for GammaBeam X200 was 1.21 ± 0.04 s. It was observed that the timer error is not affected by source to detector distance. It was also observed that the timer error of Co-60 Gamma X200 irradiator is increasing with the age of the machine. Source to detector distance and field size do not contribute towards the timer error of the irradiators. The timer error of the Co-60 Gamma X200 irradiator (the only irradiator among the irradiators with a pneumatic system) increases with the age of the irradiator.

Keywords

Timer Error, Irradiation, SSDL, Irradiators, Dose Accuracy

1. Introduction

The Secondary Standard Dosimetry Laboratory (SSDL) in Nigeria is a laboratory designated by the National regulatory body, Nigerian Nuclear Regulatory Authority (NNRA) to disseminate radiation dosimetry standards for users of ionizing radiation sources in Nigeria through calibration and irradiation activities. The SSDL has traceability to IAEA dosimetry laboratory in Seibersdorf. The Secondary Standard Dosimetry Laboratory in Nigeria has different irradiators for Therapy Level and Protection Level SSDL. The Protection Level is equipped with X-ray beam Irradiator, OB6 irradiator while the Therapy level has Co-60 GammaBeam X200 irradiator. The OB6 irradiator has Cs-137 source with initial activity of 740GBq at November, 1996 and is used for irradiation of samples and calibration of radiation monitoring equipment. The X-ray irradiator is Hopewell Designs with maximum energy of 225 kVp and 30 mA current. The X-ray irradiator is used for the calibration of radiation monitoring equipment, calibration of radio-diagnostics QC kits and irradiation of samples for research purposes. The GammaBeam X200 Co-60 teletherapy irradiator with initial activity of 192.3 TBq at February, 2011, is used for calibration of teletherapy ionization chambers and irradiation of samples for research purposes.

The dose rate of the irradiators can easily be established using reference ionization chamber and electrometer; however, accurate dose can only be obtained with accurate exposure time. The time on the irradiator control panel may not accurately indicate the exposure time due to the operation time of the irradiator shutter or the movement of the source [1]. The difference in time set on the irradiator and the actual exposure time is called timer error. Therefore timer error can have significant influence on the dose delivered or dosimeter reading. The two possible causes for timer error of irradiators are the shutter motions or motion of the source [2] [3] [4]. Timer error has been established as one of the quality control parameters that must be determined with a tolerance value of 1% in a Co-60 teletherapy unit [5]. Also in the Secondary Standard Dosimetry Laboratory, the timer error must be corrected for in order to have accurate calibration and irradiation results. There are four well documented timer error determination methods, namely two-exposure method, single/double exposure method, single/multiple exposure method and graphical method [6]. Single/multiple exposure method formula was given by [7] and [8] note that the sign of the timer error should be observed and subtracted from the irradiation time based on position on number line. Graphical method offers clarity without the possibility of confusion on how to apply timer error [9].

The Secondary Standard Dosimetry Laboratory (SSDL) in Nigeria is the body designated by law to provide reference for diagnostic, protection and therapeutic application of ionizing radiation in the country. But the effects of age and components (shutter assembly and source drawers) of the irradiators, reference conditions (field size and SSD) on the timer error of the equipment have not been established. This paper determines the timer error of the irradiators at the SSDL and the effects of age and components (shutter assembly and source drawers) of the irradiators, reference conditions (field size and SSD) on the timer error of the irradiators at the SSDL in Nigeria using single/multiple exposure method and graphical method.

2. Materials and Method

2.1. Timer Error of OB6 Irradiator

2.1.1. Single/Multiple Exposure Method

LS01 Ion-chamber was connected to PTW UNIDOS electrometer and placed at the centre of the radiation beam at 1 m using laser lights for proper alignment. The ion-chamber was pre-irradiated for thirty (30) minutes for charge stability. After the pre-irradiation, the leakage reading on the electrometer was recorded. The timer on the OB6 irradiator was set to 60 seconds and the ionization chamber was then exposed. The electrometer reading, temperature and pressure were recorded. This procedure was repeated for five (5) consecutive readings, averaged and corrected for temperature and pressure using Equations (1) and (2) [6] below. The corrected electrometer reading is M_A

$$M_A = \frac{\sum M}{n} \times k_{TP} \tag{1}$$

$$k_{TP} = \frac{273.2 + T}{293.2} \times \frac{1013.25}{P} \tag{2}$$

k_{TP} = Temperature Pressure correction factor, M = electrometer reading, n = number of readings, T = Temperature in ˚C and P = pressure in mbar

The timer of OB6 was then set for 15 seconds. A cumulative reading was taken from the electrometer while exposures were performed four (4) consecutive times using the OB6 such that the total exposure time was 60 seconds. The readings on the electrometer, Temperature and pressure were recorded. This procedure was repeated for five (5) times, averaged and corrected for temperature and pressure using Equations (1) and (2). The corrected averaged value is M_B.

Timer error, τ is then calculated using Equations (3) [6] below:

$$\tau = \frac{(M_B - M_A)T}{nM_A - M_B} \tag{3}$$

where T is the total irradiation time (60 s), n is number of irradiations in 60 s, M_B is the corrected averaged value of electrometer readings; M_A is the corrected electrometer reading.

The timer error was also obtained by positioning the ionization chamber at distances of 2 m, 3 m and 4 m away from the irradiator.

In (3), the timer error (τ) is less than zero (negative) if M_A is greater than M_B; τ will be greater than zero (positive) if M_A is less than M_B; and $\tau = 0$ if $M_A = M_B$. The Time set on the irradiator, $T = T_c - \tau$ where T_c is the calculated time using the dose and dose rate. Thus, if the timer error is less than zero (negative), its absolute value will be added to the calculated irradiation time and if the timer error is greater than zero (positive), its absolute value will be subtracted from the calculated irradiation time.

2.1.2. Graphical Method

LS01 Ion-chamber was connected to PTW UNIDOS electrometer and placed at the centre of the radiation beam at 1 m using laser lights for proper alignment. The ion-chamber was pre-irradiated for thirty (30) minutes. After the pre-irradiation, the leakage reading on the electrometer was recorded. The OB6 timer was varied from 0.2 s to 30 s, the ionization chamber was irradiated and the electrometer readings, temperature and pressure were recorded. Five (5) readings were recorded using pre-set time on the OB6 irradiator. The values were averaged and corrected for temperature and pressure using Equations (1) and (2).

Graph of the corrected chamber reading was plotted against the OB6 time. The intercept of the graph on the timer axis represents the timer error. The procedure was repeated for detector to source distances of 2 m, 3 m and 4 m.

The intercept on the negative timer axis means that the timer error will be subtracted from the calculated irradiation time while the intercept on the positive timer axis means that the timer error will be added to the calculated irradiation time.

2.2. Timer Error of X-Ray Irradiator

The same procedure in sub-section 2.1 above was used for the determination of the timer error except that the cumulative irradiation time in single/multiple exposure method was changed to 240 seconds. The timer error was performed with 100 keV and 10 mA at source to detector distance (SDD) of 2 m.

2.3. Timer error of GammaBeam X200

The same procedure in sub-section 2.1 above was used for the determination of the timer error except that the cumulative irradiation time in single/multiple exposure method was changed to 240 seconds. The timer error was performed at 80 cm and 100 cm Source to Detector Distance (SDD). The detector was placed in water phantom at depth of 5 cm and 10 cm for the SSD of 80 cm and the depth of 5 cm for the SSD of 100 cm. The field sizes of the irradiator used are 5 cm × 5 cm, 10 cm × 10 cm, 15 cm × 15 cm, 20 cm × 20 cm, 25 cm × 25 cm, 30 cm × 30 cm and 35 cm × 35 cm.

2.4. Dose Evaluation for OB6 Irradiator

The electrometer time was set to 10 s, OB6 irradiator was used for the exposure and five readings were taken from the electrometer readings. The electrometer reading was then corrected for temperature and pressure using Equations (1) and (2). The corrected reading was used to calculate the reference dose rate of the irradiator at 1 m. OB6 irradiator was then set to different time and accumulated dose for the set time on the electrometer was recorded. The percentage timer variation and percentage dose variation was calculated. These procedures were repeated for 2 m, 3 m and 4 m distance from source position (SDD).

2.5. Timer and Dose Verification for OB6 Irradiator

Irradiation time, T was calculated for 0.1 mSv, 0.2 mSv and 0.5 mSv using the dose rate at SDD of 1 m, 2 m and 3 m. The accumulated dose (D_T, $D_{T-\tau}$, and $D_{T+\tau}$) were then obtained for irradiation time, T, $T-\tau$, and $T+\tau$. Percentage error was calculated for the dose.

3. Results and Discussion

3.1. OB6 Irradiator

The timer error of the OB6 was calculated using Equation (3). Table 1 shows the timer error obtained at varied distances from the irradiator, the average timer error and the standard deviation are also indicated in the table.

Figures 1-4 show the graph of electrometer readings (nC) plotted against time for SDD of 1 m, 2 m, 3 m, and 4 m to yield 4 timer error values shown in Table 2. The correlation coefficient, $R^2 = 1$ shows that the dosimeter's reading is perfectly linear. From the timer errors obtained from the graphs, the average timer error, standard deviation, and standard uncertainty (in the average) were calculated. The

Table 1. Timer error of OB6 at different distances using single/multiple exposure method.

Distance (m)	Time, T(s)	Timer error, τ (s)
1	60	0.48
2	60	0.45
3	60	0.45
4	80	0.51
	Mean	0.48
	Standard Deviation	0.03
	Standard Deviation from mean	0.01

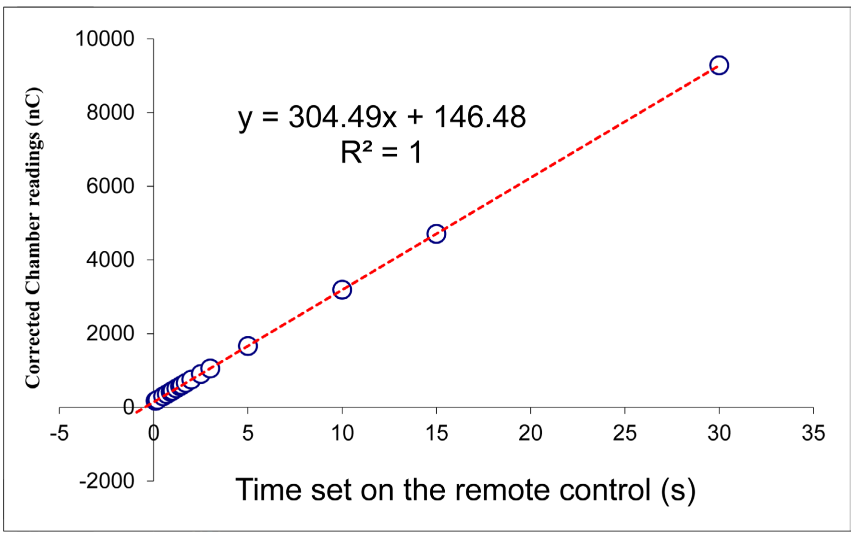

Figure 1. Graph of corrected chamber charge against irradiation time for OB6 at 1 m.

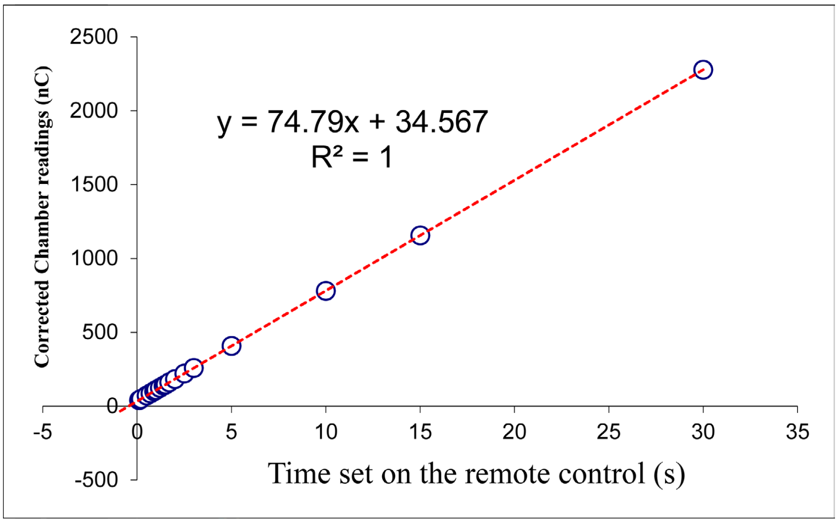

Figure 2. Graph of corrected chamber charge against irradiation time for OB6 at 2 m.

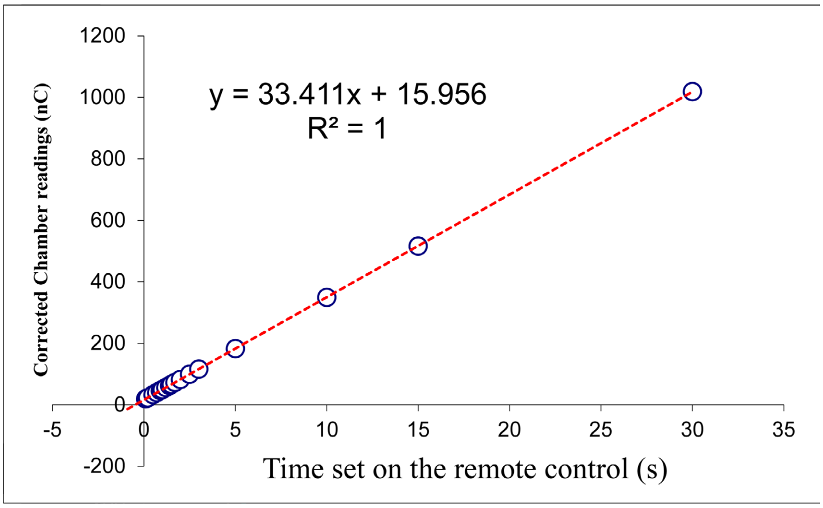

Figure 3. Graph of corrected chamber charge against irradiation time for OB6 at 3 m.

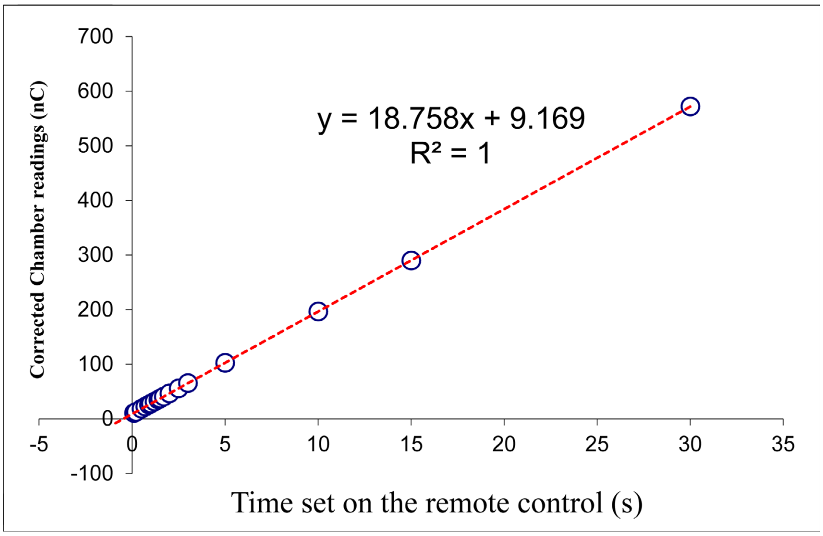

Figure 4. Graph of corrected chamber charge against irradiation time for OB6 at 4 m.

average timer error is 0.48 ± 0.01 s.

There is very close agreement between the average timer errors obtained using the graphical method and the single/multiple exposure method. The standard deviation of 0.01 obtained in the graphical method is less than 0.03 obtained from single/multiple exposure method. This shows that the timer error obtained graphically is more precise and might be more accurate.

In single/multiple exposure method, $M_B > M_A$ and thus timer error, τ calculated is positive, which implies that the timer error will be subtracted from the calculated time [8]. Also, in the graphical method, the intercept of the graph on the time axis is negative, which is in agreement with the single/multiple exposure methods.

The result in **Table 3** also implies that the actual time of exposure is greater than the set time on the OB 6 irradiator, therefore, there is need to subtract the timer error value obtained value from the calculated irradiation time. Furthermore, for OB6 set time greater than or equal to 49 s, the percentage dose error

Table 2. Timer error of OB6 at different distances using graphical method.

Distance (m)	Timer error, τ (s)
1	0.48
2	0.46
3	0.47
4	0.49
Mean	0.48
Standard Deviation	0.01
Standard Deviation from mean	0.01

Table 3. OB6 Dose evaluation.

Distance from OB6 (m)	Reference Dose Rate, D_R (mSv/s)	OB6 Time, T (s)	Expected Accumulated Dose, $D_E = D_R \times T$ (mSv)	Obtained Dose, D_O (mSv)	Actual Exposure Time, $t = D_O/D_R$ (s)	%Timer error $(100^*(T - t)/T)$	%Dose error $(100^*(D_E - D_O)/D_O)$
1	0.0091	10	0.091	0.096	10.5	−5.00	−5.49
1	0.0091	49	0.446	0.451	49.6	−1.22	−1.12
1	0.0091	79	0.720	0.724	79.6	−0.76	−0.56
2	0.0022	10	0.022	0.023	10.5	−5.00	−4.55
2	0.0022	49	0.110	0.111	50.5	−3.06	−0.91
2	0.0022	79	0.177	0.178	80.9	−2.41	−0.56
3	0.0010	10	0.01	0.011	11	−10.00	−10.00
3	0.0010	49	0.049	0.050	50	−2.04	−2.04
3	0.0010	89	0.089	0.090	90	−1.12	−1.12
4	0.00056	177.9	0.1	0.100	178.6	−0.39	0.00
4	0.00056	533.8	0.3	0.300	535.7	−0.36	0.00

obtained ranges from 0% to 2%, which means that the effect of timer error is negligible for the exposure time greater than 49 s.

The result in Table 3 was also presented graphically for 1 m, 2 m, and 3 m in Figure 5 and Figure 6 for dose error and timer error respectively. The graphs show that the percentage timer and dose errors decrease with time for the three distances.

The result of Timer and dose verification is also shown in Table 4. It was observed that the percentage error in dose is minimal for time, $T - \tau$ (time calculated minus the timer error), followed by the time, T, and $T + \tau$ has the highest dose error. Also, the percentage dose error decreases as the exposure time increases. From Table 4, the percentage dose error for the calculated exposure time of 44.69 s is less than 1%, this shows that the timer error is negligible as the time approaches 48 s.

As shown in Table 1 and Table 2, and Figure 1, the timer error of the OB6 is not significantly affected by the distance of the detector from the irradiator.

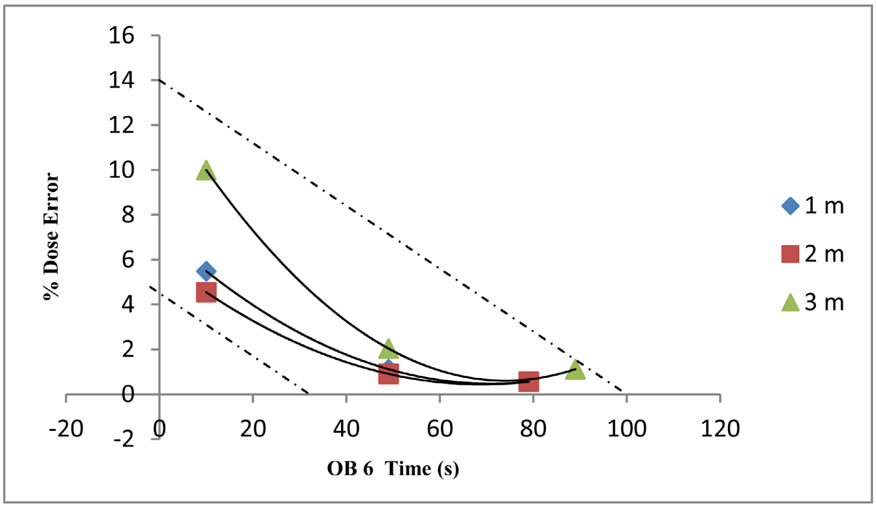

Figure 5. Graph of percentage dose error with time for different distances.

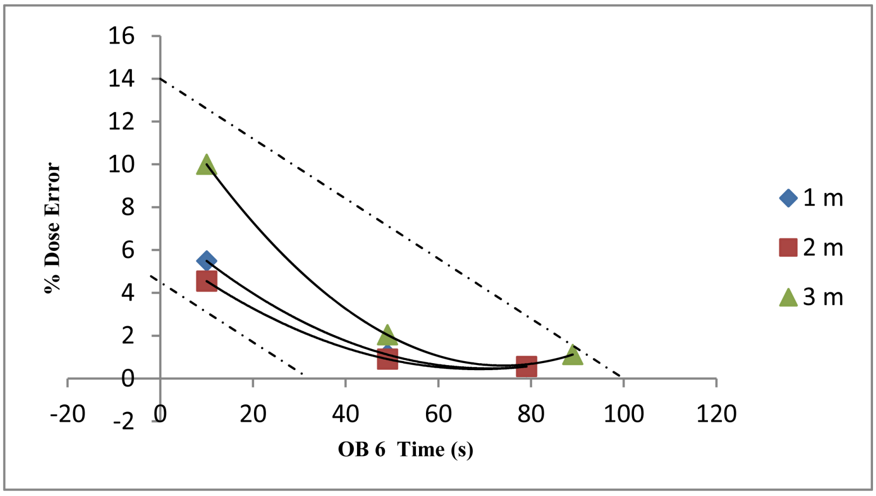

Figure 6. Graph of percentage Timer error with time for different distances.

3.2. X-Ray Irradiator

The timer error of the X-ray irradiator in Table 5 below was calculated using Equation (3). Figure 7 also shows the plot of charges against time. From the graph, the intercept on the time axis is 0.08 s which represents the timer error of the X-ray irradiator. Based on the results from the two methods used, the timer error of the X-ray irradiator can be estimated as 0.09 ± 0.01 s.

It is important to note that the solenoid in the shutter assembly of the X-ray irradiator is a new one which may account for the very short timer error.

Table 4. Timer/Dose verification.

Distance (m)	Dose (mSv)	Calculated Time, T(s)	Dose for T, D_T (mSv)	Dose for $T-\tau$, $D_{T-\tau}$ (mSv)	Dose for $T+\tau$, $D_{T+\tau}$ (mSv)	% error for D_T	% error for $D_{T-\tau}$	% error for $D_{T+\tau}$
1	0.100	10.98	0.104	0.100	0.109	−4	0	−9
1	0.200	21.95	0.205	0.201	0.209	−2.5	−0.5	−4.5
1	0.500	54.88	0.504	0.500	0.507	−0.8	0	−1.4
2	0.100	44.69	0.101	0.100	0.102	−1	0	−2
2	0.200	89.39	0.201	0.200	0.202	−0.5	0	−1
2	0.500	223.46	0.501	0.501	0.503	−0.2	−0.2	−0.6
3	0.100	100	0.100	0.100	0.101	0	0	−1
3	0.200	200	0.201	0.200	0.202	−0.5	0	−1

Table 5. Timer error of X-ray irradiator using single/multiple exposure method.

Time, T(s)	Corrected reading for T, M_A (nC)	Corrected Reading for 4 short exposures M_B (nC)	Timer error, τ(s)
240	10.32877	10.34209	0.10

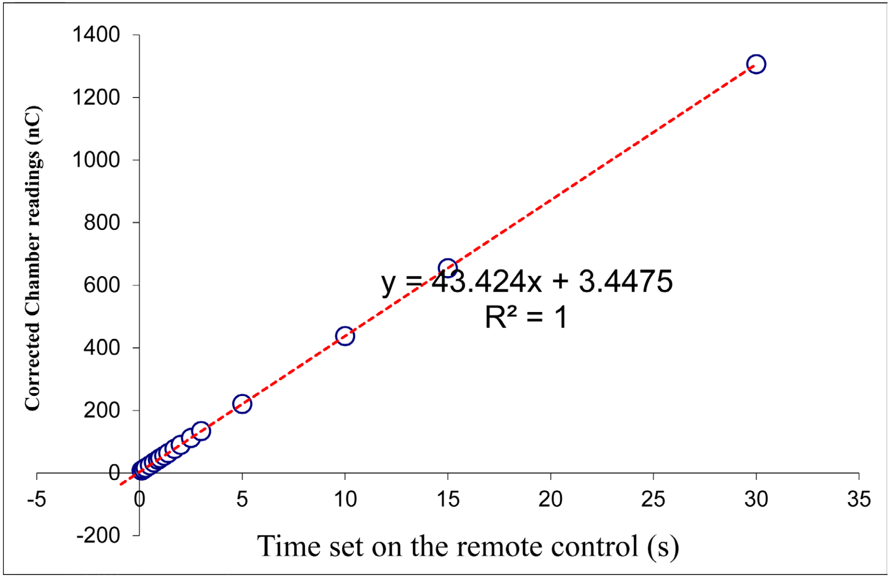

Figure 7. Graph of corrected chamber charge against irradiation time for X-ray Irradiator at 2 m.

3.3. Gamma Beam X200 Irradiator

The results obtained for timer error of GammaBeam X200 irradiator at 80 cm SSD, different field sizes and depths in water are as shown in **Table 6** and **Table 7** for the single/multiple exposure and graphical method respectively. The timer errors obtained yearly during Quality Control of the irradiator are as shown **Table 8** and reveals that there has been an increase in values obtained over the time. The present timer error is 1.21 s which is 38.8% increment from 0.74 s obtained during commissioning. This might be due to the ageing of the equipment's components.

The timer error at 5cm depth in water, 100 cm SSD, and various field sizes are as shown in **Table 9** and **Table 10** for the single/multiple exposure and graphical method respectively. A graph of timer error versus field size is shown in **Figure 8**. It was observed that the field size, SSD, and the depth of the detector in water have no significant influence on the timer error.

The GammaBeam X200 irradiator does not use a system of shutters that opens during irradiation and closes after irradiation. Instead, the Co-60 source moves through a track distance from its fully shielded position to the point of irradiation. This may account for its longer timer error when compared to both the X-ray and OB6 irradiators.

Table 6. Timer error of GammaBeam X200 irradiator obtained using single/multiple exposure method at an SSD of 80 cm with varied field sizes and varied depth in water.

Field Size (cm × cm)	Depth in water(cm)	Timer error, τ (s)
5 × 5	5	1.21
	10	1.20
10 × 10	5	1.18
	10	1.22
15 × 15	5	1.22
	10	1.22
20 × 20	5	1.22
	10	1.18
25 × 25	5	1.21
	10	1.22
30 × 30	5	1.22
	10	1.23
35 × 35	5	1.23
	10	1.20
Mean		1.21
Standard Deviation		0.02
Standard Deviation from mean		0.04

Table 7. Timer error of GammaBeam X200 irradiator obtained using graphical method at an SSD of 80 cm with varied field sizes and varied depth in water.

Field Size (cm × cm)	Depth in water(cm)	Timer error, τ (s)
5 × 5	5	1.19
	10	1.20
10 × 10	5	1.17
	10	1.20
15 × 15	5	1.19
	10	1.19
20 × 20	5	1.20
	10	1.20
25 × 25	5	1.22
	10	1.21
30 × 30	5	1.20
	10	1.20
35 × 35	5	1.22
	10	1.21
Mean		1.20
Standard Deviation		0.01
Standard Deviation from mean		0.03

Table 8. Past and Present timer error of Gamma Beam X200.

Year	Timer Error (s)
2022	1.21
2019	0.92
2017	0.79
2015	0.74
2013	0.74

Table 9. Timer error of GammaBeam X200 irradiator obtained using graphical method at a depth of 5 cm and SSD of 100 cm.

Field Size (cm × cm)	5 × 5	10 × 10	15 × 15	20 × 20	25 × 25	30 × 30	35 × 35	Mean
Timer error, τ (s)	1.15	1.19	1.19	1.2	1.2	1.21	1.2	1.20

4. Conclusion

Timer errors of irradiation devices in the Secondary Standard Dosimetry Laboratory (SSDL) in Nigeria were investigated and analyzed in this study. The timer error obtained for the OB6, X-ray irradiator, and GammaBeam X200 was 0.48 ±

Table 10. Timer error of GammaBeam X200 irradiator obtained using single/multiple exposure at a depth of 5 cm and SSD of 100 cm.

Field Size (cm × cm)	Timer error, τ (s)
5 × 5	1.20
10 × 10	1.19
15 × 15	1.21
20 × 20	1.22
25 × 25	1.22
30 × 30	1.21
35 × 35	1.22
Mean	1.21
Standard Deviation	0.01
Standard Deviation from mean	0.44

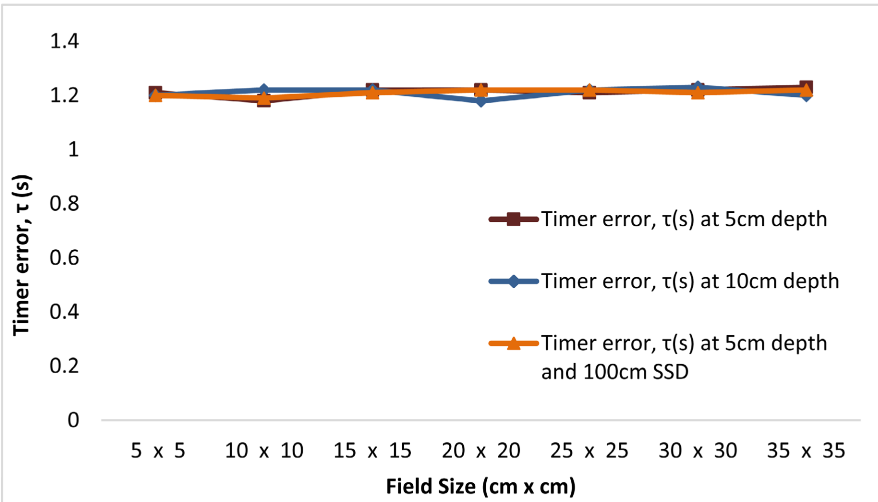

Figure 8. Graph of timer error with field size.

0.01 s, 0.09 ± 0.01 s, and 1.21 ± 0.04 s respectively. The timer error calculated using the two methods have a close value but the timer error estimated using the graphical method is more precise for the OB 6 irradiator as shown by the calculated standard deviations. From the two methods used, it was observed that the source-to-detector distance (SDD) does not have a significant effect on the timer error, therefore, the timer error can be estimated at any of the distances. Also, for OB6, the timer error can be neglected if the calculated exposure time is greater than 48 s, since the uncertainty contribution from timer error to dose will be less than 1%. The timer error of the X-ray irradiator is negligible. The timer error calculated using Single/Multiple Exposure Method ($\tau > 0$) and the timer error obtained using the graphical method (negative intercept on time axis) is in agreement that the timer error obtained from the OB6 and GammaBeam X200 should be subtracted from the calculated time exposure. The timer error of the GammaBeam X200 increases with the age of the machine which might be due to the ageing of the irradiator's shutter components. These findings are significant in estimating the irradiation time accurately, thereby improving the accuracy of dose delivery.

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Author Contribution

Conceptualization: O. O. Akerele, Methodology: D. O. Olaniyi, Formal analysis: F. A. Agada, Funding acquisition: S. M. Oyeyemi, Project administration: S. M. Oyeyemi, Visualization: L. R. Owoade, Writing—original draft: D. O. Olaniyi, Writing—review and editing: B. M. Adeniran, Approval of final manuscript: all authors.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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