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Quantifying Copper Thickness Equivalence to Regulatory and Anatomical Phantoms In Fluoroscopy

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ABSTRACT

Fluoroscopic system exposure rates are evaluated using a patient-equivalent phantom such as 7 7/8 inches of Lucite. This study evaluates whether thin copper (Cu) sheets can replicate the displayed air-kerma rate (AKR) of a Lucite phantom and an anatomical pelvis phantom, offering a lightweight alternative for routine evaluations.

Displayed AKR values were recorded using the Lucite phantom across multiple fluoroscopic systems including two GE OEC mobile C-arms, a Philips interventional radiology (IR) unit, and a Siemens cystography unit.

Using thin copper sheets, a copper thickness of 3.9 mm best matched the anatomical phantom for each unit evaluated. For the Lucite phantom, 3.5 mm Cu best matched the mobile C-arms, while 3.6 mm Cu best matched the IR and cystography systems.

Copper sheets provide a lightweight, inexpensive alternative to traditional phantoms. Further testing across additional fluoroscopic systems to verify similar results is recommended before phantoms can be reliably replaced.

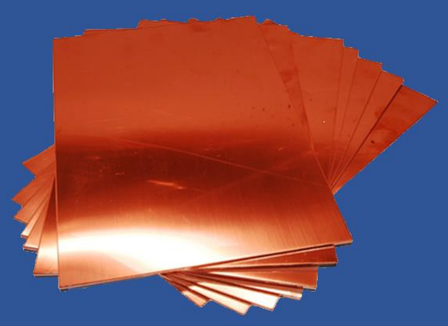

Figure 1. Stacked copper sheets used in place of regulatory and anatomical phantoms to determine a copper thickness that produces similar Automatic Exposure Control response across various fluoroscopic systems.

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INTRODUCTION

California regulations require the useful beam exposure rate of all fluoroscopic systems to be determined using a phantom equivalent to 9 inches of water or 7 7/8 inches of Lucite [1].

These phantoms are bulky and difficult to transport for annual physics evaluations. Determining a copper thickness that produces a similar Automatic Exposure Control (AEC) response would simplify routine testing.

Since regulatory requirements differ outside of California, an anatomical pelvis phantom was also evaluated to provide a clinically relevant reference.

We sought to determine the copper thickness required to reproduce the displayed exposure rates of a patient-equivalent Lucite phantom and an anatomical pelvis phantom (Fig. 2).

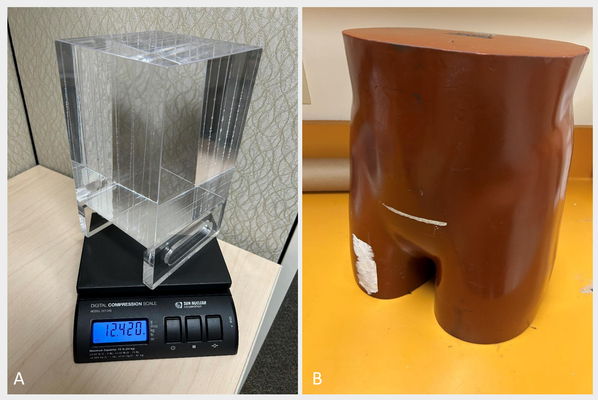

Figure 2. Phantoms used as references.
(A) Lucite phantom that meets local regulatory requirements.
(B) Anatomical phantom, mimics a patient pelvis.
(C) Fluoroscopic image of the internal structures of the anatomical phantom.

METHODS AND MATERIALS

- Displayed AKRs from four fluoroscopy systems were recorded using the Lucite phantom. The difference in displayed AKR between the anatomical and Lucite phantoms on one system was assumed to remain consistent across other systems.
- Thin copper sheets (Fig. 1) were stacked in 0.1-mm increments, from 3.2 mm to 4.0 mm total thickness. Exposures were acquired with a consistent field size at each increment. For each copper thickness, the system-displayed AKR (mGy/min) was recorded.
- Displayed AKR values were averaged over three exposures. The deviation in displayed AKR using copper compared to Lucite was quantified using percent difference.

RESULTS

- The anatomical phantom produced a 15.17% increase in displayed AKR compared to the Lucite phantom.
- For the anatomical phantom, 3.9 mm Cu best reproduced the displayed AKR on each system (Fig. 3).
- For the Lucite phantom, 3.5 mm Cu best reproduced the displayed AKR on the OEC 3D and OEC 9900 Elite C-arms. 3.6 mm Cu best reproduced the displayed AKR on the Philips Allura Xper IR system and the Siemens Uroskop Access cystography system (Fig. 4).
- This evaluation was also performed for a Ziehm Vision RFD 31 C-arm, but similar copper thicknesses yielded displayed AKRs between 45% and 200% higher for both phantoms. These results were omitted from the figures.

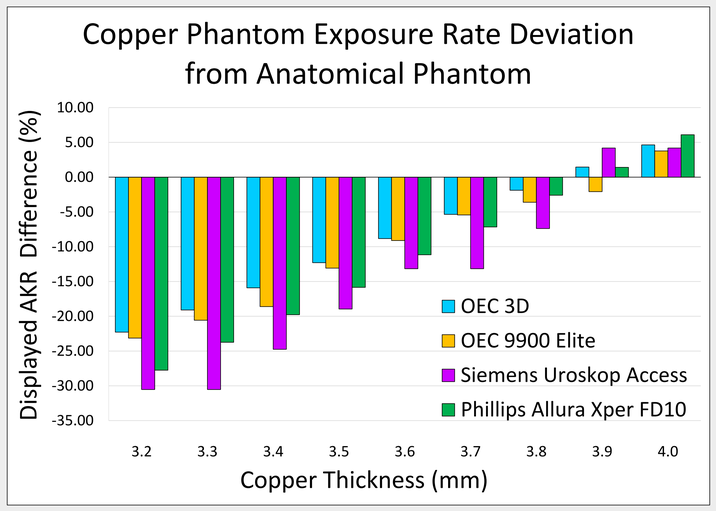

Figure 3. Copper phantom exposure rate deviation from an **anatomical phantom** for four fluoroscopic imaging systems. Bars represent mean AKR difference (%) at each copper plate thickness (3.2 - 4.0 mm).

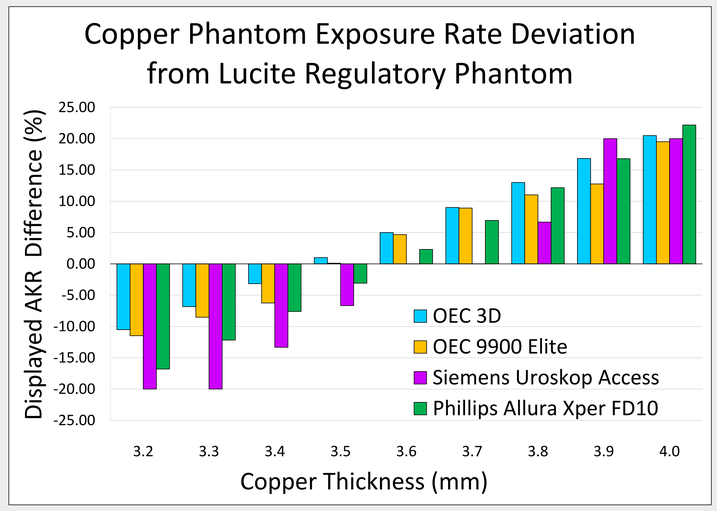

Figure 4. Copper phantom exposure rate deviation from a Lucite **regulatory phantom** for four fluoroscopic imaging systems. Bars represent mean AKR difference (%) at each copper plate thickness (3.2 - 4.0 mm).

REFERENCES

1. Cal. Code Regs. Tit. 17, § 30307 (2026).
2. Jensen, Stephanie et al. “Not All Flat-Panel C-Arms Are Created Equal: A Comparison of Three Major Manufacturers.” Journal of endourology vol. 38,3 (2024): 228-233. doi:10.1089/end.2023.0537

DISCUSSION

With the cystography unit, the displayed AKR increased only in fixed 1.0 mGy/min increments, which suggests reduced display precision. This stepwise behavior is likely due to more rigid internal thresholds for updating the AKR value.

Given this limitation of the Siemens cystography unit and the similar absolute deviation observed in the Philips IR unit, 3.5 mm Cu is an appropriate substitute to the Lucite phantom for all systems.

For the anatomical phantom, 3.9 mm Cu is ideal for mimicking the AEC response for all systems tested. Because prefabricated copper sheets are commonly available in 0.5 mm increments, 4.0 mm Cu may be more readily available. This would cause a modest increase in the displayed AKR deviation (Fig. 3).

Although Ziehm C-arms have been reported to produce higher radiation exposure than C-arms from other manufacturers [2], this alone does not explain the differences observed in copper equivalence. Additional test exposures ruled out field-size effects as a contributing factor. Ultimately, 2.4 mm Cu best matched the Lucite phantom’s displayed AKR, indicating that Ziehm systems exhibit vendor-specific AEC behavior that does not align with other units evaluated.

CONCLUSIONS

- Copper phantoms can potentially replace anatomical or regulatory phantoms. Replacing these phantoms with flat, lightweight, copper sheets would substantially simplify transport and routine use.
- 3.5 mm and 4.0 mm copper phantoms represent practical and cost-effective alternatives to regulatory and anatomical phantoms, respectively.
- The anatomical phantom used weighs 25 kg and costs approximately US$8,500. An equivalent 4.0-mm-thick, 15 x 15 cm copper sheet weighs under 1 kg, is available for under US$100, and is considerably easier to store and carry.
- Further validation across additional fluoroscopic systems, including Rad-Fluoro systems and cardiac catheterization labs, is necessary before widespread adoption.

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