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Assessment Of The Effectiveness Of Collimation Of Cs–137 Panoramic Beam On Tld Calibration Using A Constructed Lead Block Collimator And An ICRU Slab Phantom At SSDL In Ghana.

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ABSTRACT

The objective of calibrating TLD badges and radiation survey meters demand that accurate dose gets to the TLDs and radiation survey meters. A lead block mould and an ICRU slab phantom had been designed and constructed to collimate the panoramic Cs-137 source at the secondary standards dosimetry laboratory (SSDL) by experts at the National Nuclear Research Institute (NNRI) workshop of the Ghana Atomic Energy Commission according to required specifications. This is to concentrate the panoramic isotropic emission into narrow beam geometry to enhance the calibration of personnel dosimeters and radiation survey meters and further reduces scattered radiations due to backscatter and transmission through the biological shield. The designed block was tested by a series of dose measurement of 1mSv using thermoluminescent dosimeters (TLDs) placed on a standardized ICRU slab phantom to cater for backscatter conditions of the human body at specified distances of 1, 2 and 3 meters with and without the collimation. The transmission dose rates measurements through the biological shield were taken by a survey meter. The results show percentage distribution of an effective reduction of transmitted dose rate to the laboratories and offices. However, the lead door recorded very high transmitted dose rates. It was finally concluded that further collimation will be necessary to completely eliminate scatter radiations introduced by the panoramic bench and transmission through the lead door.

Keywords: *Calibration, Collimation, Phantom, TLD, Dose rates*.

1. INTRODUCTION

External radiation quantity can be measured in terms of exposure, air kerma, absorbed dose, dose equivalent, ambient dose equivalent and directional dose equivalent by using radiation measuring instruments. Various kinds of radiation measuring instruments such as survey meters, area monitors, personal dosimeters, contamination-monitoring instruments are used in irradiation facilities for radiation protection purposes. Implementation of the standard monitoring process requires that radiation-monitoring survey meters are calibrated in terms of dose equivalent quantities.

Area dosimeters or dose rate meters should be calibrated in terms of the ambient dose equivalent, H_p*(10), or the directional dose equivalent, H_p' (0.07) [1]. In radiotherapy centers, the radiation monitors are normally used for determinations of the output of Cobalt-60 teletherapy units and linear accelerators (linacs) and should be calibrated in terms of exposure [2], air kerma [3] or absorbed dose to water [4, 5].

Radiation measuring instruments need to be calibrated to ensure that they give accurate and correct reading with a certain uncertainties and to comply with the regulations imposed by the relevant authority. They should be calibrated annually [6, 7] or after major repair. In Ghana, calibration of radiation measuring instruments is a legal requirement under the Radiation Protection Regulation, (LI 1559 of 1993). The SSDL was established in late nineteen eighties and is a member of the IAEA/WHO Network of SSDLs. The calibration bunker is constructed on-top of a laboratory with a 40 cm thick of concrete, 8 meters wide and 12 meters long .The main radiation facilities include a collimated Cobalt-60 unit, constant potential X-ray system with a 320 kV tube, and a panoramic cesium irradiator. The laboratory has acquired the status of national standard laboratory with the basic aim of improving accuracy in radiation dosimetry in the country.

It is also the national focal point for the calibration of radiation measuring instruments for radiation protection purposes in diagnostic radiology, radiotherapy and industrial applications of radiation and nuclear technologies. More than 100 radiation instruments are normally calibrated every year. The laboratory has also the responsibility to ensure that the calibration services provided by the laboratory follow internationally accepted metrological standards. This is achieved by calibrating the laboratory's protection and therapy levels dosimeters against those in the Primary Standard Dosimetry Laboratories (PSDLs) or the International Atomic Energy Agency (IAEA) or by participating in the international comparison on dosimetry measurements programmes. The main objective of this study is to concentrate the panoramic beam geometry into narrow beam geometry suitable for calibration purposes; further reduce scatter radiation introduced by the panoramic bench and the wall surfaces of the calibration bunker. And eventually reduce transmitted radiation to the controlled and supervised areas during calibration.

MATERIALS AND METHODS

Panoramic Cesium source

Figure 1, is a panoramic setup of the cesium-137 radioactive source of 22.2 GBq. It has a storage lead case which houses the radioactive source when at storage position. The source is connected to a nitrogen gas which helps to move the source to the irradiation position during irradiation.

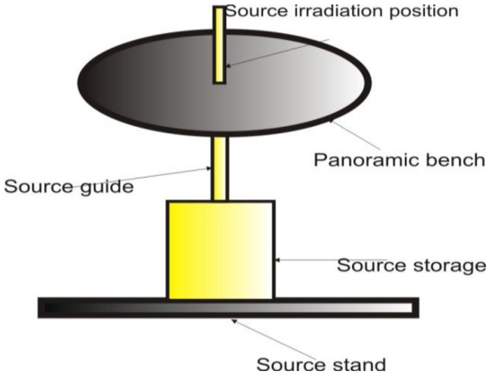

Figure 1: Panoramic setup of Cesium source indicating irradiation and storage positions

Lead Block collimator

Prior to the designing of the lead-block collimator, radiographic films were placed around the set-up of the panoramic cesium irradiator to locate accurately the exact position of the source during irradiation. The radiographic films were then developed and the source position was then located as being at the approximately the surface of the panoramic bench.

Figure 2, is the designed lead-block collimator which was based on information obtained from the developed radiographic film. The design was then handed over to the metal workshop technologists who then molded the collimator according to required dimensions stated. The lead-block collimator is made of pure lead, molded into a block with a length of 19.1 cm, a width of 15.9 cm and height of 20.1 cm. It has two drilled holes, one in front of the block which is 4.7 cm in diameter that allow radioactive photons to emerge during irradiation process. The other hole is on top of the block which is 3.2 cm in diameter serves as a support for the protruded panoramic tube.

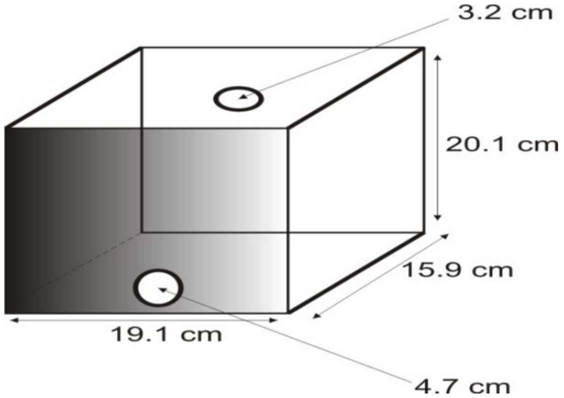

Figure 2: Lead block collimator

Figure 3, clearly shows the result of the design and constructed lead-collimator in its rightful position. It was anticipated that the panoramic bench may create scatter radiation when some of the beam hits it during irradiation.

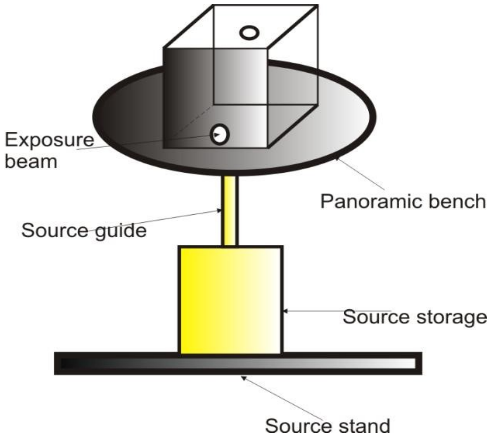

Figure 3: Collimator fixed in position

ICRU Slab Phantom

Figure 4 represent the ISO water slab phantom which was constructed using Perspex. The phantom represents the human torso with regard to backscattering of the incident radiation. The ISO water slab phantom is of dimension 30 cm × 30 cm × 15 cm depth. The front face of the water phantom consists of a 2.5 mm thick PMMA plate. The other phantom sides are 10 mm thick PMMA.

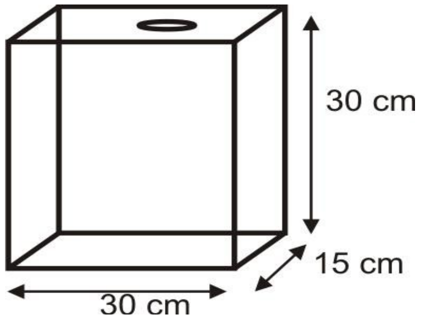

Figure 4: Designed and constructed ICRU slab phantom

Thermoluminescent Dosimeter (TLD)

Thermoluminescent dosimeters (TLD) cards containing lithium fluoride chip (LiF) fastened on the standardized designed ISO slab phantom as shown below in figure 5.

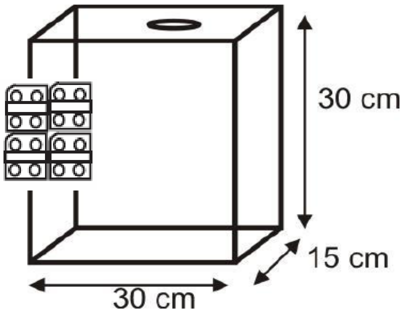

Figure 5: TLD fastened to ICRU slab phantom

Dose Rates Measurements

After the construction, the lead-block collimator was brought to the laboratory and fixed. It was then tested by a series of dose measurement of 1mSv using thermoluminescent dosimeters (TLDs) placed on the standardized designed ISO slab phantom to cater for backscatter conditions of the human body at specified distances of 1, 2 and 3 meters with and without the collimation. The transmission dose rates measurements through the biological shield were measured by a survey meter.

RESULTS AND DISCUSSION

To determine the actual exposure time required to deliver a known dose to dosimeters, there is the need to employ the decay correction factor. This is because Cs-137 undergoes radioactivity and as time elapses, the initial activity relates to the activity as at the time of using the source by the expression

$$A = A_0 e^{-\lambda t} \qquad (1)$$

Where A is the present activity, $A_0$is the initial activity at a known time, λ is the decay constant and t is the time to the date of exposure.

For every exposure, the laboratory parameters recorded were pressure, temperature and relative humidity [8]. For all calculations involving the Cs-137 source, the kerma rate at that location was first determined in order to calculate exposure time.

To determine the absorbed dose, the pressure-temperature correction factor is incorporated by using the expression:

$$D_a = D_m \, . \, PTCF \qquad (2)$$

WhereD_a is the absorbed dose, D_m is the measured dose value and $PTCF$ is the pressure-temperature correction factor [3].

$$PTCF = \frac{(273.15+T)\times 1013.25}{(293.15)\times P} \qquad (3)$$

P = pressure measured in mbar, T = temperature measured in degrees Celsius [4, 5].

The dose rate at any given time is dependent on the air kerma and distance. It is measured with an ionizing chamber which operates by the Bragg-Gray cavity theory. The kerma correction is expressed as

$$K_{air} = K_{ref} e^{-\frac{ln2}{T_{1/2}} t} \qquad (4)$$

K_{air} is the kerma in air, K_{ref} is the reference kerma, $T_{1/2}$ is the half-life of the source, t is the days elapsed since last determined [4]. This expression was corrected by the inverse square law in order to perform calculations regarding exposure times.

After exposure measurements, the experimental values were analyzed to determine if the collimation yielded narrow beam geometry for the purpose of calibrating equipment. Data below shows a comparison of measurements at various locations:

Table 1 and 2 represents the response of the TLD chips to 1mSv at one (1), two (2) and three (3) meters without collimation.

Table 1: Response of TLD chips (Channel II) to 1mSv exposures for different distances without collimation

Card ID	Exposure	Channel II Reader's value [mSv]	Average reading [mSv]
360	*1mSv @ 1 m*	1.4126	1.3227
369		1.3343	
513093		1.2531	
5440		1.2908	
360	*1mSv @ 2 m*	1.4521	1.4576
369		1.6372	
513093		1.5384	
5440		1.2026	
360	*1mSv @ 3 m*	1.4077	1.4428
369		1.5522	
513093		1.5848	
5440		1.2265	

Table 2: Response of TLD chips (Channel III) to 1mSv exposures for different distances without collimation

Card ID	Exposure	Channel III Reader's value [mSv]	Average reading [mSv]
360	*1mSv @ 1 m*	0.9130	0.9396
369		0.9189	
513093		0.9674	
5440		0.9591	
360		1.0101	

369	*1mSv @*	1.2321	
513093	*2 m*	1.0865	1.0954
5440		1.0530	
360		1.0349	
369	*1mSv @*	1.1112	
513093	*3 m*	1.0591	1.0778
5440		1.1058	

Table 3 and 4 represents the response of the TLD chips to 1mSv at one (1), two (2) and three (3) meters with collimation.

Table 3: Response of TLD chips (Channel II) to 1mSv exposures for different distances with collimation

Card ID	**Exposure**	**Channel II Reader's value [mSv]**	**Average reading [mSv]**
360		1.1022	
369	*1mSv @*	0.9525	
513093	*1 m*	1.1040	1.0683
5440		1.1143	
360		1.1892	
369	*1mSv @*	1.1008	
513093	*2 m*	0.9993	1.0790
5440		1.0266	
360		1.1457	
369	*1mSv @*	1.0267	1.0737
513093	*3 m*	1.0517	
5440		1.0705	

Table 4: Response of TLD chips (Channel III) to 1mSv exposures for different distances with collimation

Card ID	**Exposure**	**Channel III Reader's value [mSv]**	**Average reading [mSv]**
360		0.8509	
369	*1mSv @*	0.8825	
513093	*1 m*	0.8368	0.8442
5440		0.8066	
360		0.9518	
369	*1mSv @*	0.8235	
513093	*2 m*	0.8873	0.8583
5440		0.7703	
360		0.9014	
369	*1mSv @*	0.8530	0.8513
513093	*3 m*	0.8621	
5440		0.7885	

From the results in Table 3 and 4, it was observed that there was a reduction in scatter radiation which contributes to the high exposures received.

From table 5, the results show an effective reduction of transmitted dose rate to the laboratories and Offices.

Table 6 also shows the percentage dose rates attenuated by the shield.

The transmitted dose rate to all the public locations and offices were cut-off by the lead block collimator.However, the lead door recorded high transmitted dose rates compared with the transmitted dose rate without collimation. This was because the intensity of dose reaching the lead door from the emerging collimated beam was high. It is therefore necessary to further collimate the photon beam into a narrower beam taking into consideration the complete surface of the slab phantom during irradiation. A beam diameter of 1.2cm was recommended based on the geometry and diameter of the emergent beam of 4.7cm.

Table 5: Measured transmitted dose rate through the shield at various location.

Location	Dose rate without collimation(µSv/h)			Dose rate with collimation(µSv/h)		
	1 m	2 m	3 m	1 m	2 m	3 m
Pb Door	2.13	2.05	2.09	4.10	4.31	4.44
S. A(SSDL)	0.25	0.32	0.61	0.09	0.05	0.08
Scoffice	0.05	0.09	0.08	0.05	0.07	0.07
E. lab	2.45	2.44	2.98	0.30	0.42	0.22
Man. office	3.77	4.96	4.64	0.94	0.92	1.02
G. S. lab	0.32	0.07	0.23	0.05	0.08	0.11
Dir. office	1.12	1.48	1.84	0.05	0.05	0.05

Table 6: Percentage dose rate attenuated by the shield.

Location	Percentage dose rate attenuated		
	1 m	2 m	3 m
Lead Door (SSDL)	-93	-110	-112
Supervised Area (SSDL)	64	84	87
Research Scientist Office	0.0	22	13
Environmental laboratory	88	83	93
Manager's Office	75	82	78
Gamma Spectrometry lab.	84	-14	52
Director's office	96	97	97

Table 7 shows results of scatter reduction as a result of exposure to TLDs with and without collimation. It was observed that at 1 mSv, the collimated values were very close which means scatter has been eliminated to the minimum.

Table 7: Response of TLD chips with and without collimation for Hp(0.07) and Hp(10).

location @ 1mSv	Dose	Without collimation (mSv)	With Collimation (mSv)
1 m	Hp(0.07)	1.3227	1.0683
	Hp(10)	0.9396	0.8442
2 m	Hp(0.07)	1.4576	1.0790
	Hp(10)	1.0954	0.8583
3 m	Hp(0.07)	1.4428	1.0737
	Hp(10)	1.0278	0.8513

Table 8 represents the percentage scatter reduction from without collimation to with collimation.

Table 8: Fraction of scattered reduction in percentage for both Hp(0.07) and Hp(10).

Locations @ 1mSv	Dose	Fraction of Scattered Reduction (%)
1 m	Hp(0.07)	19.2
	Hp(10)	10.2
2 m	Hp(0.07)	25.9
	Hp(10)	21.6
3 m	Hp(0.07)	25.6
	Hp(10)	17.2

CONCLUSION

The lead collimator on the Cs137 panoramic source and the ICRU slab phantom had been designed, constructed and tested to be very effective based on experimental results. However, further collimation will be necessary to completely eliminate scatter radiations introduced by the panoramic bench and other surfaces in the calibration bunker.

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