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Investigation of the effect of metallic screens on image quality in gamma computed radiography

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Abstract. The role of metallic screens in computed radiography for controlling scattered radiation is very well-known. Likewise, the intensification effects of certain lead screen thicknesses with higher X-ray energies, such as those produced by gamma isotopes is also a topic that has been recently investigated in literature. This paper extends this topic further and quantitatively investigates how image quality in terms of signal-to-noise ratio (SNR) and basic spatial resolution (SR_b) is influenced by metallic screens when Iridium-192 is used as the radiation source. The result data is then used to make recommendations to achieve optimum image quality when using Iridium-192.

1. Introduction

1.1. Previous Work

This study is largely inspired by a 2016 paper [1] by Steven Mango which investigated a similar topic and provided the following conclusions and recommendations:

(1) Lead screens have a huge influence on image intensity (pixel value) in gamma exposures, especially with higher-energy isotopes such as Iridium-192. Specifically, thin lead front screens produce a greater intensification effect (maximum intensification at 0.125 mm thickness) compared to thick lead front screens. This effect is also present with rear lead screens but conversely thicker screens give more intensification than thinner screens (maximum intensification at 0.250 mm thickness). Furthermore, copper screens do not produce this intensification effect at all.

(2) This intensification is desirable in front screens as it produces an increase in image signal-to-noise ratio (SNR). However, in the case of rear screens, it is undesirable as it could cause increased unsharpness (reduced SR_b) due to the fact that it is primarily low-energy scatter radiation incident on the rear of the imaging plate that is being amplified.

(3) Consequently, the rear lead screen should not be in direct contact with the imaging plate, but instead an additional shielding of copper (between 0.125 mm and 0.250 mm is sufficient) or steel should be placed in-between in order to absorb this undesirable fluorescence produced by the lead screen.

1.2. Aims
This paper has the following aims:
- To confirm the aforementioned main findings of [1].
- To quantitatively measure the effects of various metallic screen thicknesses and types on image quality by measuring signal-to-noise ratio (SNR) and basic spatial resolution (SR_b) as well as the associated pixel value.
- To propose practical recommendations for using metallic screens with Iridium-192 based on the result data.

1.3. Theory
Although the detailed physics involved in the interaction between X-ray radiation and matter is beyond the scope of this paper, it important to understand on a high level the reasons why screens may be used in digital radiography. This topic is explored in more detail in [1] and can serve as a useful additional introduction.

1.3.1. Scattered Radiation
When a photon with sufficiently high energy collides with an orbital electron of an atom within a given material, the electron is ejected and the photon "scatters" in a different direction and with a lower energy. These scattered photons are of interest due to the fact that imaging plates have higher absorption efficiency at lower radiation energies and therefore low-energy photons traveling in an altered direction (compared to the primary X-ray beam) may have a significant effect on image quality. Thin lead screens are typically used both on the front and back of the imaging plate to absorb these undesirable photons.

1.3.2. Fluorescence

Fluorescence also known as the photoelectric effect. In this case, the incoming photon is completely absorbed by the atom when it collides with the electron (which is then ejected and becomes a "photoelectron"). Lower energy photons are produced when an electron from a higher shell drops down to the lower shell to fill the vacancy created by the ejected electron – the energy of these photons depends on the energy level difference between the two electron shells (which is characteristic for a given element). Like before, this low-energy radiation is readily absorbed by the imaging plate. For the X-ray energy levels typically used in industrial radiography, the energy required to eject electrons from the innermost shell (i.e. most strongly bounded electrons) is most relevant – the energy at which this begins to occur is known as the "K-edge" and differs depending on the material. As we increase the incoming X-ray energy above the K-edge, the probability of this photoelectric absorption occurring decreases. Note: As the K-edge of lead is approximately 88 keV (compared with 9 keV for copper), we can expect to observe this fluorescence when using lead screens in industrial radiography.

2. Methodology
2.1. Exposure Setup
In order to accurately measure the effect various screen types and thicknesses have on image quality, it is necessary to carefully ensure that any parameter that could potentially change the image quality is kept constant while the only variable that changes is the screen setup. Figure 1 and Table 1 detail the setup used throughout the entire experiment.

The following considerations were also taken to further ensure reliable data:
- All exposures were taken in a single day (over a 9-hour period) in order to reduce the influence of reducing isotope source activity.
- The same location and equipment (imaging plate, computed radiography scanner, screens, gamma source, etc.) was used throughout the entire experiment.

- The imaging plate was scanned immediately after the exposure and was read by the scanner in same orientation/direction in every scan.
- A lower sensitivity imaging plate (HD-IP) was used in combination with a longer exposure time (as opposed to a high-sensitivity IP and short exposure time) in order to reduce the influence of any slight variations in exposure time (i.e. dosage).
- The object was placed directly on top of a 16.3 mm wood board in order to allow scatter radiation to reach the rear of the imaging plate.
- The stackup from the source-side was as follows: Pb → Cu → Object → IP → Cu → Pb

Table 1. Exposure setup

Radiation Source	
Type	Iridium-192 (with collimator)
Activity	25.19 Ci
Focal Size	3 mm
Object	
Material	Stainless Steel (SS304)
Thickness	10 mm
Setup	
Imaging Plate	10x24 cm HD-IP
Source-to-Object Distance	300 mm
Exposure Time	4:00 min
Scanner	
Type	DÜRR NDT HD-CR 35 NDT
Laser Size	25 µm
Reading Pitch	25 µm

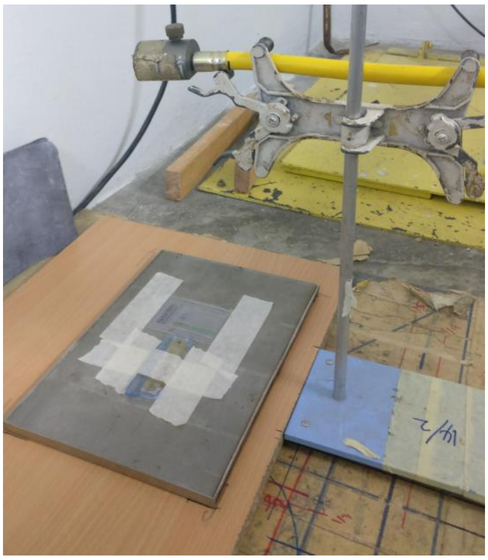

Figure 1. Exposure setup

2.2. Image Quality Measurement

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For each screen setup, a single exposure was performed and the following image quality metrics were measured using the DÜRR NDT D-Tect image analysis software:

2.2.1. Signal-to-Noise Ratio (SNR)
Mean value of 5 different areas (each with dimensions of 100x100 pixels).

2.2.2. Pixel Value.
Mean value of same 5 areas used for the SNR measurements.

2.2.3. Basic Spatial Resolution (SR_b). Measured using a source-side duplex wire IQI in accordance to ISO 19232-5 [2]. The modulation (dip) for duplex wire pairs 1D to 5D was measured over the entire width of the IQI (651 pixel lines) and the average of these five values was recorded as a measure of the image basic spatial resolution (Note: The 2nd-order interpolation method was not used as it consistently yielded incorrect results when performed with only five duplex wire pairs).

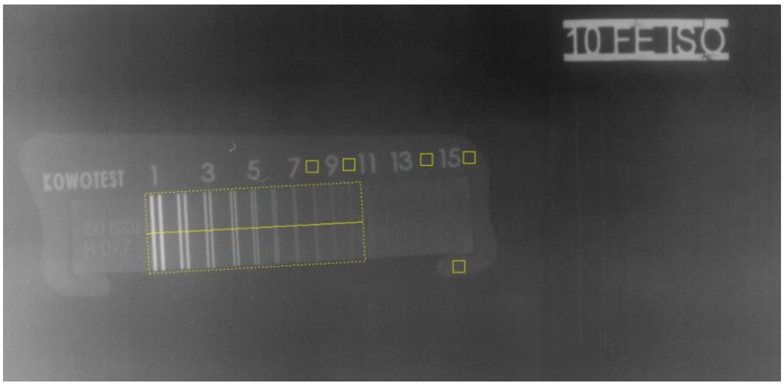

Figure 2. Cropped digital X-ray image from D-Tect software showing the areas of measurement.

3. Results
All result data is normalized to an exposure with no front and no rear screens. Furthermore, all graphs have been plotted with the same y-axis (vertical axis) range so that the relative effects of each screen configuration can be visually compared easily. For reference, the numerical value for each plotted data point can be found in the summary table (Table 2) at the end of this section.

3.1. Front Screen Only

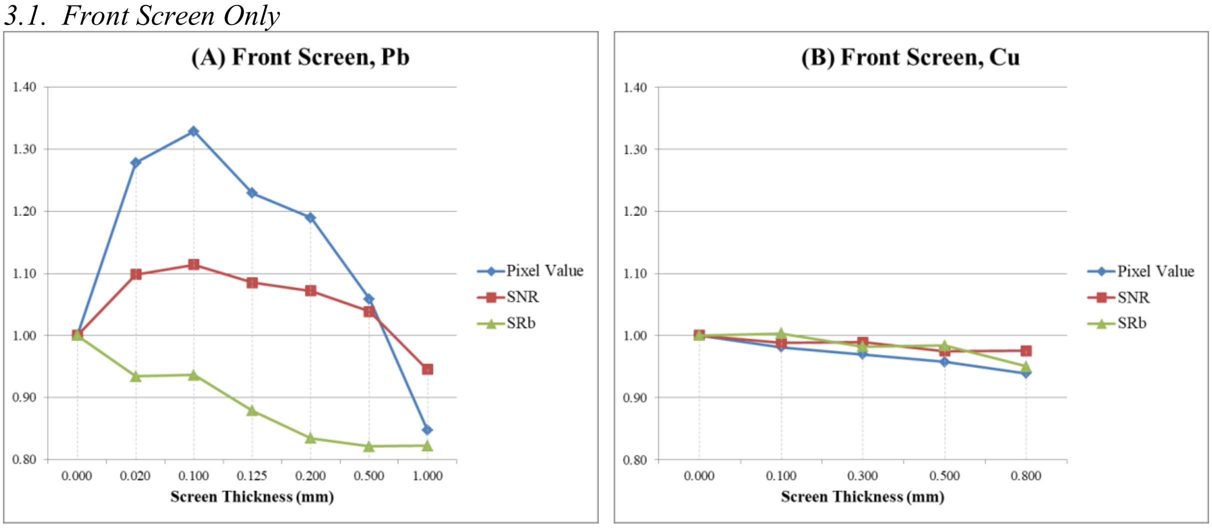

Figure 3. Effects of lead (A) and copper (B) front screen thickness on image quality.

3.1.1. Observations

- As expected, a higher pixel value corresponds to a higher image signal-to-noise ratio (SNR). This correlation is non-linear.
- Only lead screens provide intensification - copper front screens do not produce any intensification at all (instead they only attenuate the incoming radiation).
- Intensification due to the lead screen increased until a maximum at 0.100 mm thickness. The incoming radiation began to be attenuated at a lead screen thickness of between 0.500 mm and 1 mm.
- Basic spatial resolution (SR_b) seemed to decrease with lead screens until the intensification effect was no longer present (which can be interpolated to occur at slightly above 0.500 mm lead thickness).
- Compared to lead screens, copper screens gave significantly less degradation in basic spatial resolution (SR_b).

3.2. Rear Screen Only

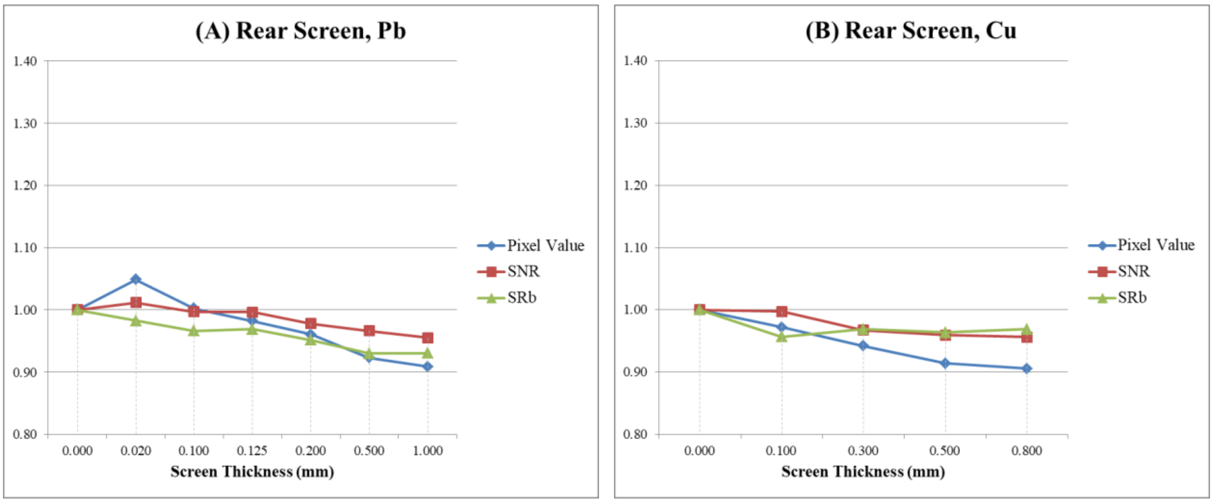

Figure 4. Effects of lead (A) and copper (B) rear screen thickness on image quality.

3.2.1. Observations

- As in the case with front screens, only lead rear screens provide intensification (not copper); however, the effect is dramatically less for rear screens compared to front screens. Both 0.020 mm and 0.100 mm lead screens provided marginal intensification – thicknesses above this attenuated the radiation.
- As expected, pixel value is strongly correlated to the signal-to-noise ratio (SNR).
- Both lead and copper screens did not seem to improve the basic spatial resolution (SR_b); however, the degradation was much less with copper.

3.3. Front & Rear Screen

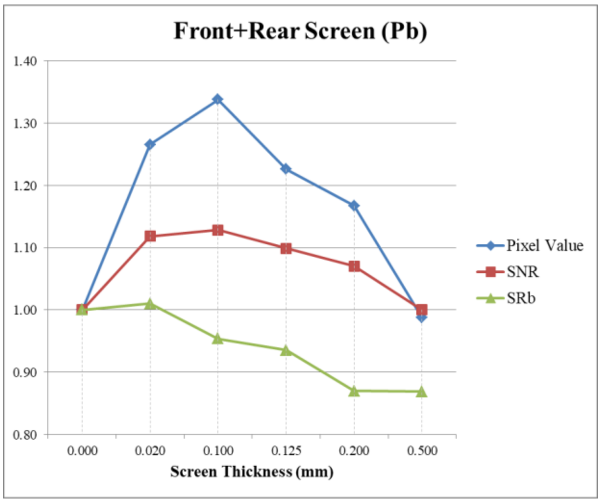

Figure 5. Effects of front and rear lead screen thickness on image quality.

3.3.1. Observations

- The overall results match closely to what we would expect if we combined together the previous results for front lead screen (Figure 3A) and rear lead screen (Figure 4A).
- Basic spatial resolution (SR_b) is better when a rear lead screen is used (as opposed to using only a front lead screen).

3.4. Practical Screen Combinations

Since a 0.100 mm lead screen was found to produce the most intensification, the effects of using this particular thickness with various copper screen thicknesses were investigated for both the front and rear of the imaging plate.

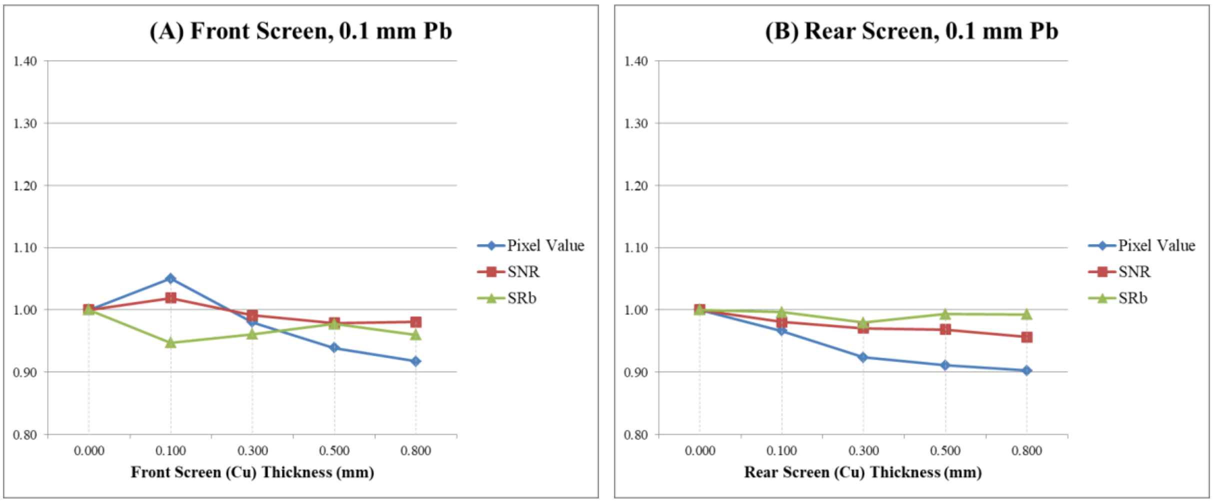

Figure 6. Effects of varying the front screen (A) and rear screen (B) copper thickness on image quality. A 0.100 mm lead screen is used in both cases. Note: The 0.000 mm Cu thickness data corresponds to the no screen exposure.

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3.4.1. Observations

- In comparison to using only a lead screen, the use of a copper screen in between the imaging plate and lead screen improved the basic spatial resolution (SR_b). This was the case for both the front and rear of the imaging plate.
- All of the fluorescence produced by the 0.100 mm front lead screen is absorbed by a copper screen with thickness 0.300 mm and above.
- With a rear copper screen thickness of 0.300 mm in combination with a 0.100 mm lead screen, most of the radiation incident on the rear of the imaging plate can be attenuated (i.e. pixel value decreases only slightly for copper screen thicknesses above this).

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4. Data

Table 2. Complete result dataset (Note: Empty cells correspond to 'no screen').

Figure	Front Screen (mm)		Rear Screen (mm)		Pixel Value	SNR	SR_b
	Pb	Cu	Pb	Cu			
-					1.00	1.00	1.00
3A	0.020				1.28	1.10	0.93
	0.100				1.33	1.11	0.94
	0.125				1.23	1.08	0.88
	0.200				1.19	1.07	0.83
	0.500				1.06	1.04	0.82
	1.000				0.85	0.95	0.82
3B		0.100			0.98	0.99	1.00
		0.300			0.97	0.99	0.98
		0.500			0.96	0.98	0.98
		0.800			0.94	0.98	0.95
4A			0.020		1.05	1.01	0.98
			0.100		1.00	1.00	0.97
			0.125		0.98	1.00	0.97
			0.200		0.96	0.98	0.95
			0.500		0.92	0.97	0.93
			1.000		0.91	0.96	0.93
4B				0.100	0.97	1.00	0.96
				0.300	0.94	0.97	0.97
				0.500	0.91	0.96	0.96
				0.800	0.91	0.96	0.97
5	0.020		0.020		1.27	1.12	1.01
	0.100		0.100		1.34	1.13	0.95
	0.125		0.125		1.23	1.10	0.94
	0.200		0.200		1.17	1.07	0.87
	0.500		0.500		0.99	1.00	0.87
6A	0.100	0.100			1.05	1.02	0.95
	0.100	0.300			0.98	0.99	0.96
	0.100	0.500			0.94	0.98	0.98
	0.100	0.800			0.92	0.98	0.96
6B			0.100	0.100	0.97	0.98	1.00
			0.100	0.300	0.92	0.97	0.98
			0.100	0.500	0.91	0.97	0.99
			0.100	0.800	0.90	0.96	0.99

5. Conclusions

Since the data collected in this investigation is largely dependent on the exposure setup, the following findings may not apply to every inspection scenario; nevertheless, they should serve as a useful starting point when using Iridium-192:

(1) A 0.100 mm front lead screen gives the largest intensification effect (>30% increase in pixel value resulting in a >10% increase in SNR).
(2) There is a trade-off when using a copper front screen in combination with a lead front screen:
   a. The benefit of increased SNR due to the intensifying effect (fluorescence) of the lead screen as mentioned previously in (1) is almost eliminated.
   b. However, a copper screen will give a slightly sharper image (in comparison to using only a lead screen).
(3) Using a 0.100 mm lead screen with a 0.300 mm copper screen on the rear of the imaging plate provides approximately the same amount of backscatter attenuation as a single 0.500 mm lead screen. This rear screen combination also produces a sharper image (in comparison to using only a lead screen).

Considering that it is always desirable to reduce the exposure time for radiation safety reasons (in particular when using a portable gamma isotope such as Iridium-192), the use of a 0.100 mm front lead screen is a simple way to achieve this while still allowing imaging plate flexibility if inspecting curved objects.

Moreover, the overall findings mostly match those of [1]; however, the experiment presented in this paper measured significantly lower rear lead screen intensification and furthermore, increasing the rear lead screen thickness did not produce increased intensification (but instead attenuated the radiation).

5.1. Future Work

In almost all screen setups, basic spatial resolution (SR_b) was measured to be lower than what was achieved when using no screens at all. It was not tested whether increasing the dose could have compensated for this slight reduction in sharpness due to the use of screens; thus, a further experiment could investigate whether using for example a copper front screen with a longer exposure time increases the image sharpness (and if so, to what extent).

Furthermore, any future similar study should ideally use averaged data from multiple identical exposures in order to improve the accuracy of the results (due to time constraints this was not possible in this experiment).

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[2] *Non-destructive testing – Image quality of radiographs, Part 5: Determination of the image unsharpness and basic spatial resolution value using duplex wire-type image quality indicators*, ISO 19232-5, 3rd ed., Aug 2018