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An Investigation on Radiation Shielding Performance of Lead Sheets Against Diagnostic X-Rays

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Abstract – In this study, radiation shielding performance of pure Lead Sheets were carried out by using new X-ray transmission set up. Diagnostic x-rays from 50 kVp to 110 kVp were applied in the experiments. Experimental set up was designed according to narrow beam geometry conditions of IEC 61331-1:2014 standard. Pure Lead sheets (99.99 % purity) having different thicknesses (0.05-0.5 mm, 0.05 mm steps), were performed against diagnostic x-rays. Radiation attenuation percentages were carried out for each x-ray peak tube voltages from 50 kVp to 110 kVp with 10 kVp steps. Radiation shielding percentages of the lead sheet for the studied x-ray peak tube voltage were in the range of 50.8-99.7 %. X-ray shielding percentages of commonly used Lead thicknesses were compared with the literature. The radiation shielding percentages of the samples were in a good agreement with the literature. The average of difference percentages of the study with the literature was 0.76 %. 0.25, 0.35 and 0.5 mm Lead thicknesses have 90.3 % , 94.7 % and 97.2 % shielding performance against 90 kVp, respectively.

Keywords – Radiation Protection, X-Rays, Lead, IEC 61331-1 Standard, Lead Equivalent Thickness

I. Introduction

Radiation protection is one of the most essential issues in nuclear applications [1]. Using radiation protective equipment is the commonly used method to avoid harmful effects of ionization radiation [2]. Lead is the most frequent used material for radiation protection including diagnostic x-rays [3]. Lead has some extraordinary properties such as high-density, easy machinability and cheap price. On the other hand, Lead is accepted as toxic substance and in a period of restriction in some applications [4]. European Union has released several Legislations (RoHS series) which restrict using some hazardous substances including Lead in the Electrical and electronic equipment [5-7]. Using Lead in Radiation Protective equipment is exempted so far, but it is possible to include in the future due to developing alternative and economic materials instead of lead. Therefore, there were many studies which tried to figure out alternative radiation protective materials instead of lead [8-13]. In this case, determining Lead equivalent thickness of the alternative material come front as an issue especially for x-rays [14]. So, the methodology of determining lead equivalent thickness was defined in the IEC 61331-1:2014 standard [15]. Narrow beam geometry, broad beam geometry and inverse broad beam geometry conditions were described in the standard.

In this study pure lead sheets were investigated against x-rays by the view of radiation protection. Radiation shielding percentages were carried out for x-ray tube peak voltages from 50 to 110 kVp. Narrow beam geometry of the standard was used in the experiments.

II. Materials and Method

Lead Sheets and X-ray Transmission system is the main parts of the Experimental study.

A. *Lead Sheets*

The Lead sheets were supplied from Ningpo Picado Trading Co. (China). Purity of the Lead sheets were over 99.99 % with the density of 11.34 g/cm^3. Surface area of the samples were 10x6 cm^2 which had the different thicknesses from 0.05 mm to 0.5 mm. Radiation shielding performance of 10 different Lead thicknesses from 0.05 mm to 0.5 mm with 0.05 mm steps were applied in the experiments. The view of some Lead sheet samples was given on Fig. 1.

(a)

(b)

(c)

Fig. 1 Some of the used Lead Reference Samples (a) 0.05 mm, (b) 0.2 mm and (c) 0.5 mm thick.

B. *X-Ray Transmission System*

X-ray Transmission Technique was used in the experiments. Narrow beam geometry of the IEC 61331-1:2014 standard was applied for X-ray transmission system. The geometry of the system was given in Fig. 2.

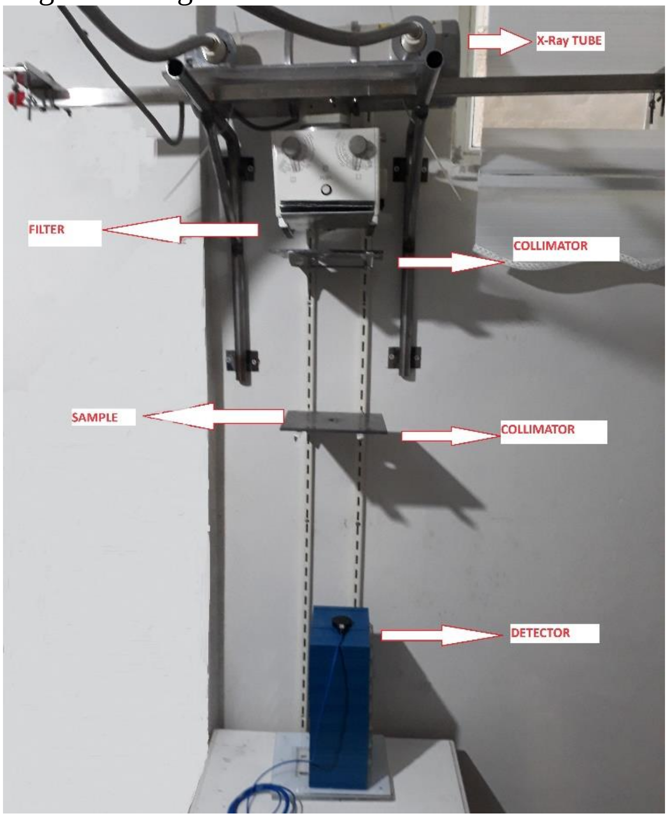

Fig. 2 X-Ray Transmission Geometry

X-Ray transmission system consists of x-ray generation part, x-ray detection part and collimators. Dynamic DRX 12-I type X-ray generator and siemens x-ray tube which had 2.9 mm Al total filtration were used in the experiments as X-ray generation part. X-ray detection part includes PTW 34069 type ionization chamber (6 cm^3) as detector and ATOMTEX AT5350/1 Standard dosimeter as electrometer. Finally, the collimators were obtained by using 20x20x0.6 cm^3 lead plates which have holes (2 cm diameter) in the center. The distance between the x-ray tube and detector was 100 cm where the sample place was half of it.

X-ray peak tube voltages from 50 kVp to 110 kVp (with 10 kVp steps) were applied in the experiments. X-ray radiation quantity was adjusted to 1 mAs for all radiation qualities. Air Kerma dose rates (µGy/s) were investigated for all measurements. At first background radiation intensity which was the radiation of medium was measured and subtracted from the all radiation intensity values to get net radiation intensities. and Radiation intensity (***I***) of each lead thicknesses were figured out for all x-ray tube peak voltages. Also, initial radiation intensity ($\boldsymbol{I_0}$) values were carried out for all x-ray tube peak voltages. X-ray shielding percentages were determined by using following Equation (1);

$$F_N(\%) = \left(\frac{I_0 - I}{I_0}\right) x100 \quad (1)$$

III. Results

Radiation shielding percentages of the studied lead reference sheets were given in Figure 3.

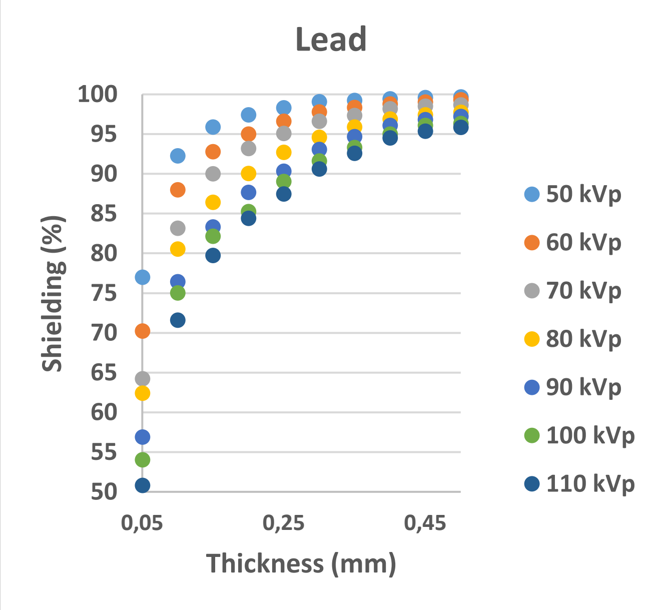

Fig. 3 X-ray Radiation Shielding Performance of the Lead sheets

According to Figure 3, it could be said that increasing the lead thickness caused to higher x-ray shielding percentage for all applied x-ray tube peak voltages. However, increasing x-ray tube peak voltage decreased the x-ray shielding percentages for lead thickness values. The shielding performance of the lead sheets in range of 50.8-99.7 % for the applied radiation qualities.

Usually 0.25 mm, 0.35 mm and 0.50 mm Lead equivalent shielding performances were used in commercial applications and radiation protective equipment such as aprons, collars, caps etc. [16]. Therefore, x-ray radiation shielding performance of 0.25 mm, 0.35 mm and 0.50 mm Lead sheets were given in Table 1.

Table 1. Shielding percentages of 0.25, 0.35 and 0.5 mm Lead sheets.

Tube Peak Voltage (kVp)	Shielding (%)		
	0.25 mmPb	0.35 mmPb	0.5 mmPb
50	98.3	99.2	99.7
60	96.6	98.3	99.3
70	95.1	97.3	98.7
80	92.7	95.9	97.8
90	90.3	94.7	97.2
100	89.0	93.3	96.3
110	87.5	92.6	95.8

Radiation shielding performance of 0.5 mm lead was 97% and 87% for 50 kVp and 110 kVp respectively. 0.25 mm Lead has the lowest shielding performance in the range of 86-89 %.

IV. Discussion

X-ray radiation shielding percentage results which were given in Table 1 was compared with the literature. The differences were given in Table 2.

Table 2. Comparison of the Results with the Literature

Tube Peak Voltage	Reference	Lead Thickness		
		0.25 mmPb	0.35 mmPb	0.5 mmPb
70 kVp	König et al. (2023) [2]	96.3	98.1	99.2
	Present Study	95.1	97.3	98.7
	Difference (%)	1.25	0.82	0.50
90 kVp	König et al. (2023) [2]	91.9	95.2	97.9
	Present Study	90.3	94.7	97.2
	Difference (%)	1.74	0.53	0.72
110 kVp	König et al. (2023) [2]	88.2	92.5	96.2
	Present Study	87.5	92.6	95.8
	Difference (%)	0.79	0.11	0.42

The difference percentages between the present study and König et al. (2023) were in the range of 0.11-1.74 %. The smallest difference was determined for 0.35 mm Pb at 110 kVp whereas the biggest difference was obtained for 0.25 mm Pb at 90 kVp. The average value of the differences was 0.76 % for the study. Therefore, it could be said that the results were in a good agreement with the literature. In addition, the results of new established

X-ray transmission system were reliable and could be applied future x-ray transmission measurements.

V. CONCLUSION

Reference lead sheets were performed against diagnostic x-rays by the view of radiation shielding. The results were compatible with the literature and could be used for further studies to make a comparison and to get lead equivalent thickness values of other materials. In addition, new experimental set up works suitably and measurements were consistent. Shielding percentages of the studied lead thicknesses could help to determine lead equivalent thickness values of alternative radiation protective materials.

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