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Differences In The Quality Of Mixed Material Radiation Aprons At Dr. Moewardi Hospital With A Review Of Attenuation Coefficient Analysis

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Abstract

Introduction
Radiation aprons are essential protective equipment in radiology, and the Regulation of the Head of BAPETEN No. 4 of 2020 requires aprons in Diagnostic and Interventional Radiology units to provide protection equivalent to 0.25 mmPb, 0.35 mmPb, or 0.5 mmPb. This study aimed to evaluate the quality of mixed-material radiation aprons at Dr. Moewardi Hospital by analyzing their attenuation coefficients.

Methods
This study assessed several apron brands available in the Radiology Installation and Cathlab Unit. Measurements were performed using a GE Proteus X-ray machine and a Raysafe X-ray Multimeter Detector. The X-ray parameters were set at 100 kV, 10 mAs, 100 cm tube-to-detector distance, and a 5 × 5 cm irradiation field, with variations in apron thickness. The reference attenuation coefficient of Pb under the same parameters was calculated as 6.32 mm^{-1}. Apron brands tested included Primax 0.35 mmPb, ProteX 0.5 mmPb, Infab 0.25 mmPb, Lead X 0.25 mmPb, Rayshield 0.25 mmPb, Xenolite 0.35 mmPb, and Trucomfii 0.5 mmPb.

Results
The attenuation coefficients obtained were 4.67 mm^{-1}, 4.49 mm^{-1}, 4.476 mm^{-1}, 3.94 mm^{-1}, 3.04 mm^{-1}, 2.63 mm^{-1}, and 2.22 mm^{-1}, respectively. The highest coefficient was observed in the Lead X 0.25 mmPb apron. All apron attenuation coefficients were lower than the Pb reference value.

Conclusion
All mixed-material aprons evaluated demonstrated lower attenuation coefficients compared with pure Pb under identical exposure conditions. These findings indicate variability in protective performance across brands, highlighting the need for routine quality assessment to ensure compliance with regulatory requirements.

Keywords: Apron, Attenuation Coefficient, Radiation Protection

Introduction

Based (Badan Pengawas Tenaga Nuklir, 2020), radiation protection is an action taken to reduce the damaging effects of radiation due to radiation exposure. In the use of ionizing radiation sources, it should meet the requirements of radiation protection.

One type of radiation source used at RSUD Dr. Moewardi is external radiation source which can be reduced by external radiation protection.

A. External Radiation Protection

External radiation protection is an effort to protect all kinds of radiation sources outside the human body, some of the techniques used are as follows

1. Exposure Time

   Exposure time limitation to reduce the danger of external radiation is based on the assumption that for a constant dose rate, the absorbed dose is proportional to the time of exposure.

$D = \dot{D} \times t$ .... (1)
With,
D = Total absorbed dose
$\dot{D}$ = Dosing rate
t = Exposure time

2. The Distance from a Radiation Source

Radiation from the radiation source is emitted in all directions. The closer the body is to the radiation source, the greater the radiation exposure received. Radiation exposure will be partially scattered when it hits matter. This scattered radiation will increase the dose of radiation received. A preventive measure can be taken by keeping a safe distance from the radiation source.

The distance factor is closely related to the radiation intensity or I, the radiation intensity at a point will be reduced inversely proportional to the square of the distance between that point and the radiation source. Radiation intensity is defined as the amount of radiation that penetrates a surface area per unit of time.

$I = \frac{P}{A}$ .... (2)

$I = \frac{P}{\frac{4}{3}\pi r^2}$ .... (3)

$\frac{I_1}{I_2} = \frac{r_2^2}{r_1^2}$ .... (4)

The radiation dose rate is identical to the radiation intensity so that the dose rate at a point is also inversely proportional to the square of the distance between the point and the source.

$\frac{D_1}{D_2} = \frac{r_2^2}{r_1^2}$ .... (5)

3. Radiation Barrier

The dose rate can be reduced by installing radiation barriers. The type and material of the radiation barrier are differentiated based on the energy of the ionizing radiation source used (Eri Hiswara, 2015).

B. Radiation Apron

An apron is a piece of equipment that is used as a protective material against X-ray radiation. Its function as a protector against X-ray radiation is indicated by its absorption of X-ray radiation. Radiation shielding has an important meaning in reducing the amount of radiation a person receives. Radiation reduction depends on the type and energy of the radiation, the type of barrier material, and its thickness. The reduction of radiation is exponentially inversely proportional to the physical properties of the barrier and its thickness.

$\dot{D} = \dot{D}_0\, e^{-\mu x}$ .... (6)

There are several types of materials for making radiation aprons; older generation radiation aprons use pure lead (Pb) material. However, aprons with lead material have a drawback, their heavy weight causes user discomfort. The new generation apron provides a solution by replacing lead with a lighter, more ergonomic material that has the same radiation absorption as lead. New generation apron uses materials such as tin, tungsten (wolfram), antimony, copper, bismuth, or barium. The material can be combined with lead, so it is called lead composite (LC), or Light Lead (LL) or Lead Free (LF) apron. Each mixture of materials has a different attenuation coefficient (König et al., 2023).

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C. Attenuation Coefficient

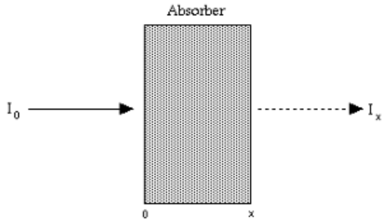

Figure 2.1 Absorber

The attenuation coeeficient, or weakening, or absorption coefficient is the fraction of the X-ray beam that is weakened per unit absorption thickness

$I = I_0 \, e^{-\mu x}$………………………………………………………. (7)

With
I is the intensity of radiation that passes through the material
I_0 is the intensity of radiation before passing through the material
μ is the linear attenuation coefficient
x is the thickness of the material

Where the linear coefficient is the number of atoms/ cm3 (n) of each unit thickness of the absorbent material (σ)

$\mu = n \times \sigma$………………………………………………………. (8)

The attenuation coefficient depends on the absorbent thickness (x), the absorbent atomic number (Z), the absorbent density (ρ), the X-ray energy. The attenuation coefficient is differentiated into 3 types$x\rho$:

a) Atom Attenuation Coefficient μ_a
It is a fraction of the X-ray beam that is weakened by a single atom. The coefficient of atomic attenuation is also called the microscopic transverse cut of the atom σ. μ_a is a unit of area cm^2.
b) Linear Attenuation Coefficient
It is the absorption coefficient with absorbent thickness measured in cm. The $\mu_l$unit is /cm. The linear attenuation coefficient describes the fraction of a gamma-ray or X-ray beam of light that absorbs or spreads each unit thickness of the absorbent materialμ_l
c) Mass Attenuation Coefficient μ_m
It is the absorption coefficient with absorbent thickness measured in gr/cm2. The μ_m unit is cm^2/gr. The mass attenuation coefficient is a measurement of how a type of chemical or element absorbs light at a given wavelength, per unit mass (Atika Rahmawati, 2009).

Research Methodology

The research was conducted in May until September 2025, this was held using apron samples from various brands in the Radiology Installation and Cathlab Unit of Dr. Moewardi Hospital. The research was started by checking the apron sample if there were any leakages. There were 7 Apron brands with 3 samples taken from each brand for data collection. This study used a MSCT Scan GE 128 Slice Sn 227327WG4 to check the apron and a GE Proteus Sn 133795BI5 stationary conventional radiography X-ray machine with an accuracy of 1.5% (the passing test score $\leq$10%) based on the result of the quality control kV accuracy test, and the result of the radiation output reproducibility test was 0.001 (the passing test score $\leq$ 0.050) to irradiate the apron.

The apron test was performed, and the results were obtained that the aprons used had no radiation leakage and no creases were found, and ROI was performed on the aprons and the results were obtained that the aprons used were homogeneous with a deviation of the HU value of each apron of less than 7 HU. The 7 brands are as follows

No	Brand of Body Apron	Thickness (mmPb)
1	Primax	0,35
2	Prote-X	0,5
3	Infab	0,25
4	Lead-X	0,25
5	Rayshield	0,25
6	Xenolite	0,35
7	Trucomfi	0,5

Table 1. Brands of sample apron at Dr. Moewardi Hospital based on brand and thickness

Data were collected on June until August 2025, measured the air kerma of GE Proteus Stasioner Radiography using an X-ray multimeter at a distance of the X-ray tube to the X-ray multimeter detector was 1 meter and the irradiation field area was 5 cm x 5 cm as an initial radiation dose data (D0). Absorbed dose (D1) was collected by measuring the amount of radiation that was not attenuated by the apron, the independent variable of the research is varying the thickness of the shield or apron. The variation of apron thickness is by multiplying the same thickness of each apron

Using data D0 and D1, a linear equation chart $\ln \dot{D}_1 = -\mu x + \ln \dot{D}_0$ was created with m being the gradient of the chart and the representative of the attenuation coefficient value of each apron.

Results

No	Apron	Thickness	Absorbed Dose (mGy)
1	Air Kerma D0 (Without Apron)		863,2
2	protex 0,5	0,5 mmPb	128,5
		1 mmPb	43,17
		1,5 mmPb	18,33
		2 mmPb	8,813
3	Rayshield 0,25	0,25 mPb	154,9
		0,5 mmPb	46,75
		0,75 mmPb	19,65
		1 mmPb	9,007
4	lead X 0,25	0,25 mmPb	102,3
		0,5 mmPb	36,29
		0,75 mmPb	14,8
		1 mmPb	6,608
5	truecomfi	0,5 mmPb	106,4
		1 mmPb	36,93
		1,5 mmPb	15,17
		2 mmPb	7,312
6	Xenolite	0,35 mm	84,8
		0,7 mmpb	37,72
		1,05 mmpb	17,88
		1,4 mmpb	9,18
7	infab	0,25 mmPb	107,8
		0,5 mmPb	44,78
		0,75 mmPb	19,21
		1 mmPb	7,732
8	Primax	0,35 mmpb	71,27

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0,7 mmpb	19,82
1,05 mmpb	7,142
1,4 mmpb	2,721

Table 2. Air Kerma (D0) and Absorbed Dose (D1)

Air kerma at 1 meter, 100 kV and 10 mAs is 863,2 mGy, each apron had 4 variation of thickness. The data indicates the absorbed dose was attenuated by apron, however the amount of absorbed dose measured by the multimeter showed that each apron had different trend of attenuation.

Discussion

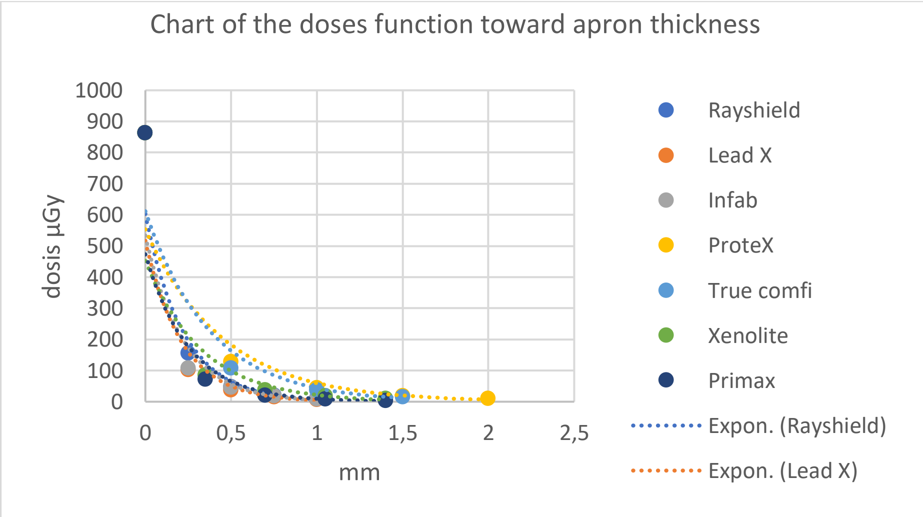

Chart 1. The function of the dose received by the detector against variations in apron thickness

Based on the chart, it can be seen that the radiation dose is exponentially reduced with the additional thickness of the apron.

A chart of the function of In D against the variation in the thickness of the apron was made. Each chart then obtained a gradient value, which is the representative of the attenuation coefficient value of each apron.

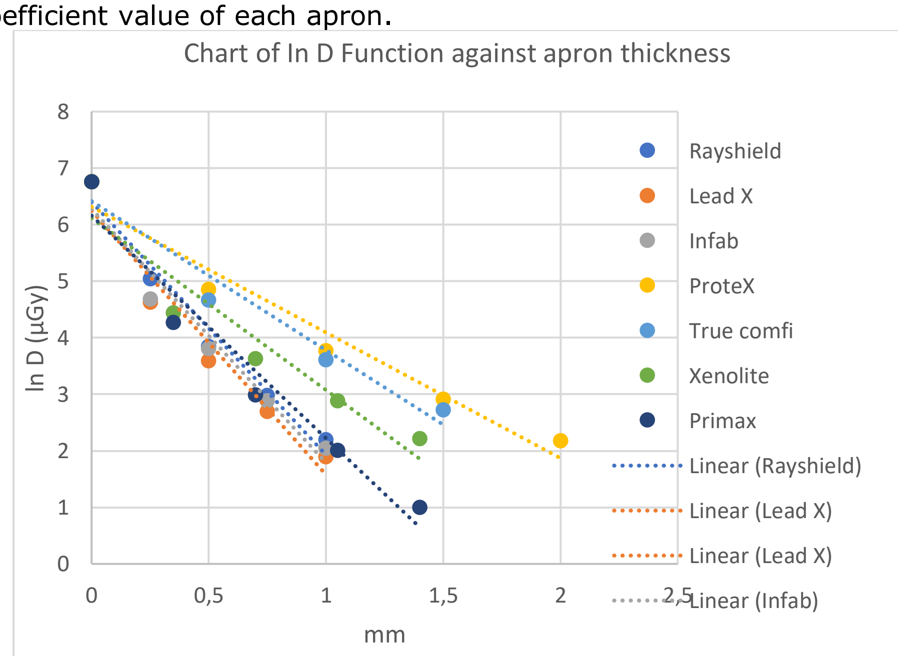

Chart 2. In D function against apron thickness

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The chart above shows a linear chart with a negative gradient showing a decrease in the value of ln D against the increase in the thickness of the radiation apron.

No	Apron Name	Thickness (mmPb)	μ (attenuation coefficient) mm^{-1}	Absorbed dose on the thickness of the apron of 1 mmPb
1.	ProteX	0,5	2,22	0,949988415
2.	Rayshield	0,25	4,476	0,98956557
3.	Lead X	0,25	4,67	0,992344764
4	Truecomfi	0,5	2,63	0,957217331
5.	Xenolite	0,35	3,04	0,978250695
6.	Infab	0,25	4,49	0,991042632
7	Primax	0,35	3,94	0,989543653

Chart 3. Table of gradient values as attenuation coefficient values

Table 3 shows the results of the chart of each apron as a function of equation 9. It obtained the results of the attenuation coefficient value of the Aprons at Dr. Moewardi Hospital from the highest to the lowest values consecutively, namely as follows: Apron brand lead X the value of the attenuation coefficient was 4.67 $^{mm-1}$ at the thickness of Apron 1 mmPb absorbing radiation intensity by 99%, Infab 4.49 $^{mm-1}$ at the thickness of Apron 1 mmPb absorbing radiation intensity by 99%, Rayshield 4.476 $^{mm-1}$ at 1 mmPb Apron thickness absorbed 98% radiation intensity, Primax 3.94 $^{mm-1}$ at Apron 1 mmPb absorbed radiation intensity 98%, Xenolite 3.04 $^{mm-1}$ at Apron 1 mmPb absorbed radiation intensity by 97%, Truecomfi 2.63 $^{mm-1}$ at Apron 1 mmPb thickness absorbed radiation intensity by 95% and ProteX 2.22 $^{mm-1}$ at a thickness of 1 mmPb apron absorbed radiation intensity by 94%.

The ability of a material to absorb radiation depends on the density of the atoms that make up the material. In general, pure lead (Pb) is used as an apron forming material with atomic number 82. Referring to the previous study, the absorption of lead (Pb) with a thickness of 0.5 mm at a voltage of 100 kV is 95.76%, then mathematically, the attenuation coefficient of lead (Pb) is 6.32 $^{mm-1}$. Using the same parameters experimentally, the apron at Dr. Moewardi Hospital had an attenuation coefficient value that was close to the value of pure Pb attenuation coefficient. Several factors in data collection can affect the results of the study. In this study, the average regression value from the linear chart of the radiation dose function to the thickness of the apron was 0.95. Some of the influencing factors are:

1. Taking data D0, the value of D0 is the radiation dose of the main beam and the radiation scattering
2. Variations in apron thickness. The aprons used in this study were aprons that came with an apron wrapper, therefore, each thickness addition to the apron was followed by an apron wrapper addition, where the apron wrapper can absorb radiation, even though the absorption is minor.

Conclusion

A. Conclusion

From the results of the study conducted on 7 brands of Radiation Aprons at Dr. Moewardi Hospital, it can be concluded that:

1. The results shows that the value of the attenuation coefficient of the apron with each of its forming materials was below the value of the Pb attenuation coefficient at the exposure parameter of 100 kV.
2. The attenuation coefficient value of each brand, from the highest to the lowest value compared to the attenuation coefficient value Pb is as follows:

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No	Apron Name	Thickness (mmPb)	μ (attenuation coefficient) mm^{-1}	μ (attenuation coefficient Pb) mm^{-1}
1.	Lead X	0,25	4,67	6,32
2.	Infab	0,25	4,49	6,32
3.	Rayshield	0,25	4,476	6,32
4	Primax	0,35	3,94	6,32
5.	Xenolite	0,35	3,04	6,32
6.	Truecomfii	0,5	2,63	6,32
7	ProteX	0,5	2,22	6,32

Chart 4. Comparison of the attenuation coefficient values of the mixed material apron with the pure Pb apron

3. The apron brands with the highest to lowest radiation intensity reduction quality are Lead X, Infab, Rayshield, Primax, Xenolite, Truecomfii, and ProteX.

B. Recommendations

1. It is necessary to conduct a study using sample aprons with the same thickness.
2. This study is only conducted on 7 apron brands; it is necessary to conduct a study on other brands.
3. In taking the dose value of D0 radiation, it is necessary to pay attention to its scattering radiation.
4. For further study, please pay attention to performing variations in the thickness of the apron related to the addition of attenuation of the apron wrapper.
5. This study is a recommendation; it is necessary to re-test the new production of apron related to the development of science and technology.

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