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Evaluation of the Biological Shields of the Secondary Standard Dosimetry Laboratory of Ghana Using MCNP5

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Abstract: The primary objective with radiation sources and facilities is the protection of both radiation workers and the general public. The biological shields of the Secondary Standard Dosimetry Laboratory of the Radiation Protection Institute (RPI) Ghana had been evaluated for a collimated isotropic cesium-137 source for calibration purpose using MCNP5 code. The dose rate at supervised areas ranged from 0.57 to 8.35 μSv/h and 0.26 to 10.22 μSv/h at control areas when the source was panoramic. When the source was collimated, the dose rate ranged from 0.05 to 0.30 μSv/h at supervised areas and 0.23 to 8.88 μSv/h at control areas for 22.2 GBq of the cesium-137 source. The scatter contribution from the surfaces of the walls and roofs were also accounted for. The scatter radiation in the room decreased to 400 μSv/h when the source was first collimated and to 3.5 μSv/h when the source was further collimated. These results agreed quite well with experimental measurement. To effectively protect the staff, a narrow beam of 1.2 cm diameter which was defined at 1.0 m by the total surface of the ISO slab phantom was recommended to reduce the dose rate to less than 1.5 μSv/h outside the calibration bunker even when the current activity is doubled. It was concluded that the 4.7 cm diameter of the existing narrow beam should be decreased to 1.2 cm by further collimation of the beam.

Key words: Ambient dose equivalent, biological shielding, MCNP5, modeling, SSDL

INTRODUCTION

The Radiation Protection Institute of the Ghana Atomic Energy Commission (GAEC), Inspectorate for Ionizing Radiation established by law, LI1559 of 1993 uses panoramic cesium-137 source, collimated cobalt-60 unit and a constant potential x-ray system with a 320 kV tube for metrological purposes, calibration and verification of dosimeters designed for detection and measurement of photon-related quantities. With these sources, it is possible to obtain air kerma rates sufficient for all the commonly used dosimeters in the country. The Secondary Standard Dosimetry Laboratory (SSDL) was established in late nineteen eighties and is a member of the International Atomic Energy Agency (IAEA) and World Health Organization (WHO) Network of SSDLs. The calibration bunker is constructed on-top of an office with laboratories surrounding it. The SSDL 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 used in radiation protection, industrial and medical facilities. 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 (ISO 4037, 1996; IAEA, 2000 and ISO 4037, 1999). This is achieved by calibrating the laboratory's protection and therapy levels dosimeters against those in the Primary Standard Dosimetry Laboratories (PSDLs) or the IAEA or by participating in the international comparison on dosimetry measurements programmes.

In assessing the shielding adequacy, various alternatives should be explored to ensure that the total detriment remains small relative to the benefit obtained from the practice (NCRP 49, 1976; IAEA, 1975; 1968; Hobson and Andrew, 2005). This means that the shielding improvements should be evaluated until the expected doses are below the limit. In the design and construction of irradiators, the biological shields constitute one of the important considerations to ensure safety of personnel and equipment in the working areas. Concretes are usually used for the walls to bring about the attenuations of photons by multiple scatter. Lead-lined or steel doors are

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used to further attenuate photons whiles serving as a barrier against inadvertent entry into the calibration bunker (Emi-Reynolds and Edward, 1994).

In this study, assessment of the concrete shields was made. These included the offices and laboratory in the neighbourhood of the SSDL using MCNP5 code (X-5 Monte Carlo Team, 2003) and also by a direct experimental measurement.

The main objectives were:

- Evaluate the effectiveness of the biological shields for a new collimated Cesium-137 panoramic source.
- To estimate the dose rate reaching the neighbouring occupied areas for protection purpose.
- To estimate the reduction in backscatter radiation to ascertain the effectiveness of the collimation.
- To estimate the percentage reduction in doses reaching public areas during calibration activities.

DESCRIPTION OF FACILITY

The plan view of the SSDL is shown in Fig. 1a and cross sectional view in fig. 1b. It is made up of a 30 cm concrete shield. It has an enclosed area of 11 m by 8 m. the bunker houses three different sources: a 44.4 GBq panoramic cesium-137, a cobalt-60 unit and a constant potential X-ray system with a 320 kV tube voltage. Currently, the panoramic cesium-137 is mainly used for calibration of personnel dosimeters and radiation protection instruments. Figure 2 is a setup of the collimated panoramic cesium-137 source.

The Cesium-137 source is located about three meters from the concrete shield opposite the control console. It is housed by a lead container under the bench when at storage and is brought to irradiation position using a pneumatic transfer mechanism. Currently the source had been collimated with lead to cut-off dose rate to the surrounding and to reduce scatter radiation reflected by the walls of the SSDL during irradiation. Fig. 2 also shows the lead block collimator fixed in position. The lead-block collimator is made of pure lead, moulded into block with a length of 19.1 cm, 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 allows 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 which is intern blocked by lead.

The SSDL is located on the first floor with offices located at the top and bottom. It has a student laboratory located at the left and with a store and offices located in front of it.

MATERIALS AND METHODS

MCNP calculation: This study was carried out from February to August 2011 at the only SSDL located at the Radiation Protection Institute of Ghana. The bunker of the SSDL was modelled using the visual editor of the MCNP5 code taken into considerations the shields, the source and the surrounding offices according to the design specification of the facility. The panoramic calibration was done in air but when the source was collimated, an International Standardization Organization (ISO) water slab phantom of dimension 30 cm × 30 cm × 15 cm depth with the front face of the water phantom consisting of a 2.5 mm thick PMMA plate and the other phantom sides 10 mm thick PMMA was located 1m and covered completely by the photon beam during calibration. The concrete shield was made up of ordinary concrete with a density of 2.3 g/cm^3 and with material specification (Williams III *et al*., 2006). The door of the bunker is wooden door with iron frame, and lined with 9 mm of lead of density 11.4 g/cm^3. The cesium-137 source was assumed to be a point isotropic source and as a point source collimated into a cone of direction with a half angle of 0.957 corresponding to the angle of the lead mould, with the photon beam directed toward the control console as in the case of calibration for the panoramic and collimated orientation respectively with a corrected activity of 22.2 GBq using the decay equation:

$$A = A_0 e^{-\lambda t} \tag{1}$$

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. The variance reduction technique employed was cell division and photon importance to increase the photon populations toward regions of importance and to reduce unimportant regions for optimization. In order to sample the average fluence at the locations of interest, small spheres of radius 1.81 cm which is a representative of the sensitive area of a detector was modeled at each detector locations. The average fluence that stream through the shield was all sampled on the surfaces of the sphere by this method. The average weight of the photons crossing the surface of each sphere per unit area in time in all direction from the source was sampled by the relation below:

$$\phi(r, E, \Omega) = \frac{1}{a} \int_a da \int_e de \int_{4\pi} d\Omega \, \phi(r_s, e, \Omega) \tag{2}$$

where, a is the area of sphere, $\theta$is direction of photons, is the energy, r is the distance and ϕ(r, E, Ω) is the energy

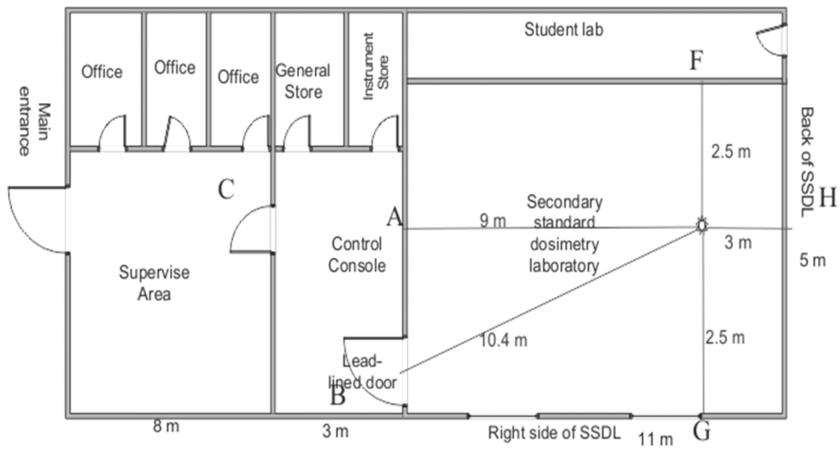

Fig. 1a: Plan view of the Secondary Standard Dosimetry Laboratory

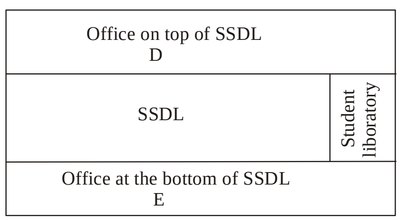

Fig. 1b: Cross sectional of the Secondary Standard Dosimetry Laboratory

and angular distribution of the fluence. The sum of the contribution is reported as a function of position (Kenneth and Richard, 2008). The photons in the room as a result of reflection from the walls and other surfaces was also sampled by placing similar detectors near the wall surfaces. The resulting fluence was then normalized to be per starting particle. In order to change the resulting fluence into dose rate, a special card was employed. This card employed a dose energy and function factors by using ICRP 74 dose conversion factors (ICRP 74, 1997). These dose conversion factors multiply the resulting fluence into photon ambient dose equivalent H*(10mm) which is appropriate for calibration of radiation protection dosimeters and is described by the relation below:

$$D_{(r)} = \int_E \Phi\gamma(r,E)R(r,E)dE \qquad (3)$$

where $\Phi\gamma$(r, E) is the resulting photon fluence, $D_{(r)}$ is the dose rate and R(r, E) is the fluence to dose conversion factor or the detector response (Kenneth and Richard, 2005).

Experimental assessment:

The areas of survey: Figure 1a and b show the locations around the SSDL where measurements were taken and

Table 1: Represent locations around the SSDL where dose rate calculations and measurements were taken and their corresponding dose limit or constraint

Locations	Reference dose rate (µSv\h)
Control console (A)	7.5
SSDL lead door (B)	7.5
SSDL supervise area (C)	0.5
Office on top of SSDL (D)	0.5
Office at bottom of SSDL (E)	0.5
Student laboratory (F)	0.5
Right side of SSDL (G)	0.5
Back of SSDL (H)	0.5

Table 1 also shows their corresponding local limits. Location A and B are control areas where activities within the SSDL during calibration are performed. Location A is the control console and B is the lead door. Locations C, D, E, F, G and H are designated as the public areas.

Dose assessment: Critical locations were first identified as positions were maximum dose rate were expected for radiation protection purposes and the corresponding distances from the source measured. Dose rate monitoring was carried out for the selected locations A, B, C, D, E, F and G with a universal survey meter with a sensitivity of ±10% and capable of measuring doses in the range of 0.05-10 Sv/h. Initially, the collimator was removed and instantaneous dose rate were recorded at the various locations. Secondly, the collimator was placed back and dose rate measurement recorded. The measurements were taken 1 m from the ground and 0.3 m from the shield. Three readings each were taken and the average values recorded as a representative of each location. The results were then tabulated as in Table 3.

RESULTS AND DISCUSSION

The results from Table 2 and 3 showed a similar behaviour between MCNP5 and experimental measurement for both panoramic and collimated calculations. These are also clearly shown by Fig. 3, 4 and

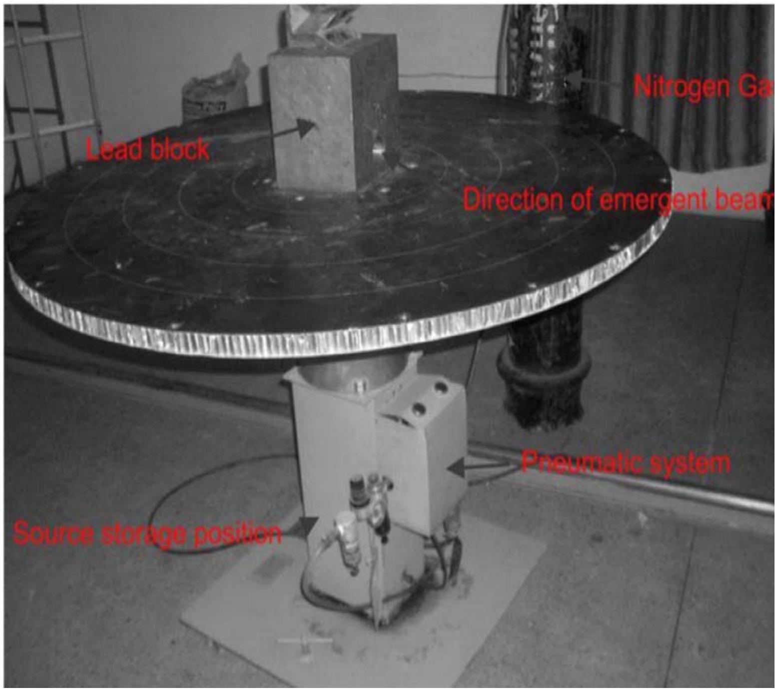

Fig. 2: presents panoramic Cesium source with the lead block collimator in place

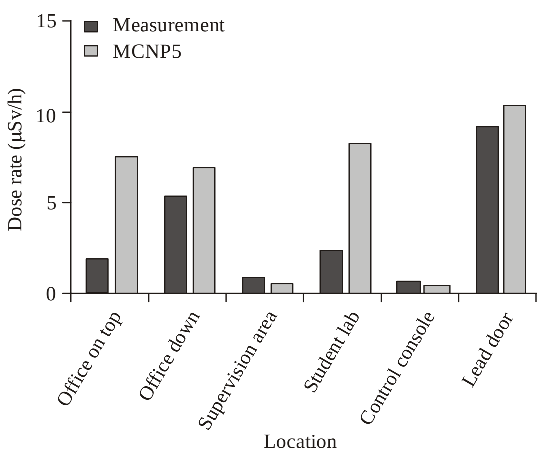

Fig. 3: Presents Comparison of measured and MCNP5 calculated dose rate for the case of panoramic setup for 22.2GBq cesium-137 source

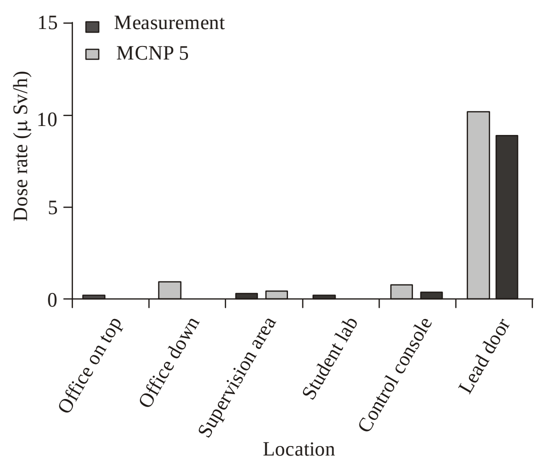

Fig. 4: Presents comparison of measured and calculated MCNP5 dose rate for the case of collimated setup for 22.2GBq cesium-137 source

5. Even though MCNP5 predicted a higher dose rates than the experimental, they both showed a decrease in dose rate when the source was collimated except in the direction of the beam. The difference in dose rate can be attributed to the geometric modeling of the collimated source as a conical beam instead of a lead block with a circular collimation. The average percentage reduction indicated 86.8% for MCNP5 and 87.3% for the experimental in all public locations. There was also reduction in back-scatter radiation as a result of multiple scattering from the surfaces of the walls and the concrete roof. This is clearly shown by Fig. 6 which was when the source was collimated and when it was further collimated by Fig. 7. It became obvious after collimation when MCNP was used to calculate the dose rate, that there was a complete cut-off of radiation to some sides of the collimator and the majority of the sampling was as a result of scatter radiation within the room. This is described by the abbreviation N/A on Table 3 and 4. Both the MCNP calculations and experiment revealed a higher

Table 2: Calculated dose rate with and without collimation and with their percentage reduction in dose rate at locations around the SSDL for the current 22.2GBq Cs-137 calibration source

	MCNP22.2GBq ^{137}Cs Calibration Source H*(10 mm) (µSv\h)		
Location	Panoramic	Collimated	% reduction in dose
Control console (A)	0.26±0.02	0.23±0.04	11.2
SSDL lead door (B)	10.22±0.07	8.88±0.02	13.11
SSDL supervise area (C)	0.57±0.07	0.30±0.01	47.4
Office on top of SSDL (D)	7.45±0.10	4.22E-04±2.15E-05	99.9
Office at bottom of SSDL (E)	6.86±0.10	8.34E-04±4.21E-05	99.9
Student laboratory (F)	8.35±0.07	N/A	-
Right side of SSDL (G)	7.50±0.07	N/A	-
Back of SSDL (H)	6.50±0.08	9.95E-04±2.45E-05	99.9

Table 3: Measured dose rate with and without collimation and with their percentage reduction in dose rate at locations around the SSDL for the current 22.2GBq Cs-137 calibration source

	Experimental 22.2 GBq ^{137}Cs calibration source H* (10 mm) (µSv\h)		
Location	Panoramic	Collimated	% reduction in dose
Control console (A)	0.50	0.77	-54.0
SSDL lead door (B)	9.17	10.20	-11.2
SSDL supervise area (C)	0.75	0.21	72.0
Office on top of SSDL (D)	1.80	0.05	97.2
Office at bottom of SSDL (E)	5.53	0.95	83.2
Student laboratory (F)	2.46	0.08	96.7
Right side of SSDL (G)	N/A	N/A	N/A
Back of SSDL (H)	N/A	N/A	N/A

NB: N/A is non-accessible locations or unreliable sampling location

Table 4: Calculated dose rate with collimation with a narrow beam diameter of 1.2cm for the current 22.2 GBq Cs-137 calibration source.

Location	MCNP (Reduction of collimator’s diameter from 4.7 to1.2 cm) Current 22.2 GBq Cs-137 calibration source H*(10 mm) (µSv\h)
Control console (A)	0.01±0.002
SSDL lead door (B)	0.57±0.06
SSDL supervise area (C)	0.01±0.001

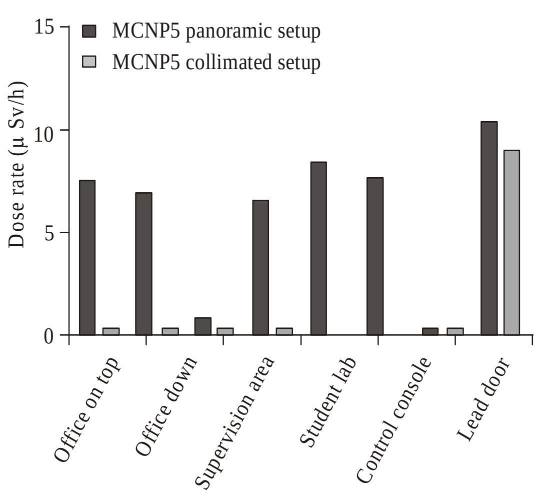

Fig. 5: Presents the comparison of calculated MCNP5 dose rate for the case of both collimated and panoramic setups for 22.2 GBq cesium-137 source

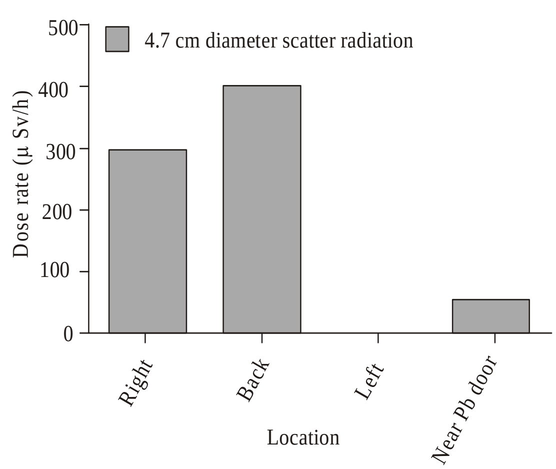

Fig. 6: Presents calculated MCNP5 scatter dose rate inside the bunker for collimated setup of 22.2 GBq cesium-137 source

dose rate behind the lead door of the bunker. This was higher than the dose rate recommended for control areas by the local regulatory Authority. It also became obvious from the results that, assuming the same conditions and with an increase in the activity of the source from its current state to a maximum of 44.4 GBq will double the radiation dose to all locations. This will be a violation of regulatory requirement.

In order to protect staff who may be involved in calibration activities in the control console of the SSDL to

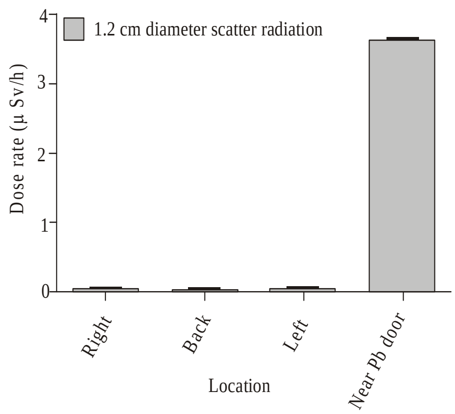

Fig. 7: Presents the calculated MCNP5 scatter dose rate inside the bunker for further collimated setup of 22.2 GBq cesium-137 source

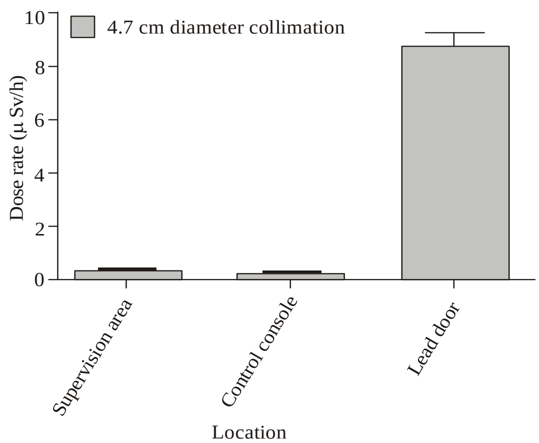

Fig. 8: Presents the MCNP5 estimation of dose rate outside the bunker when the diameter of the diameter of collimation is 4.7 cm for the 22.2 GBq cesium-137 source

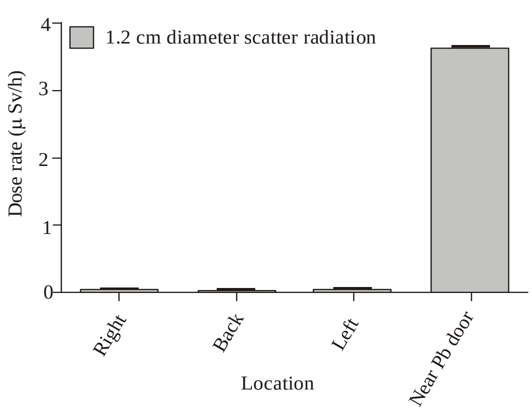

Fig. 8: Present MCNP5 estimation of dose rate outside the bunker when the diameter of collimation is reduced from 4.7 cm to 1.2 cm for the 22.2GBq cesium-137 source

meet regulatory requirement of 1 mSv/month by the Regulatory Authority of Ghana, it was postulated by MCNP 5 simulation that by further collimation of the broad beam into a narrow beam of diameter 1.2 cm as indicated by Fig. 8 and 9, will reduce dose rate to the control console, the lead door and the supervised areas to less than 1.5 µSv/h even when the source is increased from 22.2 to 44.4 GBq which has been tabulated in Table 4.

CONCLUSION

Radiation shielding is an integral part of radiation protection; hence all efforts should be channeled into putting in place the tools, practices and methods to reduce dose to staff and the general public. MCNP5 had been used to assess the biological shields of a collimated cesium-137 source considering controlled and public occupied areas. For the shield to be very effective, it is recommended to further collimate the beam to a diameter of 1.2 cm so as to effectively protect the staff at these occupied areas during calibration.

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