RPE | Radiation Physics & Engineering
A Peer-Reviewed Journal
Published by K.N. Toosi University of Technology
http://rpe.kntu.ac.ir
Research Article

Radiation Physics and Engineering 2026; ?(?):?–?

Computational investigation of the effect of polyethylene and aluminum sample thickness on neutron radiography using emulsion films

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HIGHLIGHTS

- Monte Carlo simulation of neutron radiography using emulsion films.
- Polyethylene and aluminum samples were comparatively analyzed.
- mage quality variations with sample thickness were evaluated.

ABSTRACT

Neutron radiography is a non-destructive imaging technique used to study the internal structures of materials. In this work, a computational investigation was conducted to evaluate the effect of sample thickness on neutron radiography of polyethylene- and aluminum-based samples using emulsion films. The MCNPX 2.7.0 code was employed to simulate the imaging geometry, including the sample, gadolinium converter, and emulsion film, for both polychromatic and monochromatic neutron beams. Sample thicknesses of 2, 4, and 6 cm were analyzed, and the contributions of neutrons and gamma rays to image formation were quantified through (n, γ) reaction rates and gamma deposited energy in the emulsion layer. Results show that increasing sample thickness reduces image quality, particularly for polyethylene due to its high thermal neutron scattering. Gamma-induced images provide improved contrast for thicker samples, moreover this imaging would result in better contrast and resolution than neutron imaging of the thicker investigated samples. The computational investigations showed there is noticeable differences between the samples' images formed by monochromatic and polychromatic neutron beams. These findings provide insights for optimizing imaging conditions, and detector selection in neutron radiography studies.

KEYWORDS
Neutron radiography
Gadolinium Converter
Emulsion film
Sample thickness
MCNPX

HISTORY
Received:
Revised:
Accepted:
Published:

1 Introduction

Neutron radiography (NR) is a non-destructive imaging technique analogous to X-ray radiography, but it exploits the interaction of neutrons with matter, offering high sensitivity to light elements and the ability to penetrate heavy metals (Wei, 2012). Indirect neutron radiography (INR) using neutron converters combined with detection media, such as X-ray films or imaging plates (IP), enables both qualitative and quantitative analysis of complex samples (Wei et al., 2015). In the film-based approach, emulsion films containing silver halide crystals capture the image, while in indirect neutron radiography, a neutron converter -commonly materials with high thermal neutron cross sections such as gadolinium, dysprosium, boron-10, or lithium-6- is placed in contact with the film (Morgan et al., 2013; Kljuev, 2001). Thermal neutrons interacting with the converter produce secondary radiation, including internal conversion electrons and gamma-related particles, which expose the film and enable high-resolution imaging, although gamma sensitivity can influence image contrast (Soltes et al., 2017). Compared with traditional films, IPs offer several advantages, including shorter exposure times, a wide linear dynamic range, and digital quantification, facilitating both qualitative and quantitative analysis of complex samples (Wei et al., 2015). Previous studies at the China Advanced Research Reactor (CARR) demonstrated that INR with imaging plates allows precise evaluation of sample features, including industrial sensors and dummy nuclear fuel rods, while reducing total exposure time to less than half that required with conventional films (Wei et al., 2015). Complementary research at low-power and educational reactors, such as VR-1 and LVR-15 in the Czech Republic, has confirmed that self-developing X-ray

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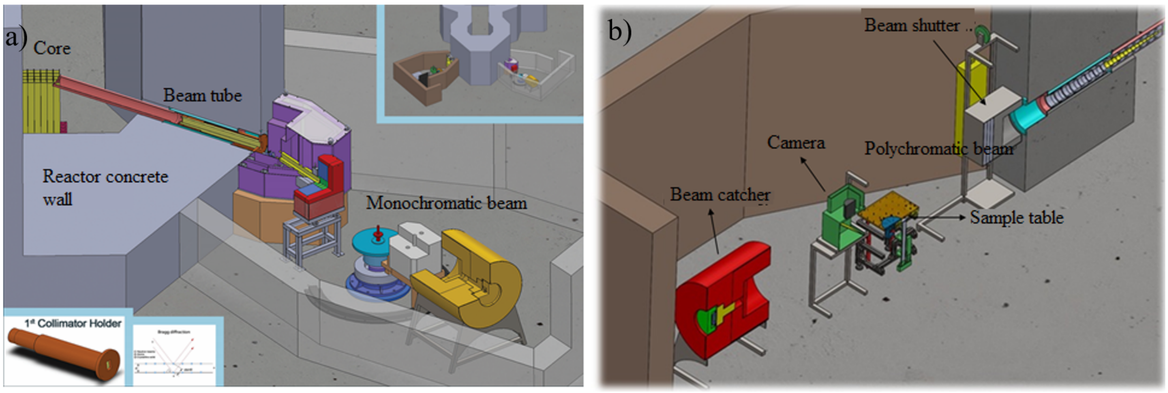

Figure 1: Schematic view of the Tehran Research Reactor (TRR) neutron facilities: a) Neutron diffraction setup using a monochromatic neutron beam. b) Neutron radiography setup using a polychromatic neutron beam.

films can provide a simple, portable, and cost-effective tool for thermal neutron imaging, although their efficiency is limited for epithermal and resonance neutrons, and spatial resolution may decrease when using converters like gadolinium (Soltes et al., 2017). Collectively, these investigations highlight the balance required between detector sensitivity, exposure time, and image resolution, emphasizing the need for optimized experimental setups for both educational and research applications in neutron radiography.

The quality and contrast of neutron radiographic images are strongly dependent on the sample thickness, since neutron transmission decreases with increasing material thickness according to the exponential attenuation law. Consequently, variations in thickness directly affect the intensity of the transmitted neutron beam and the resulting image quality (Hassanein et al., 2005).

In this study, a computational investigation of polyethylene and aluminum samples with varying thicknesses is carried out to evaluate their impact on neutron- and gamma-induced image formation in emulsion film-based INR. The results provide insight into the relationship between sample geometry, material properties, and image resolution, which is critical for optimizing INR experiments.

2 Material and Methods

The neutron radiography experiments were conducted at the Tehran Research Reactor (TRR), which is equipped with a dedicated neutron radiography laboratory. This facility provides both digital and film-based imaging capabilities. A schematic view of the laboratory setup is shown in Fig. 1.

The MCNPX2.7.0 computational code was employed to model the neutron radiography setup. The SDEF card was used to define the neutron and gamma sources, while only the sample, converter, and emulsion film were included in the imaging geometry. These components were modeled to simulate their exposure to neutron and gamma beams, as illustrated in Fig. 2.

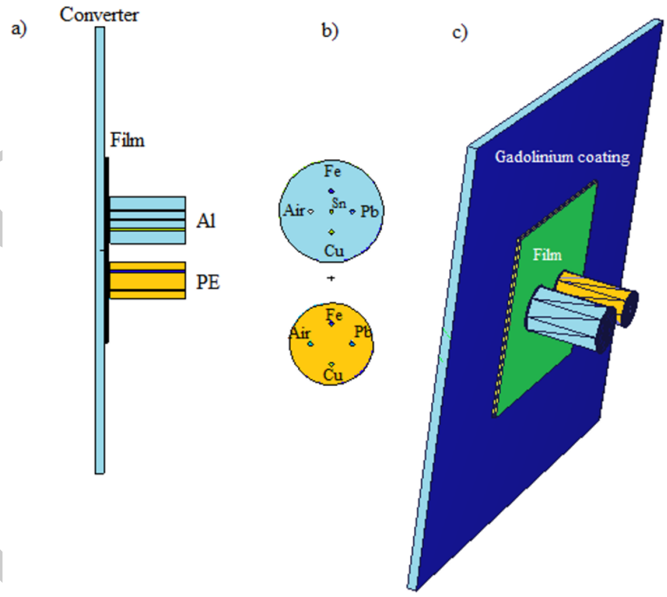

Figure 2: MCNPX 2.7.0 simulation of polyethylene- and aluminum-based samples: a) Axial view of the modeled samples. b) Cross-sectional view of the two modeled samples c) 3D view showing the aluminum sample with five 1 mm holes and the polyethylene sample with four 1 mm holes.

The aluminum sample has a diameter of 2.5 cm and contains five 1-mm holes filled with lead, copper, iron, air, and tin. The polyethylene sample has a diameter of 2.0 cm and includes four 1-mm holes filled with lead, copper, iron, and air. To investigate the effect of sample thickness on image resolution, the thickness of both samples was varied at 2 cm, 4 cm, and 6 cm. Both neutron and gamma particles contribute to image formation in the emulsion layer. Therefore, the (n, γ) reaction rate inside the gadolinium converter and the gamma deposited energy in the emulsion layer were evaluated using the mesh tally feature of MCNPX. This allowed quantitative analysis of neutron- and gamma-based contributions to image formation as a function of sample thickness. Since the TRR facility is also equipped with a monochromatic neutron beam, a comparison was made between the image quality produced by the polychromatic TRR beam and the monochromatic beam for the 2 cm thick sample. In the monochromatic beam

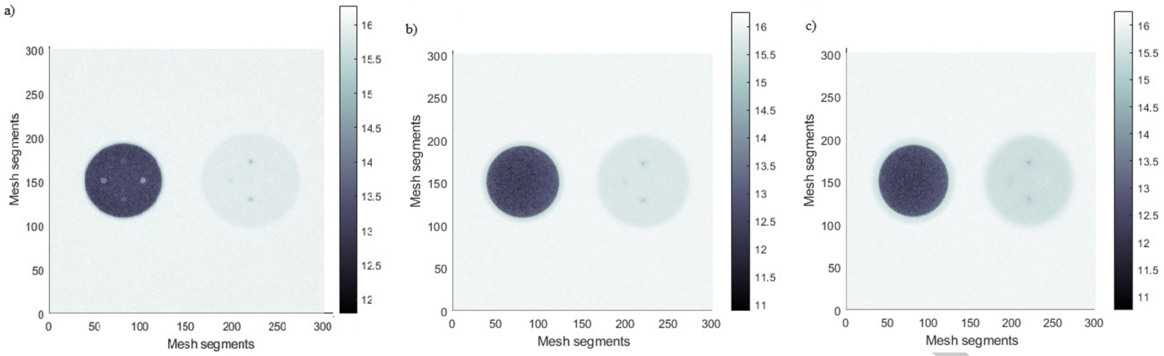

Figure 3: Simulated polychromatic (n,γ)-induced images of polyethylene- and aluminum-based samples with varying thicknesses: a) 2 cm thickness, b) 4 cm thickness, c) 6 cm thickness

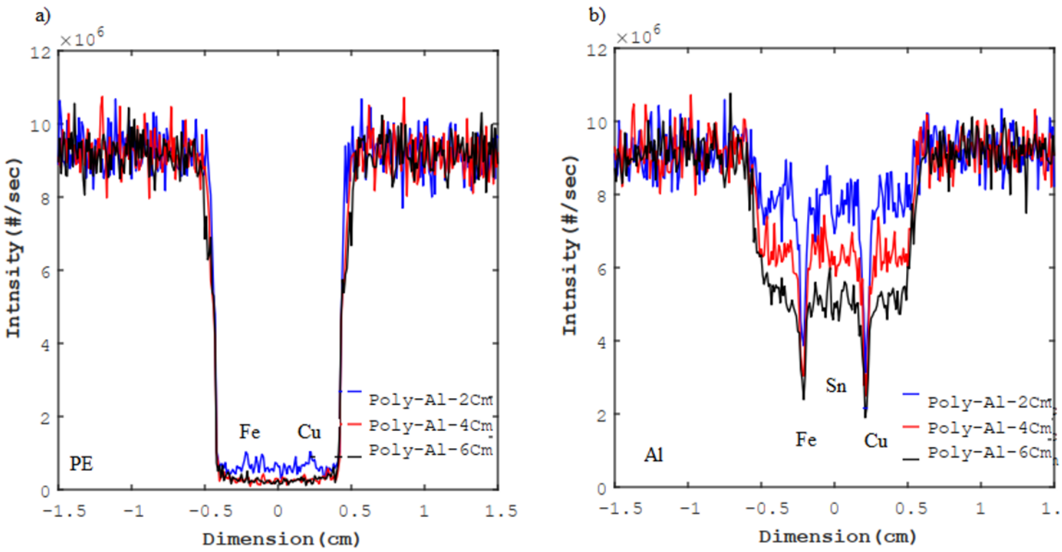

Figure 4: One-dimensional X-axis profiles of polychromatic (n,γ)-induced images for polyethylene- and aluminum-based samples with varying thicknesses: a) Polyethylene samples, b) Aluminum samples, Blue: 2 cm, red: 4 cm, black: 6 cm.

setup, no gamma rays are present to contribute to image formation, allowing an isolated assessment of neutron-induced imaging.

3 Result and Discussion

The simulated images, representing the (n,γ) reaction rate inside the gadolinium converter, demonstrate that increasing the sample thickness from 2 cm to 4 cm and 6 cm leads to a noticeable decrease in image quality. This effect is particularly pronounced for the polyethylene-based sample due to its high thermal neutron scattering properties, which reduce neutron transmission and degrade spatial resolution (Fig. 3).

1D profiles show in the case of polyethylene sample, the image contrast is approximately the same for all 2 cm, 4 cm, and 6 cm thick samples but the image resolution disturbs by the sample thickness enhancement. In the case of Aluminum sample, the image contrast enhances by the sample thickness enhancement while the image resolution decreases clearly as a result of thermal neutron absorption rate enhancement of the different materials filled inside the holes (Figs. 4 and 5).

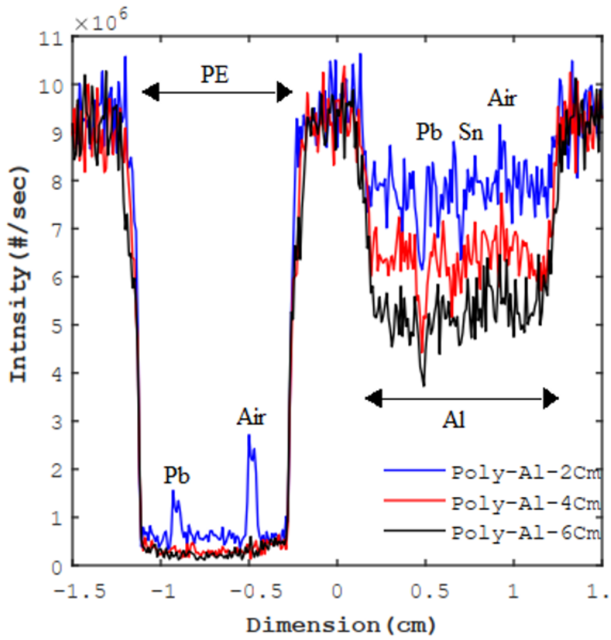

Figure 5: One-dimensional Y-axis profiles of polychromatic (n,γ)-induced images for polyethylene- and aluminum-based samples with varying thicknesses: Blue: 2 cm, red: 4 cm, black: 6 cm

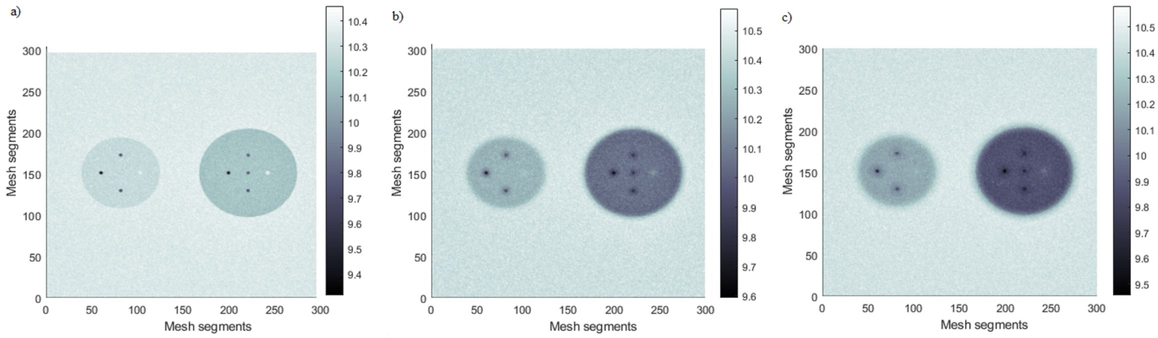

Figure 6: Simulated gamma energy-induced images of polyethylene- and aluminum-based samples with varying thicknesses: a) 2 cm thickness, b) 4 cm thickness, c) 6 cm thickness.

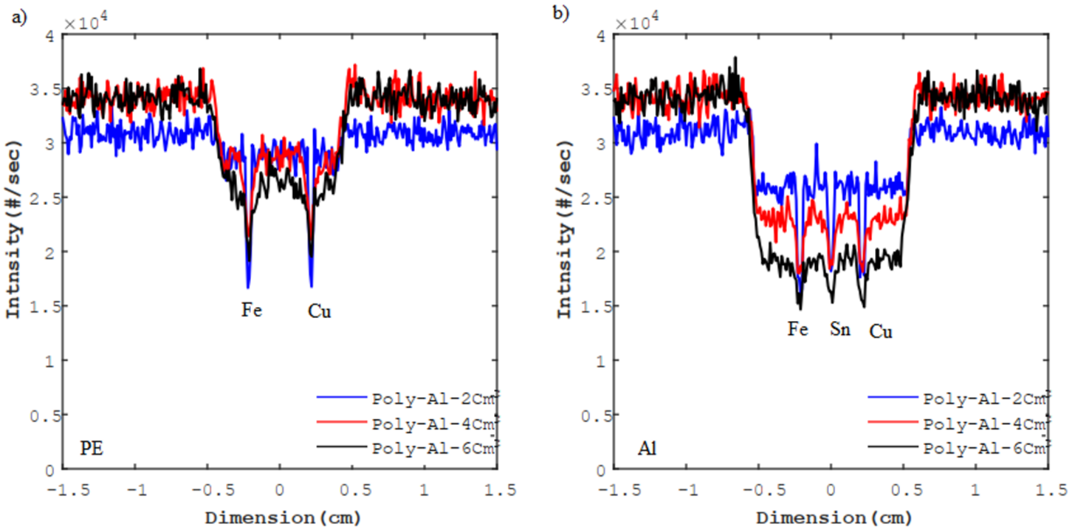

Figure 7: One-dimensional X-axis profiles of gamma energy-induced images for polyethylene- and aluminum-based samples with varying thicknesses: a) Polyethylene samples, b) Aluminum samples, Blue: 2 cm, red: 4 cm, black: 6 cm.

The 1D computational results showed the image contrast enhances for both aluminum and polyethylene samples exposing the core-emerged gamma on account of the sample thickness enhancement. The behavior is prominent for Aluminum sample clearly it has higher atomic number. But the image resolution is lost a bit however is not much in comparison with (n,γ)-induced image formation (Figs. 7 and 8).

The computational images formed by gamma rays present in the TRR neutron radiography laboratory are shown in Fig. 6. The simulations indicate that for thicker samples, gamma-induced images exhibit better quality compared to the (n,γ)-induced images. Therefore, in some cases, core-immersed gamma rays can be effectively utilized to enhance image quality in film-based neutron radiography.

The simulations indicate that there is significant difference between the (n,γ)-induced images obtained using monochromatic and polychromatic neutron beams exposed 2 cm thick samples, as shown in Fig. 9. The difference is better understood when the 1D profiles are regarded.

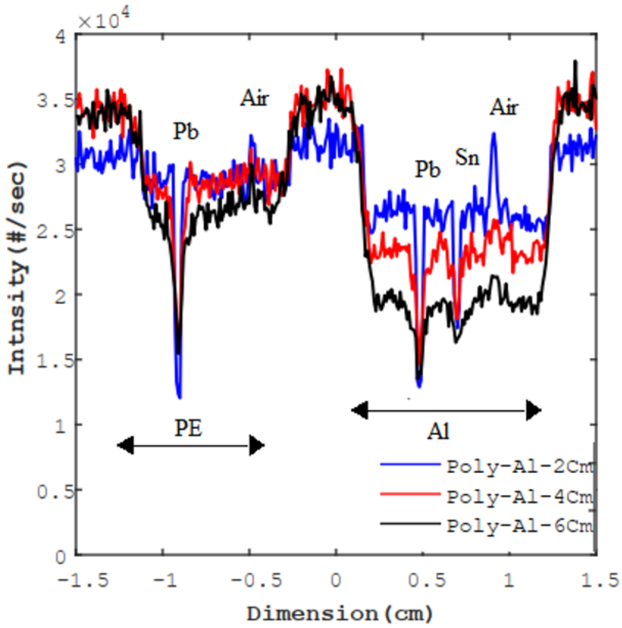

Figure 8: One-dimensional Y-axis profiles of gamma energy-induced images for polyethylene- and aluminum-based samples with varying thicknesses, Blue: 2 cm, red: 4 cm, black: 6 cm.

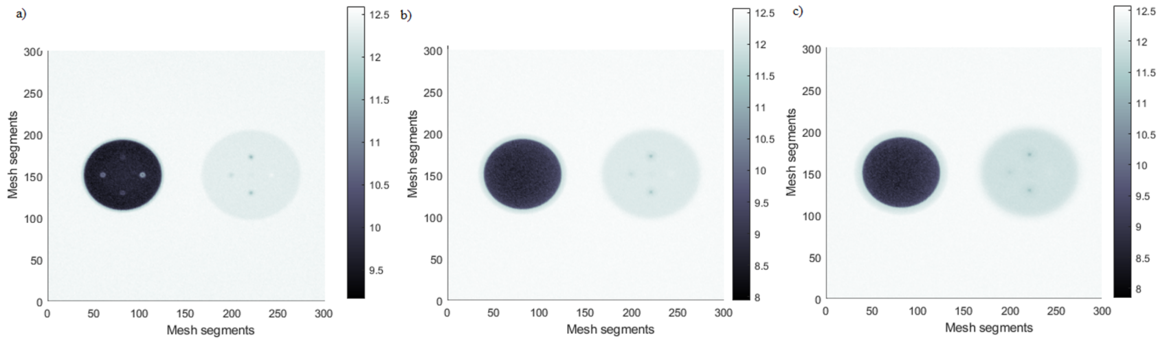

Figure 9: Simulated (n,γ)-induced images of polyethylene- and aluminum-based samples with varying thicknesses (2 cm, 4 cm, and 6 cm) exposed to a monochromatic neutron beam with an energy of 0.06 eV: a) 2 cm thickness, b) 4 cm thickness, c) 6 cm thickness.

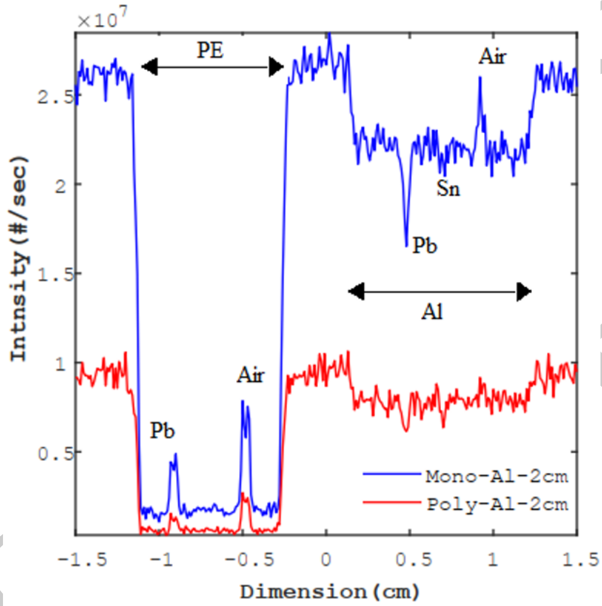

Figure 10: 1D Y-axis profile of monochromatic and polychromatic (n,γ) induced images of polyethylene and aluminum samples having 2 cm thicknesses.

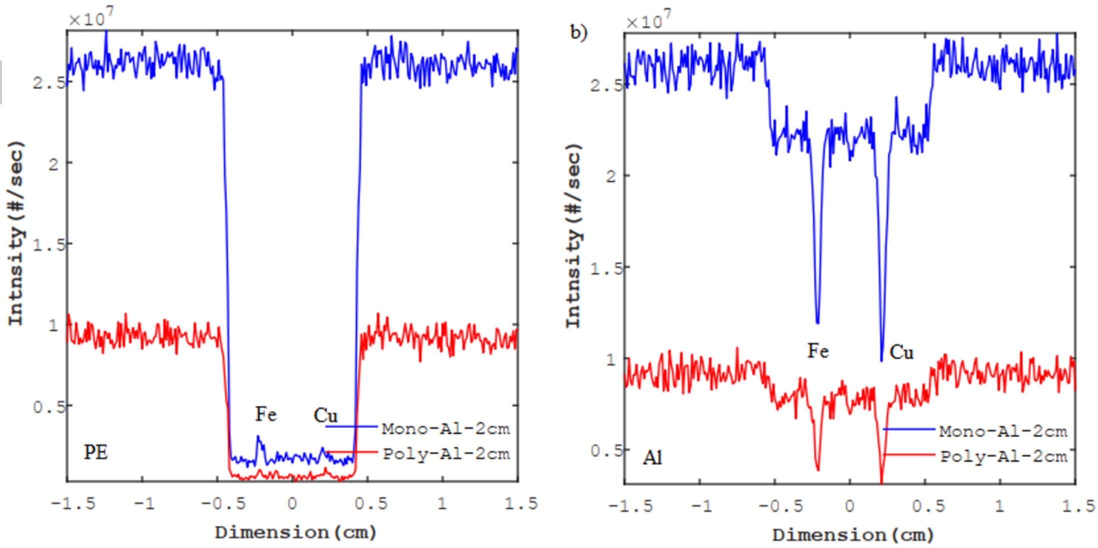

Figure 11: 1D X-axis profile of monochromatic and polychromatic (n,γ) induced images of polyethylene and aluminum samples having 2 cm thicknesses a) Polyethylene b) Aluminum.

As Figs. 10 and 11 show, the monochromatic (n,γ)-induced images would result in better contrast and resolution in the case of both samples because fast neutron scattering of polychromatic neutron beam inside both sample and converter causes the sample map inside converter is missed.

4 Conclusions

In this study, the effect of sample thickness on neutron radiography of polyethylene- and aluminum-based samples was investigated using MCNPX simulations and emulsion film detection. The results indicate that increasing sample thickness reduces image quality, particularly for polyethylene samples, due to their high thermal neutron scattering properties. Gamma-induced images were found to provide better contrast for thicker samples, suggesting that core-immersed gamma radiation can be effectively utilized to enhance image quality in film-based neutron radiography. Comparisons between monochromatic and polychromatic neutron beams showed noticeable differences in the (n, γ)-induced images, highlighting the robustness of neutron imaging under different beam conditions. These findings provide valuable guidance for optimizing imaging conditions, and detector selection (film or digital-based CCD camera) in neutron radiography studies. Computational procedures vastly help to predict the image quality before consuming time and cost on experimental imaging.

Conflict of Interest

The authors declare no potential conflict of interest regarding the publication of this work.

Funding

The authors declare that no funds, grants, or other financial support were received during the preparation of this manuscript.

References

Hassanein, R., Lehmann, E., and Vontobel, P. (2005). Methods of scattering corrections for quantitative neutron radiography. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 542(1-3):353–360.

Kljuev, V. (2001). Ndt techniques: Radiographic. *Encyclopedia of Materials: Science and Technology*, pages 6029–6032.

Morgan, S. W., King, J. C., and Pope, C. L. (2013). Simulation of neutron radiograph images at the neutron radiography reactor. *Annals of Nuclear Energy*, 57:341–349.

Soltes, J., Viererbl, L., Klupak, V., et al. (2017). Performance of Self-developing Radiography Films in LVR-15's Neutron Beams. *Physics Procedia*, 88:237–242.

Wei, G. (2012). Application of neutron radiography for non-destructive testing nuclear fuel elements. *Nuclear Techniques*, 35(11):821–826.

Wei, G., Han, S., Wang, H., et al. (2015). Experience of the indirect neutron radiography method based on the X-ray imaging plate at CARR. *Physics Procedia*, 69:258–264.

To cite this article:

H. Saebi, Z. Gholamzadeh, P. Tyyebi. Computational investigation of the effect of polyethylene and aluminum sample thickness on neutron radiography using emulsion films. *Radiation Physics and Engineering*, In Press.

DOI:

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