PRACTICAL CONSIDERATIONS AND EFFECTS OF METALLIC SCREEN FLUORESCENCE AND BACKSCATTER CONTROL IN GAMMA COMPUTED RADIOGRAPHY

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Abstract. It is a fairly common misconception that the role of metallic screens used with computed radiography is primarily that of scatter control, and that any amplification of the image signal is minimal. To the contrary, this paper shows how the physical interaction between gamma rays and front metallic screens can yield a significant boost in signal and whether that increased signal is, in fact, beneficial or detrimental to image quality. For rear metallic screens, this signal boost is differentiated from backscatter, and image quality considerations should be more carefully thought out because of the separation between the screen and the imaging layer provided by the imaging plate support. Various physical interactions are explained, and a series of practical experiments show the various changes in signal level and image quality with various thicknesses of lead and copper screens. Recommendations are made for the configuration of the imaging plate and screens for optimum image quality and for the control and monitoring of scatter.

1. Introduction

The use of lead screens with industrial X-ray films is a universal practice, providing a twofold improvement in imaging quality and efficiency. The lead absorbs low energy image-degrading X-ray scatter, and it also provides a source of low energy secondary electrons resulting from its interaction with the primary X-ray beam. These secondary electrons play an important part in image amplification, as the very thin film emulsions are quite inefficient in absorbing the primary high energy X-rays (at very low energies [<100 KeV], the lead will actually absorb and attenuate low energy X-rays, and hence, the lead screens are generally not used under such conditions). The end result is improved sharpness and more efficient techniques, i.e., shorter exposure times. Figure 1 shows the dramatic difference in a film radiograph made with and without lead screens.

The same is not true in computed radiography (CR), however. With CR, electrons generated within lead screens do not result in any appreciable gain or accelerated formation of latent image sites [1] at typical X-ray energies. Instead, the secondary electrons are readily absorbed by the thin overcoat that protects the sensitive phosphor layer. For this reason, protective coatings, or layers, on lead foil screens are not commonly used in film applications [2], but they remain a benefit in protecting imaging plates from the direct contact with lead. Figure 2 shows a CR image made on a general purpose storage phosphor imaging plate using an exposure technique identical to that used for the film radiograph in Figure 1. Note that the lead screens do not provide any amplification, and in fact, they attenuate the primary X-rays, resulting in a lower signal.

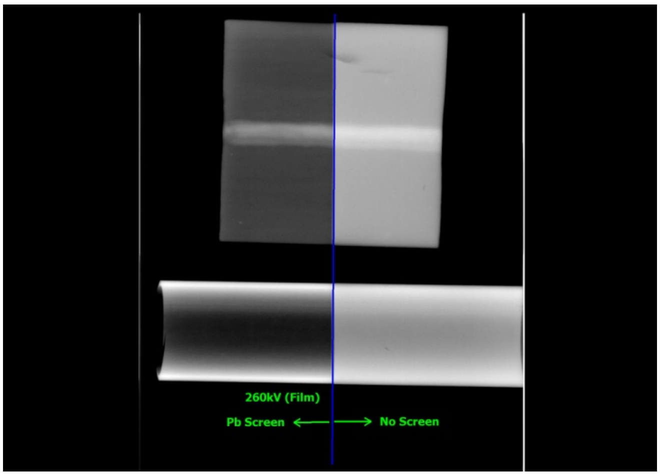

Fig. 1. Film radiograph showing the effect of Pb screens (left side of image) at 260 KeV X-ray

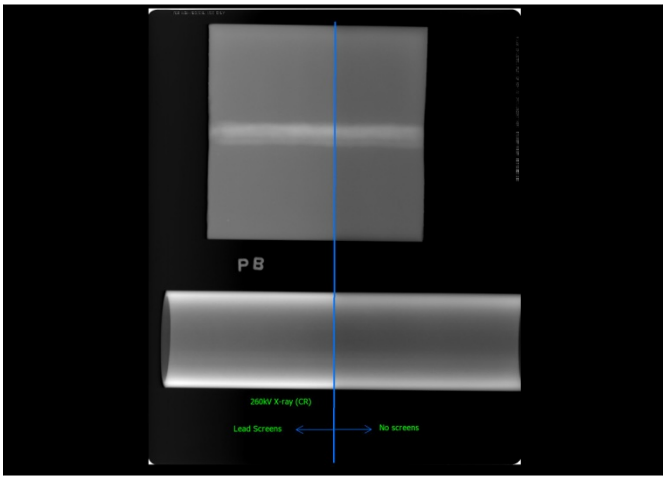

Fig. 2. CR radiograph showing minimal effect of Pb screens (left side of image) at 260 KeV X-ray

The physics get interesting at much higher energies (in the approximate range of 750 KeV and higher), where an increase in "classical scattering" within the lead foil produces more secondary emissions and scattered X-rays, resulting in increased latent image production (amplification). This is particularly important in gamma CR applications, because the "no appreciable amplification" rule no longer applies!

Let's take a closer look at these physical effects, how they affect image formation, and some simple experiments showing how they affect image quality in gamma computed radiography.

2. Simple Particle Physics

While a detailed review of particle physics is beyond the scope of this paper, a high level review is helpful in understanding how radiation interacts with matter. It's the basis of X-ray scattering, how we control it, and it explains the physical mechanism and functioning of the lead screens.

2.1 Photoelectric Effect

Also known as fluorescence, photoelectric effect occurs when an incident X-ray photon of sufficient energy (at least the binding energy of an electron shell) is completely absorbed by an atom, ejecting an electron from its shell. As stated above, such electrons have an amplification effect on film but minimal effect in CR, as they are readily absorbed by typical overcoats used on CR imaging plates. When an electron of a higher energy shell moves in to fill the vacancy, X-ray photons are produced. These X-rays are lower in energy (longer wavelengths) than the incident X-rays, and they are readily absorbed by the imaging plate. Because each atomic element is different, this radiation is called "characteristic" of that element, and it is the basis of elemental analysis by X-ray fluorescence. Figure 3 shows these interactions in the production of photoelectrons and characteristic X-rays. K, L, and M refer to the orbital electron energy levels.

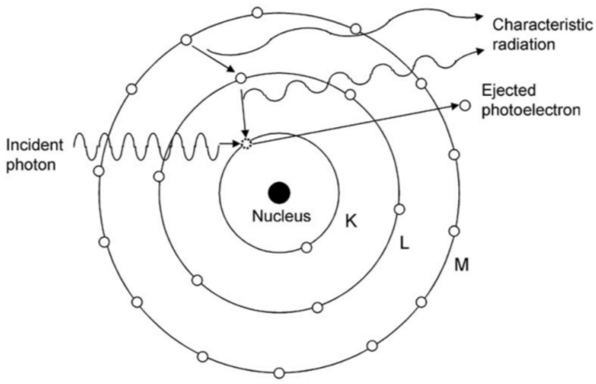

Fig. 3. Characteristic X-rays and photoelectrons produced by the Photoelectric Effect (from whs.wsd.wednet.edu)

While both of these emissions contribute to amplification in film systems, it is the characteristic radiation from the lead screen in gamma radiography that is primarily responsible for the amplification observed with CR imaging plates.

2.2 Compton Scattering

Upon increasing the photon energy (past the K edge), the process changes from the photoelectric effect to the Compton effect (Figure 4), in which a photon collides and shares

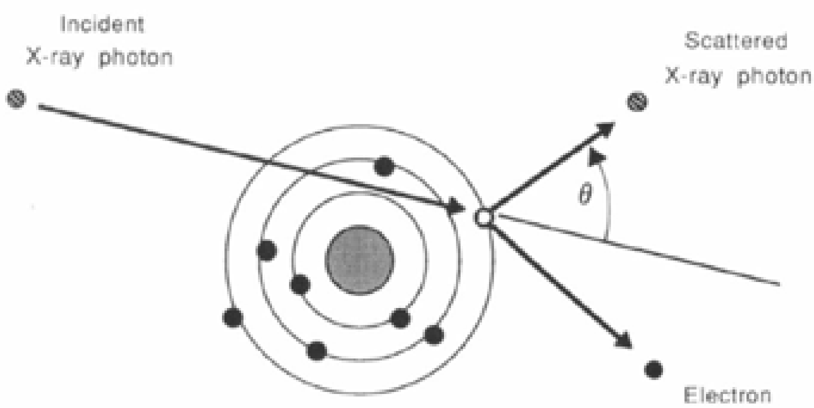

Fig. 4. Compton scattering (from www.jpi.co.kr)

its energy with an orbital electron, ejecting the electron and a scattered photon of lower energy than that of the primary photon [3]. The scattered photon usually travels in a different direction from the original photon and may be at any angle, even 180 degrees, to the direction of the original photon. This scattering contributes to unsharpness and a reduction in image quality. The ejected electron has low penetrating properties in most materials, and it is not considered part of the scattered radiation. We use lead screens to absorb and control this "classical" scattering that readily occurs in the part or material under inspection, as well as in any matter near or behind the detector (backscatter). Scattered radiation from the specimen itself is cut almost in half by the lead screens, contributing to maximum clarity of detail in the radiograph [4].

Note that in both photoelectric and Compton scattering cases, the energy released is lower than that of the incident X-ray, having important implications in computed radiography. The absorption efficiency of CR imaging plates is much higher at lower energies and decreases with increasing energies. Because of this, the plate will readily absorb this scattered energy, and its effect on image formation and quality bears careful consideration.

3. Practical Considerations in the Use of Lead Screens

3.1 Energy Level Dependence

3.1.1 Low Energy X-ray

One of the first considerations is whether or not to use screens at all, and at what energy levels. As stated previously, screens are not used at low X-ray energies, below about 100 KeV. At such low energies, there is relatively little Compton scatter to begin with, but more important is the attenuation by the screen itself, which reduces the photon quanta (amount) reaching the detector. This warrants an increase in exposure, which is counterproductive from a productivity standpoint. Figure 5 illustrates the effect of attenuation of lead screens at very low energy. This attenuation effect is observed in both film and CR applications.

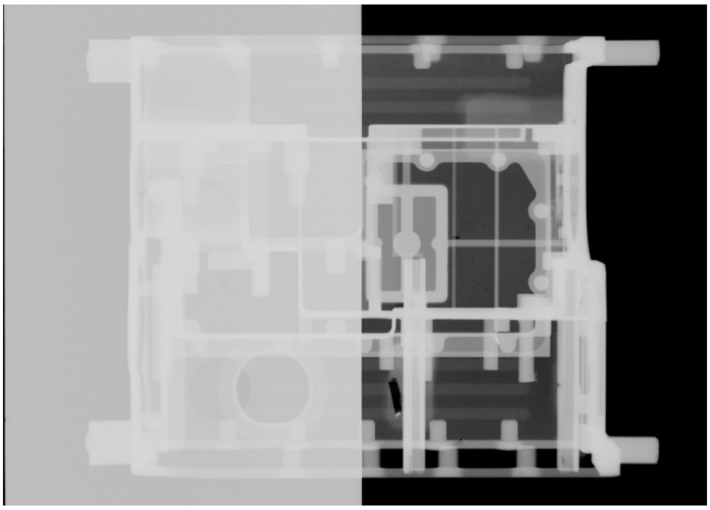

Fig. 5. Attenuation effect of Pb screens (left side of image) at 60 KeV X-ray

Such attenuation is well characterized and quantified in the technical literature. Figure 6, from a joint study by BAM and Applus RTD [5], shows the influence of front and back lead screens on image intensity at various X-ray energies. It is important to note that despite the attenuation of the thicker screens, the benefit of scatter control still applies.

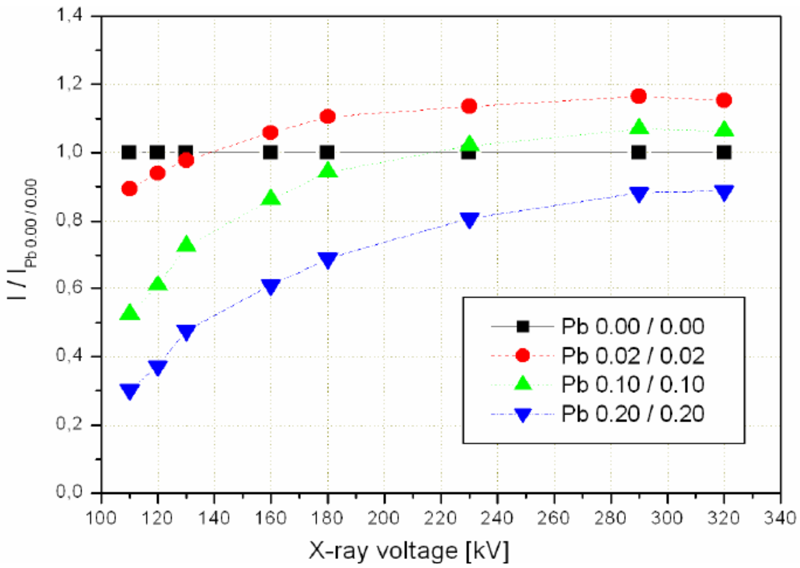

Fig. 6. Influence of Pb screens on image intensity as a function of screen thickness (mm) and KeV

3.1.2 Gamma Energy Considerations

Scatter control and gamma energy considerations become more important in the application of CR with gamma energies. High energy in this realm results in much more scatter—not only in the material under inspection but the backscatter as well—and even more so within the lead screen with increased production of characteristic X-rays (fluorescence). Unlike the behavior at lower energies, the "no appreciable amplification" rule is broken here, with notable increases in CR image intensity observed for both front and back screens in contact with CR imaging plates. Figure 7 shows this intensity amplification for various Pb screen thicknesses compared to no screens and a Cu screen (Ir192 exposures on HR imaging plate).

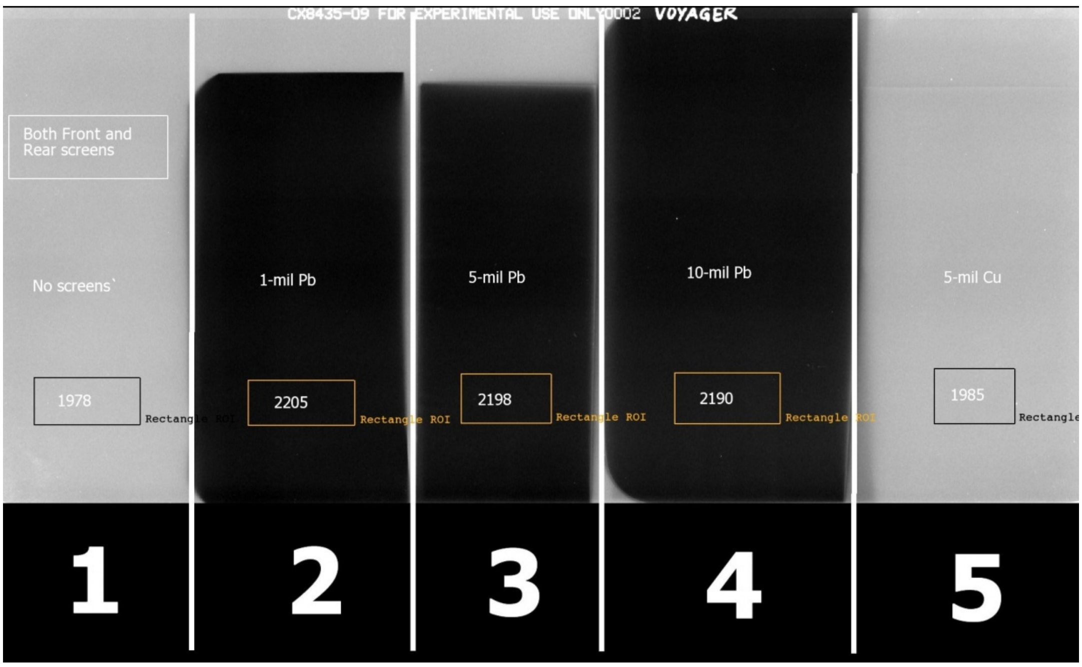

Fig. 7. Amplification of CR image intensity with Ir192 gamma source and front/back screens: (1) No screens;(2) .025 mm Pb; (3) .125 mm Pb; (4) .250 mm Pb; (5) .125 mm Cu

A few key points can be derived from Figure 7. One is that the lead screens impart a huge influence on image intensity with gamma exposures. Note that the signal amplification is greater with the thinnest screen, and it is less so with the thickest screen. This is due to the attenuation effect of the lead itself, consistent with Figure 6, as the thicker Pb attenuates a portion of its own characteristic emissions. Also of note is that the Cu screen does not produce any amplification. This is explained by the difference in characteristic X-ray emissions between the two elements: Pb emits at about 75-85 KeV and 11-15 KeV for K-band and L-band, respectively, while Cu emits at 8-9 KeV and 1 KeV [6].

The intensification (amplification) effect shown in Figure 6 is from both the front and back screens combined; however, there is a considerable difference between the front screens and the rear screens in their contribution to intensification. Intensification is greater with front screens, because they are in direct contact with the phosphor imaging layer, and the intensification decreases with increasing screen thickness, because the thicker screens attenuate their own fluorescence. With rear screens, overall intensification is less, but it increases with screen thickness, because the thicker screens absorb more of the primary beam and hence generate more fluorescence. Table 1 summarizes the normalized intensification factors (compared to no screens) for the four screens tested.

Table 1. Intensification factors for various front and rear screens

	No screens	.025 mm Pb	.125 mm Pb	.250 mm Pb	.125 mm Cu
Front Only	1	1.59	1.49	1.44	1.00
Rear Only	1	1.05	1.12	1.18	1.00
Front + Rear	1	1.67	1.64	1.61	1.02

It is now clear that gamma energies produce an abundance of characteristic X-ray emissions in lead screens, resulting in image intensification. An important question, then, is whether or not this increased signal has a positive or negative impact on CR image quality.

3.2 Effect on Image Quality

Because front screens are in close contact with the phosphor imaging layer, any intensification effect is considered "image-wise," and it is not detrimental to image quality, much like the role of screens in a close-contact film-screen application. While the increased signal contributes to a measurable increase in signal-to-noise ratio (SNR), practical effects on contrast-to-noise ratio (CNR) and other aspects of detectability are negligible. The primary role of the front screen is to absorb and control the scatter contribution from the material under inspection.

Emissions from the rear screen, on the other hand, must travel along a relatively long path through the polyester support of the imaging plate. With Compton scattering, the change in direction of these emissions, along that relatively long path, contributes to unsharpness where the image is ultimately formed. The challenge, then, in scatter control is to absorb the scatter with an efficient screen while minimizing the effect of any fluorescence and scatter from the screen itself. The absorption characteristics of lead screens make them the most popular for scatter control, and yet their fluorescence plays a competing role. A remedy is to incorporate a secondary screen between the lead screen and the imaging plate. The lead screen may remain for optimum scatter control, while the role of the secondary screen is only to block the emission from the lead screen.

This unsharpness effect from the lead screens at the back of an imaging plate has been well documented, for example, in a study by Ewert et. al. [7] for the European FilmFree Project, and it is shown in Figure 8.

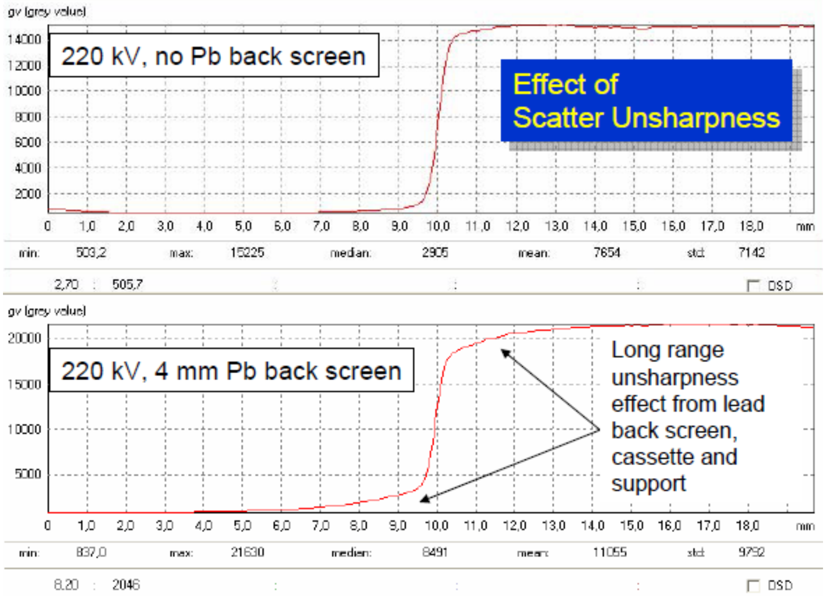

Fig. 8. Influence of rear Pb screens on image unsharpness (from European FilmFree Project)

More important is how this degradation in unsharpness affects detectability and radiographic sensitivity. The FilmFree Project showed a 14% decrease in Equivalent Penetrameter Sensitivity (EPS) and a loss of up to two wires on a standard EN 462-1 wire penetrameter. This can mean the difference between a successful and unsuccessful shot in code and other critical applications.

4. Summary and Recommendations

It has been shown that the fluorescence from rear lead screens in gamma computed radiography can adversely affect image quality and detectability. Still, the role of rear screens remains important in the absorption and control of backscatter radiation. The remedy is to keep the rear screen away from the rear of the imaging plate, and/or to block the fluorescence with a layer of copper or steel. Although the detriment to image quality is not huge, it can make a decided difference in cases where even experienced radiographers struggle with obtaining "threshold" sensitivity. For this reason, industry standards now recommend [8] or even require [9] that additional shielding of steel or copper be applied between the rear lead shield and the detector to reduce the influence of lead X-ray fluorescence radiation, and that no lead screens shall be used in contact with the back side of the detector for radiation energies above 80 KeV. Where flexibility of the imaging plate/cassette combination is important, this can be accomplished with a copper foil of only .125 to .250 mm.

5. Acknowledgements

The author wishes to thank Carestream physicists, Pavlo Baturin, PhD, and Samuel Richard, PhD, for their advice, review, and mentorship in "Physics 101."

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