



Determination of the X-ray Linear Attenuation Coefficient of Clay-Originated Bricks in Central Java Province, Indonesia

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ABSTRACT

The widespread use of radioactivity has culminated in adverse health consequences and has generated an entire health science study. It is established practice that certain precautions must be taken to avoid potential exposure to ionizing radiation like an x-ray. One way to control radiation hazards external is to use a radiation shield. In this study, clay-originated bricks were used as a shield and determine its linear attenuation coefficient of x-ray radiation. The bricks were collected from 5 regencies in Central Java province. Digital fluoroscopy was used as an x-ray radiation source and operated in 81 kV 32 mAs; also, it associated with the multi-purpose detector. It shows that linear attenuation coefficient of Boyolali, Klaten, Magelang, Temanggung, and Semarang bricks respectively are 0.8896 cm^{-1} ; 0.7455 cm^{-1} ; 0.7115 cm^{-1} ; 0.7254 cm^{-1} ; and 0.7972 cm^{-1} . Furthermore, we calculate the half-value layer of each brick and indicates that brick from Boyolali is the most effective as a shielding among others that can reduce half value of x-ray radiation dose. This research is expected to enhance the systems integration of radiation shielding safeties and allow for the effective treatment of radiation sources for both humans and the environment.

INTRODUCTION

Radiation is a process of transferring energy and is divided into several types based on the cause, including natural radiation and artificial radiation. The state of the earth itself generates natural radiation either inside the earth or through cosmic radiation. One of the natural sources of radiation is clay. Clay is an element that is collected from several substantial and unbound parts where there are cavities filled with water and air [1]. Meanwhile, artificial radiation is generated due to human activity in combining radioactive materials such as uranium to produce coloured glass or due to the large amount of radioactive dust scattered in the air from world wars [2]. Radiation cannot be separated from radioactivity because when there is a spontaneous decay of an unstable isotope into another isotope accompanied by radiation emission, it is called radioactivity.

Radiation protection is an activity to reduce the total dose of existing radiation spreads by affecting its process. It consists of external radiation protection and internal radiation protection. External radiation protection can be done by taking into account the working time factor, the distance factor to the source, and the radiation barrier factor. Meanwhile, internal radiation protection can be done by preventing the spread of radioactive substances at the source, namely by containing it or confining it, monitoring the environment by monitoring ventilation and cleanliness of the workplace, monitoring workers by providing protection, such as gloves, shoe covers, and respiratory protection [3]. Recently, the utilization of radioactive sources is expanding in various fields, namely exploratory space missions [4], power plants [5], nuclear testing centres [6], medical science [7], and so on, due to the advancement of nuclear technology and nuclear science. Nuclear radiation history was started when a French physicist, Antoine Henri Becquerel (1852-1908), inadvertently discovered in 1896 that a mineral-rich in uranium called pitchblende emits invisible. The darken-side of a photographic plate wrapped in a murky wrapper was caused by penetrating rays that convey energy. The condition happened without any energy supply where the pitchblende (uranium oxide) emits them perpetually [8] [9] [10] [11]. This thing is a clear violation of the law of energy conservation. We acknowledge that it is indeed responsible for converting a smaller amount of mass into energy, as in equation (1).

$$E = mc^2 \quad (1)$$

where E is energy (J), m is mass (kg), and c is the speed of light (m/s^2). It soon became clear that the rays of Becquerel originated in the nucleus of the atoms and had other unique characteristics. The emission of these kinds of rays is related to as simply radioactivity or nuclear radioactivity. The rays themselves are known as radioactive radiation. A nucleus that drops part of its mass unexpectedly to emit radiation is stated to decay (a term also used to define the emission of radiation by atoms in excited states). A material or object which emits nuclear radiation is said to be radioactive [12] [13].

Some kinds of radiation have enough energy to force electrons out of their orbits around atoms, disrupting the equilibrium of the electron/proton and giving a positive charge to the atom. Electrically charged molecules and atoms are referred to as ions [14]. The radiation that can cause ions is called ionizing radiation. There are various forms of ionizing radiation, such as alpha radiation, beta radiation, gamma radiation, and x-rays [15] [16]. X-rays are part of the waves of electromagnetic energy travelling and a form of ionizing radiation produced by the acceleration or deceleration of charged particles [17].

X-ray is high-energy of electromagnetic radiation, but it has similar characteristic to those of the generally familiar electromagnetic spectrum component (such as infrared radiation, visible light, and ultraviolet radiation). As in other types of electromagnetic radiation, x-rays could be described as combination waves of magnetic and electric fields moving at a speed of light (about 300,000 km) [18] [19] [20]. X-rays with wavelengths in the range from about 10^{-8} to 10^{-12} m and frequencies range from about 1016 to 1020 Hz could be shown and defined by interference consequences arising from the overlapping of two or more waves in space. X-rays also demonstrate particle-like properties; they can be portrayed as a flow of photons with discreet amounts of energy and momentum. The condition is thoroughly explained in the theory of quantum mechanics, where dual presence is the characteristic of all sources of matter and radiation [21] [22]. To avoid or to minimize radiation exposure, there is such a thing called radiation protection.

Radiation protection or radiation safety is a science and technique for human study health and environmental issues related to providing protection to a person or group of people against possibilities detrimental to health due to exposure to radiation [23] [24]. The purpose of radiation protection is to prevent dangerous deterministic effects and reduce stochastic effects as low as possible [25] [26]. Stochastic effects related to exposure to low doses of radiation can appear in the human body in the form of cancer (somatic damage) or defects in heredity (genetic damage).

The deterministic effect associated with exposure to the high doses of radiation it occurs can be immediately seen or felt by the individual exposed to the radiation. Humans every day are always exposed to natural radiation from cosmic radiation (extraterrestrial) and terrestrial radiation, especially from primordial radionuclides on the earth's crust, i.e. uranium and thorium overlapped [27]. Based on the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) Report, the average annual exposure of natural radiation sources is 2.4 mSv, which is 1–10 mSv / year [28]. The intended natural radiation source consists of external exposure to cosmic radiation (0.4 mSv/year) and terrestrial radiation (0.5 mSv/ year), as well as internal exposure, namely inhalation (1.2 mSv/year especially radon) and ingestion (0.3 mSv/year) [29] [30].

The danger of radiation from this external source can be in control by using three basic principles of radiation protection, namely regulation time, distance setting, and shield usage [31] [32]. Ishafani et al. found that radiation protection used bentonite clay samples with 40% of barite powder as a shielding [33]. Mann et al. in their study verified that common brick possesses the maximum shielding effectiveness for a wide energy range of 0.015–15 MeV [34]. Those previous studies then lead to this study that focused on using bricks as a shielding. A broad range of knowledge on photon penetration and energy deposition in biological protection is given by the linear attenuation coefficient [35]. For the comprehensive development of nuclear use and extensive use of radioactive materials, it is essential to consider inexpensive and readily available evolving shielding material. Materials should be cost-effective, good for the environment and preferably used for toxic waste.

The interaction between electromagnetic radiation (x-rays) and material causes a reduction in radiation dose according to the equation (2) and (3)

$$D = D_0 e^{-\mu x} \tag{2}$$

$$HVL = \frac{0.693}{\mu} \tag{3}$$

where D is the incident radiation after it has passed through a thickness of an absorbing material (Gy), D_0 is the original incident radiation after it has passed through a thickness of an absorbing material (Gy), μ is linear attenuation coefficient (cm^{-1}), and x is the thickness of absorbing material (cm), HVL is the abbreviation from half-value layer [36].

METHOD

In this study, the sources of clay-originated bricks were collected from 5 regencies in Central Java province, namely Boyolali regency, Klaten regency, Magelang regency, Temanggung regency, and Semarang regency, as shown in Figure 1. The bricks dimension was 21 cm x 11 cm x 6 cm (length x depth x height). The digital fluoroscopy (Siemen AG, Germany) was used as an x-rays source that located in the centre of the brick and had 5 cm x 5 cm field size, associated with black piranha 657 multi-purpose detector (MDP) (RTI Group, United Kingdom) to measure the dose of x-ray radiation. The voltage and current exposure time product value of digital fluoroscopy continually were operated in 81 kV 32 mAs. The brick was set 100 cm from the x-ray source, and the detector was placed 3 cm under the brick, as shown in Figure 2. The collected bricks, their surface, was smoothed and will be x-rayed for ten times on each brick. To calculate the linear attenuation coefficient we used the derivative formula from equation (2) as shown in equation (4), then implementing equation (3) to obtain the half-value layer.

$$\mu = \frac{1}{x} \ln \left(\frac{D}{D_0} \right) \tag{4}$$



Fig 1. Map of Central Java province

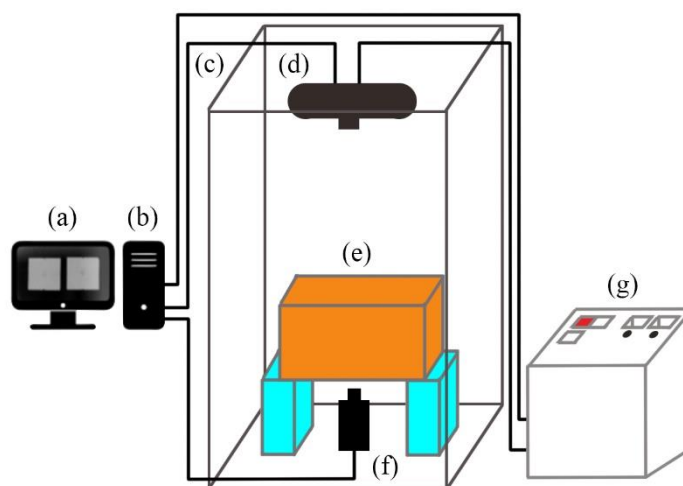


Fig 2. Experimental setup (a) Monitor screen, (b) CPU, (c) Copper shielding box, (d) X-ray tube, (e) Clay Brick, (f) MDP, and (g) Panel control

RESULTS AND DISCUSSIONS

X-rays were generated by the digital fluoroscopy x-rays tube and passed through its filter [37]. Doctors commonly use this fluoroscopic imaging technique to obtain a real-time moving image of a patient's body [38]. One of the principal uses of fluoroscopy is interventional radiology, a branch of radiology that performs diagnosis and therapy on the patient's body through the outside of the body with guide cables, stents, etc. x-rays [39]. These rays were transformed into visible light, then 400 nm light photons interacted with the photocathode and creating photoelectrons with an efficiency of

approximately 10% [40]. These electrons were then exacerbated to an anode next to the viewer's end. The utilization of electron lenses generated an electrical field in the tube to deflect the electrons from their original path straightway to the bricks. Once targeted, they interacted with a fluorescent screen and emitted ~1000 light photons [41]. X-rays emitted on the brick samples produce radiation doses, as shown in Table 1.

Table 1. Initial and Transmitted Dose

Test-nth	Initial Dose (mGy)	Transmitted Dose (mGy)				
		Boyolali Brick	Klaten Brick	Magelang Brick	Temanggung Brick	Semarang Brick
1	2.713	0.0354	0.0639	0.0755	0.0691	0.0482
2		0.0298	0.0678	0.0784	0.0737	0.0525
3		0.0273	0.0641	0.0796	0.0744	0.0492
4		0.0342	0.0652	0.0749	0.0696	0.0493
5		0.0333	0.0632	0.0788	0.0731	0.0478
6		0.0339	0.0668	0.0774	0.0741	0.0531
7		0.0284	0.0675	0.0772	0.0699	0.0487
8		0.0344	0.0633	0.0781	0.0739	0.0538
9		0.0313	0.0649	0.0764	0.0715	0.0518
10		0.0294	0.0659	0.0771	0.0724	0.0494
Average	2.713	0.0317	0.0653	0.0773	0.0722	0.0504

This result showed obtained the initial radiation dose (without bricks) was 2.713 mGy, while the average the transmitted radiation dose of Boyolali, Klaten, Magelang, Temanggung, and Semarang bricks, respectively, were 0.0317 mGy; 0.0653 mGy; 0.0773 mGy; 0.0722 mGy; 0.0504 mGy. Even though the thickness of brick samples was made the same (5 cm), the dose radiation still varied. It could happen due to the differences in the chemical compositions and temperatures used by the factory when making bricks [42]. The initial radiation dose and the average radiation dose result were used to calculate the linear attenuation coefficient and half-value layer using equation (2) and (3), as shown in Table 2.

Table 2. Linear Attenuation Coefficient and Half-Value Layer

Bricks Origin	Linear Attenuation Coefficient (cm ⁻¹)	Half-Value Layer (cm)
Boyolali	0.8896	0.7790
Klaten	0.7455	0.9296
Magelang	0.7115	0.9740
Temanggung	0.7254	0.9554
Semarang	0.7972	0.8692

Linear attenuation coefficient was defined as the probability of absorbed or scattered photons per unit length of the absorptive materials [43]. The linear attenuation coefficient of the building materials had great importance for the determination of protection towards the damaging effects of photons on the human body [44]. The Table 2 showed the linear attenuation coefficient of Boyolali, Klaten, Magelang, Temanggung, and Semarang bricks respectively were 0.8896 cm⁻¹; 0.7455 cm⁻¹; 0.7115 cm⁻¹; 0.7254 cm⁻¹; and 0.7972 cm⁻¹. The lowest value of the half-value layer was Boyolali brick as 0.7790 cm, and the highest value was Magelang brick as 0.9740 cm. It indicated that brick from Boyolali could reduce x-rays radiation to half of its initial dose. The lower the value of the half-value layer, the better the radiation building material in terms of thickness requirement. Reduction in the beam's dose could be predisposed by the atomic number of beam energy or absorbing building material (bricks).

CONCLUSION AND SUGGESTION

Based on the result and discussion above, it could be concluded that clay-originated bricks were the cheap and eco-friendly shielding for x-ray radiation. Using voltage and current exposure time product value of digital fluoroscopy constantly that operated in 81 Kv 32 mAs to determine the linear attenuation coefficient. The obtained linear attenuation coefficient of Boyolali, Klaten, Magelang, Temanggung, and Semarang bricks respectively were 0.8896 cm^{-1} ; 0.7455 cm^{-1} ; 0.7115 cm^{-1} ; 0.7254 cm^{-1} ; and 0.7972 cm^{-1} . In this study, we found that brick from Boyolali was the most effective as a shielding among others that could reduce 50% of x-ray radiation dose. Finally, we suggested that this research can continue by using varying thickness material and precisely defining chemical composition.

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