



## Evaluation of 1.5mm Lead Shield for Radiological Protection and Comparison of Calculated and Measured Results of Equivalent Dose

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**ABSTRACT:** Evaluation of radiation protective devices in radiology departments is one of the practices that ensure radiation protection and staff and patients safety in hospitals. A research work to evaluate 1.5mm lead shield used for radiological protection was carried out in Radiological Unit of Sharda Hospital, of Sharda University, India, using 300mA fixed x-ray machine room. The evaluation was done in the x-ray energy (kVp) range between 52- 81 and by using calculative procedure and by direct measurement of the radiation dose rates. The two results were compared. The results shows that, in the absence of the shield, only 11.82% of the radiation exposure was attenuated by the air space before reaching the radiographer's stand, while in the presence of the shield, 96.50% was attenuated, whereas, for the measured result only 10.17% was attenuated in the absence of the shield and 89.83% was attenuated in the presence of the shield before reaching the radiographer's stand. The unit of radiation exposure was converted to that of equivalent dose and that of effective dose in order to assess the radiographer's safety level behind the shield. It was found that, the equivalent/effective dose is as low as to be accepted according to the policy of ALARA (As Low As Reasonably Achievable), and within the NCRP recommended limit. This guaranteed the effectiveness of the lead shield of 1.5mm thickness in the x-ray energy range used in this study.

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Exposure to x-ray as other ionizing radiations has dangerous biological effects to radiological workers and the patients. According to Oyar and Kışlaloğlu, 2011; Thayalan (2014), the effect may be stochastic effect, in which the probability of occurrence of such effects may start at any given dose and will be increasing as the dose increases, or deterministic effect, in which the effect only started when the absorbed dose is up to some threshold level, and its severity will then be increasing as the dose increases. This necessitated the adoption of various protective measures in radiological units, among which are (1) the use of radiation protective devices (Egbe *et al.*, 2008; Livingstone and Varghese, 2018). Example of such devices are lead apron, thyroid shield, gloves, thick walls, lead cubicles (Daniel and Xavier, 2018) etc., (2) proper adjustment of exposure factors (kVp and mAs). It was observed by Egbe *et al.*, (2008) that the entrance doses for chest radiography in some hospitals in Western Nigeria are higher than the recommended values due to the lack of standardization in procedure, which resulted in improper adjustment of the exposure factors (kVp and mAs), (3) optimization, which involves the regular periodic monitoring and assessment of radiological

equipments, (Egbe *et al.*, 2008; Livingstone and Varghese, 2018) at least once in a year (Oyar and Kışlaloğlu, 2011). The radiation protective devices (shields) are placed or wore as physical barriers against the radiation in order to attenuate its intensity for the safety of the radiographer and the parts of the diagnosed patient which are not under study (McCaffrey *et al.*, 2007; Oyar and Kışlaloğlu, 2011; Thayalan, 2014; Yücel *et al.*, (2016); Omojola and Isiodu, (2018). For effective protection, high atomic number materials such as lead, Antimony, Bismuth (Johansen *et al.*, 2018) and Tungsten or their substitutes or equivalents are used as shielding materials (McCaffrey *et al.*, 2007). Other elements such as Cadmium (Cd), Indium (In), Tin (Sn), Antimony (Sb), Cesium (Cs) etc. are also imbedded into natural rubbers of some polymers, due to their lightweight and effectiveness, for commercial radiation shielding (Yücel *et al.*, (2016); McCaffrey *et al.*, 2007). The radiation Shield, whether made from lead or non-lead material, is among the radiological devices that must be monitored and evaluated periodically (Oyar and Kışlaloğlu, 2011; Egbe *et al.*, 2008). Studies by Christodoulou *et al.*, 2003; McCaffrey *et al.*, 2007; Johansen *et al.*, (2018)

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revealed that, the effectiveness of a particular protective material is not general for all ranges of energies of the ionizing radiations like diagnostic x-rays; it is effective only for a particular range of energies. In line with this, several researches had been made earlier by researchers on attenuation properties of radiation shielding materials using different procedures, materials used, ranges of x-ray energies and the thicknesses of the protective material(s). Some researchers also made the study and comparison between some materials, like McCafferey *et al.*, (2007) who utilized well characterized x-ray and gamma ray beams and using air KERMA measurements to compare variety of commercial and pre-commercial radiation shielding materials over mean energy ranges from diagnostic range; 60-120kVp up to therapeutic level of 250kVp. Also like Johansen *et al.*, (2008) who studied and made comparison between lead apron and two lead-free aprons in the energy ranges of 60 to 113kVp. In this work, we evaluated the radiographer's weekly equivalent/effective dose in the presence of lead shield of thickness 1.5mm in the control panel and in the absence of the shielding and estimated the equivalent dose.

## MATERIALS AND METHOD

We made use of 300mA fixed x-ray machine room of size 27.7m<sup>2</sup>. The machine was Pleophos D Siemens X-ray machine, and patients between 75 and 85 are attended for x-ray radiography every day. The exposure factor, mAs, applied for the radiography of each patient was recorded for the average number of patients radiographed daily ( $N_{p-ave}=80$ ) and two handheld dosimeters, capable of measuring radiation dose rate of 0 - 2000 $\mu$ Sv/hr (0-200mRem/hr) were used to measure the radiation dose rates per exposure at the internal surface and at the external surface/position of the lead shield. The number of patients for any given mAs,  $N_p$ , the number of radiographic films used for each patient,  $N_f$ , the number of days that the radiographer was on duty,  $N_d$ , were tabulated in table 1 and table 2 for the patients radiographed while standing in the chest stand and those radiographed on the table top respectively. The weekly workloads,  $W_1$  and  $W_2$ , were calculated for each table respectively, using the equation below (Bushberg, 2002; Thayalan, 2014).

$$W = \frac{NO_p}{day} \times \frac{NO_t}{week} \times \frac{NO_f}{patient} \times \frac{mAs}{film} \times \frac{1min}{60s}$$

The total weekly workload,  $W$ , was determined by simple addition of the two workloads.

A measuring tape calibrated in centimeters, cm and meters, m, was used to measure the following (1) the

closest distance from the primary x-ray source (the focal spot of the x-ray machine's tube) to the patients surfaces at the chest stand, called scatterer distance 1,  $d_{sca1}$ , (2) the distance from the primary x-ray source to the closest patients surface on the tabletop, called scatterer distance 2,  $d_{sca2}$ , (3) the distance from the primary x-ray source to 0.3m behind the shield position, where the radiographer stands to operate the machine, called primary distance,  $d_{pri}$ , (4) the distances from the secondary radiation source (the closest surface of the patients at the chest-stand and those on the tabletop) to 0.3m behind the shield position called secondary distances 1 and 2,  $d_{sec1}$ , and  $d_{sec2}$  respectively, and (5) the distance from the leakage radiation source (the x-ray tube back housing) to 0.3m behind the shield position called tube leakage distance,  $d_{leak}$ , (Barghava, 2011; Thayalan, 2014).

Other x-ray room and the x-ray machine tube's parameters such as maximum continuous current,  $mA_{max}$ , maximum leakage radiation,  $X_{Lmax}$ , average applied peak voltage, kVp, scatter fraction,  $S$ , occupancy factor,  $T$ , primary used factor,  $U_{pri}$ , secondary used factor,  $U_{sec}$ , were determined. The tube output, TOP, of the machine at 1m for mAs = 32 and an average maximum voltage applied,  $kV_p=81$ , was obtained in milliGray (mGy) using the 'Acceptance/Performance Test Report' of the machine used in this study (Narayan, 2015) and then converted into Roentgen, R, using the conversion factor below (Saha, 1993; Thayalan, 2014).

$$TOP = \frac{TOP (mGy)}{8.76} \text{ Roentgen}$$

The Tube Output per mAs in (mR/mAs) was calculated and then converted into TOP per  $mA_{min}$  in (mR/ $mA_{min}$ ) and the lead shield information; the thickness,  $x$ , and the linear coefficient of attenuation,  $\mu$ , within the selected energy range were determined and all were tabulated in table 3.

The weekly primary exposure from the x-ray source,  $X_p$ , was calculated using the equation below (Barghava, 2011).

$$X_p = W(mA_{min}/week) \times TOR(mR/mA_{min})$$

The Primary exposure incidents at the closest surface of the scatterer (the patient),  $X'_p$ , was calculated using inverse square law for radiation intensity (radiation dose) (Bushberg, 2002; Barghava, 2011; Thayalan, 2014).

$$X'_p = \frac{X_p}{(d_{sca})^2}$$

The scatter exposure per week,  $X_s$ , was calculated using the equation below (Barghava, 2011).

$$X_s = X'_p \times S \times \frac{\text{field size}}{400\text{cm}^2}$$

The total leakage radiation per week,  $X_L$ , was calculated using the equation (Barghava, 2011).

$$X_L = \frac{X_{L\text{max}} (mR / mA.min) \times W (mA.min / week)}{mA_{\text{max}}}$$

The total weekly radiation dose incident at the position/external surface of the Lead Shield,  $X_{\text{inc1}}$ , was considered to be the total radiation exposure due to the primary, the secondary and the leakage radiations and the weekly radiation dose at the control panel, in the absence of the shield ( $X_{\text{no-shield-1}}$ ) were calculated using the equation (Bushberg, 2002; Thayalan, 2014).

$$X_{\text{no-shield1}} = \left\{ \left[ \frac{X_p}{(d_{\text{pri}})^2} \times U_{\text{pri}} \times T \right] + \left[ \frac{X_s}{(d_{\text{sec}})^2} \times U_{\text{sec}} \times T \right] + \left[ \frac{X_l}{(d_{\text{lead}})^2} \times U_{\text{sec}} \times T \right] \right\}$$

In the presence of the shield, the weekly radiation dose transmitted through the lead shield ( $X_{\text{trans.}}$ ) to its inner surface was calculated using the equation.

$$X_{\text{trans}} = X_{\text{inc}} \times e^{-\mu x}$$

The percentage of the calculated radiation dose that reaches the control panel from the shield position, in the absence of the shield,  $\%X_{\text{inc1}}$  was calculated and was used to determine the radiation dose from the measured incident exposure that would travel to reach the radiographer’s stand if there would be no shield at the control panel,  $X_{\text{no-shield-2}}$ . This is achieved by equating the percentage of the calculated incident radiation,  $\%X_{\text{inc1}}$  attenuated from the shield position to the radiographers stand in the absence of the shield and the percentage of the measured incident radiation,  $X_{\text{inc2}}$  attenuated from the inner shield surface to the radiographers stand, 300mm (0.3m) behind the shield, i.e. by neglecting the thickness of the shield, 1.5mm, as (1.5mm << 300mm). The unit of mR/week was converted to mRem/week using the weighting factor of x-ray (Saha, 1993; Thayalan, 2014),  $W_r = 1$ , and conversion factor of Roentgen to rad. (Saha, 1993) as  $1R = 0.869\text{rad.}$ , it follows that, for x-ray the equivalent dose of 1unit (1Rem ) =  $1\text{rad} \times 1$ , and thus,  $1R = 0.869\text{rad} \times 1 = 0.869\text{Rem.}$

The dose rates at the outer and at the control panel, inside the lead shield and the total weekly workload were used to determine the weekly radiation equivalent doses and the radiation exposure reaching the radiographer at 0.3m behind the shield  $X_{\text{shielded-2}}$  using the relation (Barghava, 2011).

$$X_{\text{shielded-2}} = \frac{\text{Dose rate (m Rem / h)} \times W (mA.min / week)}{mA \times 60 \text{ min}}$$

Where;  $X_{\text{shielded-2}}$  is the weekly shielded exposure. The units of the equivalent dose were converted into the unit of effective dose of microSievert ( $\mu\text{Sv}$ ), using the conversion factor below (Saha, 1993; Thayalan, 2014).

$$1 \text{ Seivert (Sv)} = 100 \text{ Rem}$$

Which implies that;

$$1 \text{ m Rem} = 0.1 \mu\text{Sv}$$

The results found were compared and the effectiveness of the lead shield was evaluated.

## RESULTS AND DISCUSSIONS

Workload tells us about the measure of the expected exposure level due to the number of patients, the applied mAs for each patient and the machine ON time (Thayalan, 2014). This measure contributes to the radiographer’s equivalent dose. The guidelines for diagnostic x-ray installation provides that, the x-ray room housing shall not be less than  $18\text{m}^2$  for general purpose radiography and there should be 2mm lead or its equivalent in front of the door(s) and windows of the room or thick brick of equivalent effectiveness. There should be a separate control room for machine operating at 125kVp and above with appropriate shielding of 1.5mm for direct viewing or protective barrier of adequate thickness for less than 125kVp (Thayalan, 2017). The x-ray room and the machine used in this study have the following parameters.

**Table 1:** The weekly workload due to the patients, who stood at the chest stand

mAs/film	No <sub>p</sub> /day	No <sub>p</sub> /patient	No <sub>p</sub> /week	W <sub>r</sub> (mA.min/wk)
16	4	1	7	7.467
19	29	1	7	64.283
26	28	1	7	84.933
40	1	1	7	4.667
80	4	1	7	37.333
96	3	1	7	33.600
160	2	1	7	37.333
Total				269.617

**Table 2:** The weekly workload due to the patients imaged on the tabletop

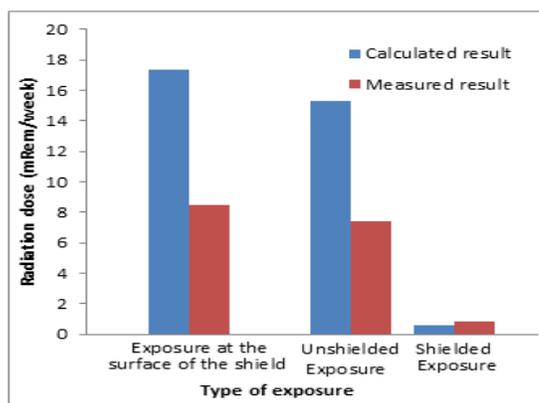
mAs/film	No <sub>p</sub> /day	No <sub>p</sub> /pat.	No <sub>d</sub> /week	W <sub>2</sub> (mA.min./week)
13	1	1	7	1.517
16	1	1	7	1.867
19	5	1	7	11.083
26	2	1	7	6.067
Total				20.534

The total weekly workload,  $W = W_1 + W_2; = 290.151 \text{ mA.min/week}$

**Table 3:** X-Ray room and the x-ray tube's parameters

Parameter	Symbol	Value
Size of the x-ray room	A	27.7m <sup>2</sup>
Scatterer distance 1	d <sub>sca1</sub>	1.85m
Scatterer distance 2	d <sub>sca2</sub>	1m
Primary distance	d <sub>pri</sub>	4.3m
Secondary distance 1	d <sub>sec1</sub>	6.15m
Secondary distance 2	d <sub>sec2</sub>	4.3m
Tube leakage distance	d <sub>leak</sub>	4.2m
Maximum Continuous Current	mA <sub>max</sub>	5Ma
Maximum Leakage Radiation	X <sub>Lmax</sub>	1.65mR/mA.min
Average applied peak voltage	kV <sub>p</sub>	81V
Scatter fraction	S	0.15%
Occupancy factor	T	1
Primary used factor	U <sub>pri</sub>	0
Secondary used factor	U <sub>sec</sub>	1
Tube Output in milliGray	TOP	1.713mGy
Converted Tube Output into (mR/mA.min)	TOP	366.66mR/mA.min
Lead shield thickness	X	1.5mm
Linear coefficient of attenuation of lead	μ	2.143mm <sup>-1</sup>

Note: Radiation dose measured in Roentgen (R) or milliroentgen (mR) gives the measure of the x-ray output, but not the absorb dose



**Fig1 :** Radiation dose incident at the external surface/ position of the lead shield, the one reaching the radiographer's stand in the absence of the shield and the one reaching the radiographer's stand in the presence of the shield, both for measured and calculated results

The figure 1 summarizes the radiation doses in the presence and in the absence of the 1.5mm lead shield, obtained from the direct measurement and from the calculated result. The calculated result shows that the exposure incident at the external surface/position of the lead shield was 17.34mRem/week whereas the measured incident exposure was 8.46mRem/week. This difference could be attributed to the consideration of the scattered radiation as a separate source of radiation in line with the over estimation policy adopted in this procedure when the radiographers effective/equivalent dose is to be assessed for safety purpose. On the other hand, the radiation dose reaching the radiographers stand behind the lead shield, (the equivalent dose) was 0.61mRem/week

which is just 3.5% of the radiation exposure incident at its external surface of the shield in the calculated result and 0.86mRem/week, (which is 10.17%) in the measured result. This could be attributed to the approximations made in the theoretical approach and the fixed/constant values of some parameters involved in the calculative procedure. The percentage deviation of the calculated result from the measured one was 29%.The result above shows that the effective dose that a radiographer would have exposed to is 0.061μSv/week (or by projection, 0.061μSv/week × 52weeks = 3.172μSv/year) in the calculated result and 0.086μSv/week (or by projection, 0.086μSv/week × 52weeks = 4.472 μSv/year) in the measured result. Comparing this with the recommendation of the ICRP

(2007), report no. 105, that the occupationally exposed people should not exceed 100mSv (10Rem) in 5 consecutive years (averagely 20mSv or 2Rem per year), and not exceeding 50mSv (5Rem) in any single year, it can be concluded that the radiographer working for 7days every week, operating the x-ray machine behind 1.5mm lead shield placed at at least 1m away from the source of the secondary radiation (scattered and leakage x-ray), and the x-ray focal spot is never directed towards the control panel during the week, is expected to be safe due to the minimal equivalent dose he exposes to in the kVp range not exceeding 81kVp .

*Conclusion:* Effectiveness of lead shield of various thicknesses or its equivalent were assessed by different researchers for various ranges of x-ray energy and mAs settings, this work had assessed the effectiveness of 1.5mm lead shield and within the x-ray energy range of 52-81kVp and current-time settings of 13-160mAs. The work also suggests that the calculative method should not be relied upon alone due to the high percentage deviation of the calculated shielded exposure from the measured shielded exposure.

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