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Determination of Half and Tenth Value Layer Primary and Secondary Walls of X-ray Room in Bali Jimbaran General Hospital

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Abstract

The research has been carried out on the HVL and TVL values of the primary and secondary walls of the radiology installation radiology room at RSU Bali Jimbaran. The aims of this study were (1) to determine HVL and TVL values on the primary and secondary walls in the x-ray room, (2) to determine the differences between HVL and TVL values if the tube voltages are varied. In determining the HVL and TVL values, the linear attenuation coefficient of the walls must be known. The linear attenuation coefficient was determined by measuring the wall thickness by using a caliper, and measuring the radiation dose rate before and after passing through the primary and secondary walls. The results of the analysis of the HVL and TVL values on the primary wall were 1.668 cm and 5.540 cm, meanwhile on the secondary wall were 1.915 cm and 6.362 cm. When the voltage was varied 40 kV, 50 kV, 60 kV and 70 kV, there was no difference in the HVL or TVL values. Based on the results of the analysis, the HVL and TVL values on the primary and secondary walls have a significant average difference.

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Introduction

Ionizing radiation means a radiation that can cause an ionizing effect when it interacts with another matter such as living thing. Ionizing radiation is widely used in daily, for example in the health sector, specifically the use of X-ray. It is especially important to diagnose the clinical condition of patients. X-rays can describe the structure of the patient's body without surgery. Beside the positivity of it, the use of X-ray may give a negative impact or side effect. In this case, if a person gets exposed to X-rays continuously, the amount of radiation will be accumulated on that body and may be interfered with its health [1-4].

Radiation protection is an action to reduce the negative effects of the radiation exposure. Three basic principles of protection radiation are justification, optimization and limitation. Justification is when the use of a radiation source must produce more the expected diagnostic and therapeutic benefits than the negative effects of radiation on the person exposed to the radiation. Optimization means that the radiation dose received by a person is kept as low as possible based on what is needed to achieve diagnostic goals by considering socio-economic aspects. Limitation is when the limit of radiation dose received by radiation workers and public. The dose limitation of radiation for the worker is 10 mSv/year while for the public is 0.5 mSv/year. One way to reduce the radiation dose is the use of radiation shields. Radiation shielding is needed to reduce the intensity of radiation, as well as to reduce the reception of radiation doses in the human's body. In a radiology installation which uses X-rays as a radiation source, there are two categories of protection. They are source protection and structural protection. Structural shields protection are divided into two, namely primary radiation retaining walls or primary walls and secondary radiation retaining walls or secondary walls. The primary wall is the part of the wall that is exposed to direct X-ray irradiation, while the secondary wall is the wall that is exposed to scatter radiation and leak radiation [5-7].

Determination of the thickness of the radiation shielding wall can be determined by the Half Value Layer (HVL) and Tenth Value Layer (TVL) methods. HVL is the thickness of the material to reduce the radiation intensity by half from the initial intensity. Meanwhile, TVL is the thickness of the material to reduce the radiation intensity to one to tenth of the initial intensity. The HVL and TVL values depend on the constituent materials that are used [8].

From the description above, it is necessary to conduct a research on the HVL and TVL values on the primary and secondary walls of the X-ray room at the radiology installation in RSU Bali Jimbaran. The purpose of this study was to determine the difference in primary and secondary wall thickness based on HVL and TVL values and to find out the difference in HVL and TVL values when the tube voltages are varied in 40 kV, 50 kV, 60 kV and 70 kV.

Theory

When X-ray radiation passes through a material, the X-ray radiation intensity will be absorbed by the material, and some of the radiation will be transmitted. The intensity will experience the attenuation exponential, which is expressed in Equation (1) [5,9].

$$I = I_0 e^{-\mu x} \tag{1}$$

with I_0 initial intensity (W/m^2), I intensity after passing through the material (W/m^2), x is the thickness of the material (m), μ is linear attenuation coefficient (m^{-1}). The HVL and TVL values of a material can be derived from equation (1), where $I = ½ I_0$ for HVL and $I = \frac{1}{10} I_0$ for TVL, the HVL and TVL are formulated in Equations (2) and (3) [10-12]

$$HVL = \frac{\ln 2}{\mu} \tag{2}$$

$$TVL = \frac{\ln 10}{\mu} \tag{3}$$

Determination of wall thickness based on HVL and TVL, $x = n\,HVL + n\,TVL$, can be derived from equation (1), (2), (3) can be calculated by Equation (4). n_{HVL} shows the wall thickness in the HVL layer and n_{TVL} shows the wall thickness in the TVL layer.

$$\frac{I}{I_0} = \left(\frac{1}{2}\right)^{n_{HVL}} \left(\frac{1}{10}\right)^{n_{TVL}} \quad (4)$$

Experimental Method

The study was conducted at the radiology installation of RSU Bali Jimbaran, Jimbaran, South Kuta, Badung Bali. Based on equations (2) and (3), the HVL and TVL values can be determined if the linear attenuation coefficient of the material is known. The radiation intensity is identical to the radiation dose rates [13]. The linear attenuation coefficients of the primary and secondary walls were determined by measuring the radiation dose rates before and after passing through the walls and the thicknesses of the primary and secondary walls. Several tools used are x-rays as a radiation source, X-ray protection lead aprons to reduce the intensity of radiation received by observers, calipers to measure wall thickness, and gamma surveymeter for dose rates. X-ray specifications can be seen in Table 1 and surveymeter specifications can be seen in Table 2.

Table 1. X-ray specifications

X-ray room data	Information
Room size	5,2 m x 2,6 m x 3 m
X-ray machine brand	SIEMENS AG
X-ray machine type/model	Multix Swing
No. Permission	110647.17/180719
Production year	2012
Year of Installation	2015
Tube data	
Tube Brand	SIEMENS AG
No. Tube series	359708
Maximum time flow	800 mA
Maximum voltage	70 kV

Tabel 2. Surveymeter specifications

Surveymeter Data	Information
Tool's name	*Surveymeter gamma*
Type/series	Fluke 451P-DE-SI-RYR
Range/scale	µSv/h
No. Certificate	30689/LT/KAUR/03/2022
Calibration factor	1,09
Recalibration date	6 April 2024

Radiation dose rate measurements were carried out at several measurement points as shown in Figure 1. Background radiation measurements were taken before the exposure. Before measuring the radiation dose rate, the observer used a lead apron to reduce the radiation intensity. X-ray examination is a set for examination of the thorax with posterior anterior (PA) projection. Therefore, standard chest radiographs are obtained by the standing, and with the

X-ray beam passing through, the voltage was set at 40 kV with current strength times 12.5 mAs constant. Furthermore, measurements of the radiation dose rate before and after passing through the wall were carried out together when the exposure was occurred. Measurements were made at each sample point that has been determined in Figure 1. Those measurements were repeated for tube voltages of 50 kV, 60 kV and 70 kV.

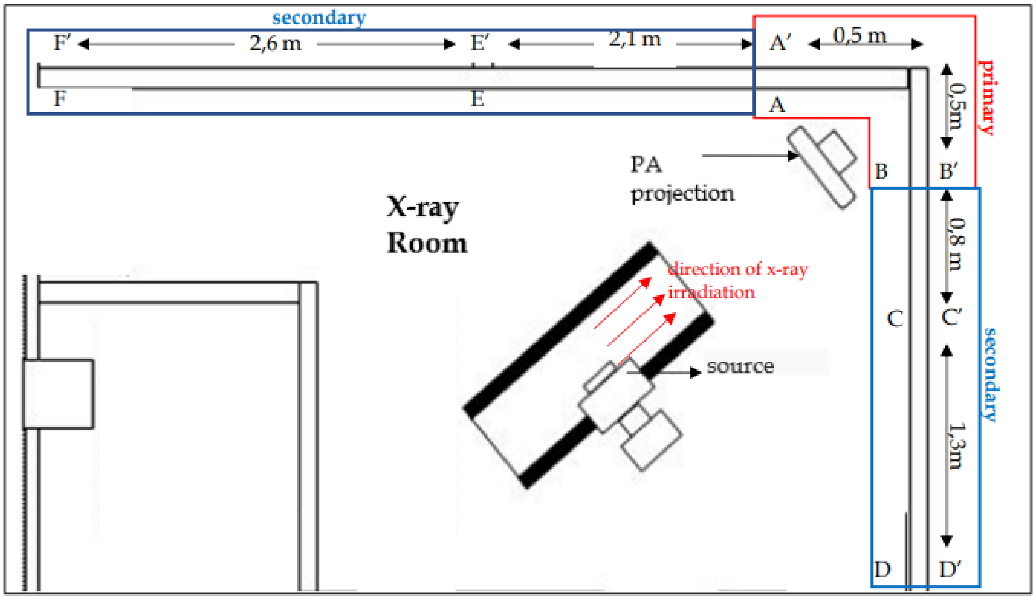


Figure 1. Schematic of dose rate measurement points before and after passing through the primary and secondary walls. If the source is pointed at the PA projection, A and B before passing through the primary wall, A' and B' after passing through the primary wall. C, D, E, and F before passing through the secondary wall, C', D', E', and F' after passing through the secondary wall.

Next, the wall thickness was measured using a caliper. The primary and secondary wall constituent materials were bricks plastered with Portland cement mortar and black sand and coated with 2 mm Pb. Therefore, the primary and secondary walls have the same thickness. Before measuring the radiation dose rate, the equipment used should be prepared. First, check the calibration date and battery on the surveymeter and then the X-ray machine is turned on and warmed up.

After obtaining the results of measurements of the background radiation rate and the radiation dose rate before and after passing through the primary and secondary walls, the next was data analysis. The first is the calculation of the actual radiation dose rate. The difference in the value displayed on the surveymeter and the actual value must be corrected with a parameter called the calibration factor. The measured radiation dose rate is the radiation dose rate read on the measuring instrument minus the background radiation and the calibration factor can be seen in Equation (5). [14]

$$\dot{D} = (\dot{D}_u - \dot{D}_{BG})f_K \quad (5)$$

Where $\dot{D}$ is the radiation dose rate (μSv/h), $\dot{D}_u$ is the dose rate read on the surveymeter (μSv/h), $\dot{D}_{BG}$ is background radiation and f_K is the calibration factor. Background radiation is a radiation that comes from natural radiation sources.

Next, calculate the linear attenuation coefficient (μ) on the primary and secondary walls. Based on Equation (1) the linear attenuation coefficient can be found if you know the thickness and the radiation dose rate before and after passing through the wall. Equation (6) is the formula to determine the linear attenuation coefficient.

$$\mu = \frac{\ln\left(\dot{D}_0 / \dot{D}\right)}{x} \quad (6)$$

$\dot{D}_0$ is the dose rate before passing through the wall (μSv/h), $\dot{D}$ is the radiation dose rate after passing through the wall (μSv/h), and x is the wall thickness (cm). Then, calculate the HVL and TVL values using equations (2) and (3). Afterward, calculate the wall thickness based on HVL and TVL using equation (4). After obtaining the HVL and TVL values, an independent t-test statistical analysis was carried out to find out whether there were differences in the average HVL and TVL values on the primary and secondary walls using the IBM SPSS Statistics 25 application in this study the null hypothesis (H_0) was not present difference HVL and TVL values on the primary and secondary walls. Alternative hypothesis (H_1) there were differences in HVL and TVL values on the primary and secondary walls. And One-way ANOVA analysis was carried out to determine the difference in HVL and TVL values at voltages of 40 kV, 50 kV, 60 kV and 70 kV. In the one-way ANOVA analysis the null hypothesis (H_0) was there was no difference in the HVL and TVL value when the tube voltage varied to 40 kV, 50 kV, 60 kV and 70 kV. The alternative hypothesis (H_1) was, there was a difference in the HVL and TVL values when the tube voltage was varied. The conditions required to conduct a independent sample t-test and One-way ANOVA were homogeneity of variance dan normal distribution of data. A p-value for statistically significant was set at 0.05.

Result and Discussion

The results of measurements of the radiation dose rate on the primary and secondary walls of the x-ray room at the radiology installation of the Bali Jimbaran General Hospital were shown in Table 3. Measurement of the radiation dose rate and background radiation was carried out at several measurement points as shown in Figure 1 with the measured wall thickness in the X-ray room 14.075 cm.

Tabel 3. Results of Radiation Dose Rate Measurements Around the X-Ray Room of the Radiology Installation of Bali Jimbaran General Hospital

Voltage (kV)	Dose Rate (µSv/h)											
	Primary				Secondary							
	Before		After		Before				After			
	A	B	A′	B′	C	D	E	F	C′	D′	E′	F'
40	5.00	5.50	0.11	0.13	3.00	2.30	1.90	1.70	0.11	0.13	0.13	0.11
	4.70	5.70	0.12	0.11	2.80	2.20	2.00	1.40	0.12	0.10	0.12	0.13
	4.60	5.40	0.10	0.10	2.70	2.50	1.80	1.50	0.10	0.11	0.11	0.12
50	30.00	28.00	0.17	0.19	13.00	6.20	5.60	2.10	0.16	0.13	0.16	0.13
	27.00	30.00	0.19	0.16	11.00	6.00	5.70	2.30	0.17	0.12	0.13	0.11
	29.00	29.00	0.16	0.18	10.00	6.10	6.00	2.40	0.18	0.10	0.14	0.12
60	64.00	66.00	0.32	0.32	23.00	9.00	8.40	3.70	0.27	0.14	0.17	0.15
	67.00	69.00	0.28	0.29	25.00	8.70	7.80	4.00	0.25	0.13	0.18	0.14
	66.00	65.00	0.29	0.30	22.00	8.20	8.20	3.90	0.24	0.16	0.16	0.12
70	80.00	80.00	0.37	0.40	28.00	20.00	20.00	6.70	0.31	0.19	0.24	0.17
	79.00	79.00	0.38	0.39	27.00	18.00	17.00	7.00	0.32	0.22	0.27	0.16
	77.00	77.00	0.39	0.37	26.00	19.00	18.00	6.50	0.30	0.21	0.23	0.18
Background radiation	0.20	0.20	0.10	0.10	0.20	0.20	0.20	0.20	0.10	0.10	0.11	0.11

Next, the calculation of the average radiation dose rate was carried out in Table 3. The results of calculating the average radiation dose was shown in Table 4.

Table 4. Average Radiation Dose Rate Before and After Passing Through the Primary and Secondary Walls

V (Kv)	Dose Rate (µSv/h)											
	Primary				Secondary							
	Before		After		Before				After			
	A	B	A'	B'	C	D	E	F	C'	D'	E'	F'
40	4.767	5.53	0.110	0.113	2.833	2.333	1.900	1.533	0.110	0.113	0.120	0.120
50	28.67	29.00	0.170	0.177	11.333	6.100	5.767	2.267	0.170	0.117	0.143	0.120
60	65.67	66.67	0.296	0.303	23.333	8.633	8.133	3.867	0.253	0.143	0.170	0.137
70	78.67	78.67	0.380	0.387	27.00	19.00	18.33	6.733	0.310	0.207	0.247	0.170

Surveymeter which is used to measure the radiation dose rate is periodically calibrated. There is a difference between the radiation dose rate value read on the device and the actual radiation dose rate value. The actual value must be corrected with a parameter called the calibration factor. The actual value of the radiation dose rate is the radiation dose rate that is read minus the radiation background multiplied by the instrument calibration factor. Where in this study used surveymeter gamma with a calibration factor of 1.09. Actual radiation dose rate calculations for measurements on the primary and other secondary walls were shown in Table 5 and Table 6.

Table 5. Actual Dose Rate Calculation at Measurement on the Primary Wall

Voltage (kV)	Dose Rate (μSv/h)			
	Before		After	
	A	B	A'	B'
40	4.978	5.595	0.0109	0.0142
50	31.029	31.392	0.0796	0.0839
60	71.359	72.449	0.215	0.221
70	85.529	85.529	0.305	0.313

Table 6. Actual Dose Rate Calculation at Measurement on the Secondary Wall

Voltage (kV)	Dose Rate (μSv/h)							
	Before				After			
	C	D	E	F	C'	D'	E'	F'
40	2.870	2.325	1.853	1.453	0.0109	0.0142	0.0109	0.0109
50	12.135	6.431	6.068	2.253	0.0763	0.0185	0.0360	0.0109
60	25.215	9.192	8.647	3.997	0.167	0.0469	0.0654	0.0294
70	29.212	20.492	19.765	7.121	0.229	0.117	0.149	0.0654

The value of the linear attenuation coefficient can be determined if it is know the radiation intensity before and after passing through the material and the thickness of the material. Because the radiation intensity is directly proportional to the radiation dose rate, the linear attenuation coefficient of the primary and secondary walls can be determined by equation (6). Based on the results, the wall thickness measurement at the Radiology Installation of RSU Bali Jimbaran was 14.075 cm for both primary and secondary walls. The calculation of the attenuation coefficient (μ) at other measurement points was shown in Table 7.

Table 7. Calculation Coefficient Linear Attenuation (μ)

Voltage (kV)	Linear attenuation coefficient (μ) cm^{-1}					
	Primary		Secondary			
	A	B	C	D	E	F
40	0.435	0.425	0.396	0.362	0.365	0.348
50	0.424	0.421	0.360	0.416	0.364	0.379
60	0.412	0.412	0.356	0.375	0.347	0.349
70	0.400	0.399	0.344	0.367	0.347	0.333

The HVL value was calculated by equation (2) while the TVL was calculated using equation (3). Calculation results for HVL and TVL values were shown in Tables 8 and 9.

Table 8. Calculation of HVL Value

Voltage (kV)	HVL (cm)					
	Primary		Secondary			
	A	B	C	D	E	F
40	1.593	1.631	1.750	1.915	1.899	1.992
50	1.635	1.646	1.925	1.666	1.904	1.829
60	1.682	1.682	1.947	1.848	1.998	1.986
70	1.733	1.737	2.015	1.889	1.998	2.082

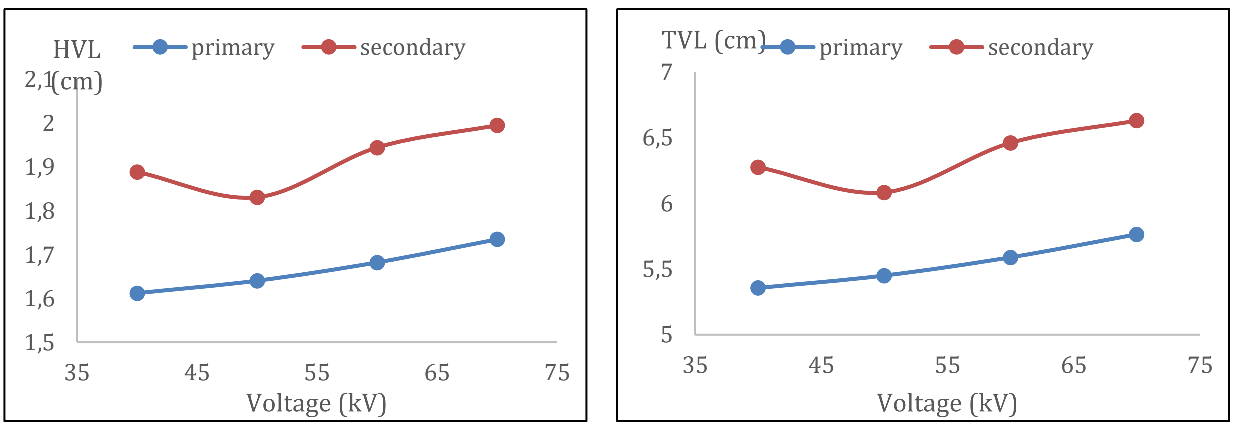
Table 9. Calculation of TVL Value

Voltage (kV)	TVL (cm)					
	Primary		Secondary			
	A	B	C	D	E	F
40	5.293	5.418	5.815	6.361	6.308	6.617
50	5.431	5.469	6.396	5.535	6.326	6.075
60	5.589	5.589	6.468	6.140	6.636	6.598
70	5.756	5.771	6.694	6.274	6.636	6.915

Table 10 showed the average HVL and TVL values on the primary and secondary walls. The graph of the voltage relationship with the HVL and TVL values was shown in Figure 2.

Table 10. Average HVL and TVL values on Primary and Secondary Walls

Voltage (kV)	HVL (cm)		TVL (cm)	
	Primary	Secondary	Primary	Secondary
40	1.612 ± 0.027	1.889 ± 0.101	5.356 ± 0.088	6.275 ± 0.335
50	1.641 ± 0.008	1.831 ± 0.118	5.450 ± 0.027	6.083 ± 0.390
60	1.682 ± 0.000	1.945 ± 0.068	5.589 ± 0.000	6.460 ± 0.225
70	1.735 ± 0.003	1.996 ± 0.080	5.764 ± 0.010	6.629 ± 0.266



(a) (b)

Figure 2. Graph of Voltage Relationship to (a) HVL and (b) TVL

Primary and secondary wall thickness in HVL and TVL, wall thickness calculation in HVL and TVL used equation 3.5. It was known that on the primary wall at point A when the tube voltage was 40 kV, the radiation dose rate before passing through the wall was 4.978 μSv/h and after passing through the wall was 0.0109 μSv/h and at point B the radiation dose rate before passing through the wall was 5.595 μSv/h and after passing through the wall was 0.0142 μSv/h. The average radiation dose rate before passing through the primary wall was 5.2865 μSv/h and after passing through the primary wall was 0.01255 μSv/h. Calculation results were shown in Table 11.

Table 11. Determination of wall thickness based on HVL and TVL

V (kV)	Primary	Secondary
40	2 HVL + 2 TVL	1 HVL + 2 TVL
50	2 HVL + 2 TVL	1 HVL + 2 TVL
60	2 HVL + 2 TVL	1 HVL + 2 TVL
70	2 HVL + 2 TVL	1 HVL + 2 TVL

The t-test can be used to determine if there is a significant difference between two unpaired groups. To find out whether there are differences in HVL and TVL values on the primary and secondary walls. The test is carried out with independent t-test. The requirements for the parametric statistical test that must be met in order to carry out the t-test. Meanwhile, the data must be normally distributed and homogeneous. If the conditions are met, then the t-test can be performed. The basis for making a decision for the t-test is if the value reaches Sig.(2-tailed) > α, then there is no difference in the average HVL and TVL values on the primary and secondary walls, whereas if the value reaches Sig.(2-tailed) < α, there is a difference between the average HVL and TVL values on the primary and secondary walls. This study used $\alpha = 0.05$.

The normality test results for the HVL value on the primary wall, the p-value is 0.588, while on the secondary wall is 0.391. For the TVL value on the primary wall, the p-value is 0.588 and on the secondary wall is 0.391. Because p-value > 0.05 means the data is normally distributed. From the t-test results, the p-value for the data homogeneity test is 0.159> 0.05, its data has a homogeneous variance. Based on the results of the independent sample t-test, Sig.(2-tailed) value <0.05 then H_0 is rejected and H_1 is accepted. The value of HVL and TVL on the primary wall is different from the value of HVL and TVL on the secondary wall. The average HVL value on the primary wall is 1.668 cm and the average HVL value on the secondary wall is 1.915 cm. On the other hand, the average HVL value on the primary wall is 5.540 cm and the average TVL value on the secondary wall is 6.362 cm. The results of the t-test analysis of HVL and TVL values on the primary and secondary walls have a significant difference. It might happen because the differences in the density of the primary and secondary walls. Coefficient linear attenuation increases with increasing concrete density and when coefficient attenuation increases the value of HVL and TVL decreases. [15]

Wall thickness can be expressed in HVL and TVL based on the calculation results which were summarized in Table 11. The primary wall requires 2 HVL + 2 TVL to reduce the radiation dose rate, while the secondary wall requires 1 HVL + 2 TVL to reduce the radiation dose rate. The primary wall requires more HVL than the secondary wall. The reason is because the primary wall receives a higher radiation dose than the secondary wall.

Analysis of variance (ANOVA) is a statistical analysis method that examines the average difference between data groups. In this study, one-way ANOVA analysis was carried out to determine the difference in the values of HVL and TVL at voltages of 40 kV, 50 kV, 60 kV and 70 kV. The requirements of the ANOVA test are where the data is normally distributed and the variance of the data is homogeneous. Based on the normality test of HVL and TVL values each voltage has different p-value. Voltage at 40 kV has p-value = 0.454. Voltage at 50 kV has p-value = 0.112. Voltage at 60 kV has p-value 0.114. Voltage at 70 kV has p-value = 0.294. The results of the normality test for each group data has normal distribution that can be seen from the p-value > 0.05. It can be seen from the homogeneity test p-value = 0.920 means the data has the same variance.

Based on ANOVA analysis, the value has p-value 0.377 > 0.05 means that there is no significant difference in the average of HVL or TVL values when the tube voltages are 40 kV, 50 kV, 60 kV and 70 kV. It shows that the HVL and TVL depend on the linear attenuation coefficient of the material. On the other hand, the material attenuation coefficient depends on the material. The wall components include bricks plastered with Portland cement and sand mix plus a 2 mm Pb layer.

Conclusion

The HVL and TVL values on the primary wall are 1.668 cm and 5.540 cm. Meanwhile, on the secondary wall the HVL and TVL values are 1.915 cm and 6.362 cm. The wall thickness based on HVL and TVL on the primary wall is 2 HVL + 2 TVL, while on the secondary wall is 1 HVL + 2 TVL. The primary wall requires one more layer of HVL than the secondary wall, because of the primary wall receives more radiation intensity than the secondary wall. Based on the independent t-test analysis of the sample, p-value<0.05 means that there is a difference between the average of HVL and TVL values on the primary and secondary walls. It is due to the possibility that there are differences in the density of the primary and secondary walls. Based on ANOVA analysis, p-value 0.377 > 0.05 means that there is no difference in the average HVL or TVL values when the tube voltages are at 40 kV, 50 kV, 60 kV and 70 kV. It happens because the HVL and TVL depend on the linear attenuation coefficient of the material. Meanwhile, the material attenuation coefficient depends on the material. Therefore, the wall components include bricks plastered with cement and Portland sand mix plus a 2 mm Pb layer.

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