ENGPHYS 3D04

Lab 4: Neutron Radiography

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Lab date: November 22 (Group 6)

Submission Date: December 6

Executive Summary:

This laboratory report details an experiment on neutron radiography, aimed at analyzing its imaging capabilities compared to other techniques. The experiment used key equipment like a Beam Purity Indicator, a Sensitivity Indicator, and a No Umbra device, and focused on imaging a mystery box containing a watch and a lighter.

The procedure involved capturing neutron radiographs and adjusting the L/D value, which was determined to be 41.7, indicating a high level of image sharpness. The data analysis followed ASTM E545 standards, with the images falling under Category I, signifying superior quality. Key measurements included optical density and effective thermal neutron content, revealing detailed internal structures of the imaged objects.

Material impact on image quality was significant. Organic materials and plastics were more clearly imaged than metals and composites. The experiment also noted the effects of exposure time and converter-film separation on image quality.

The lab highlighted the use of reactors as a primary neutron source, emphasizing their role in fast and detailed imaging. Neutron radiography was shown to be particularly effective in non-destructive testing in nuclear industries.

Data Analysis and Discussion:

Analysis:

The radiography images, Figures 1 and 2, obtained from the lab, illustrate the results from neutron radiography imaging. Figure 1 showcases a mystery box containing a watch and a lighter, while Figure 2 displays the LD device positioned to the left. Both images were captured with an exposure duration set to 160,000 neutron counts in BP1.

Figure 1: This image displays the contents of the mystery box at the top

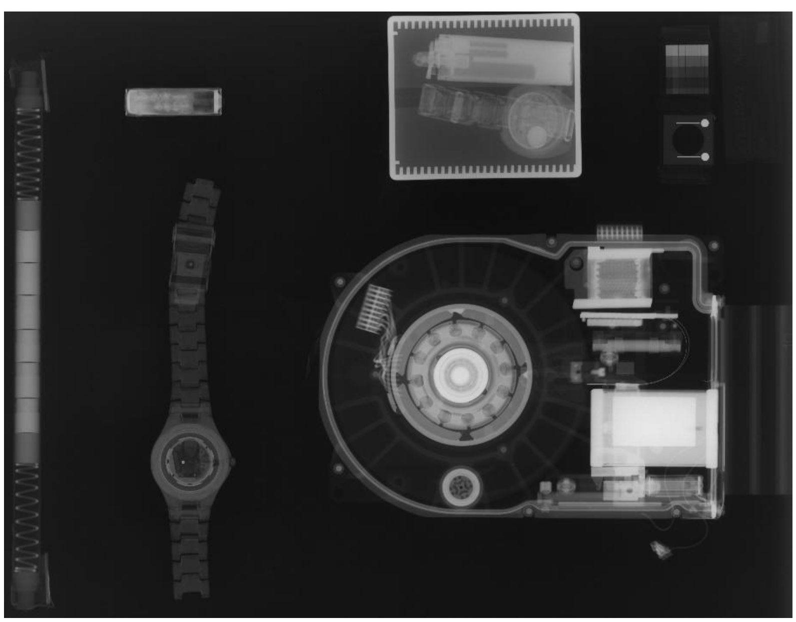
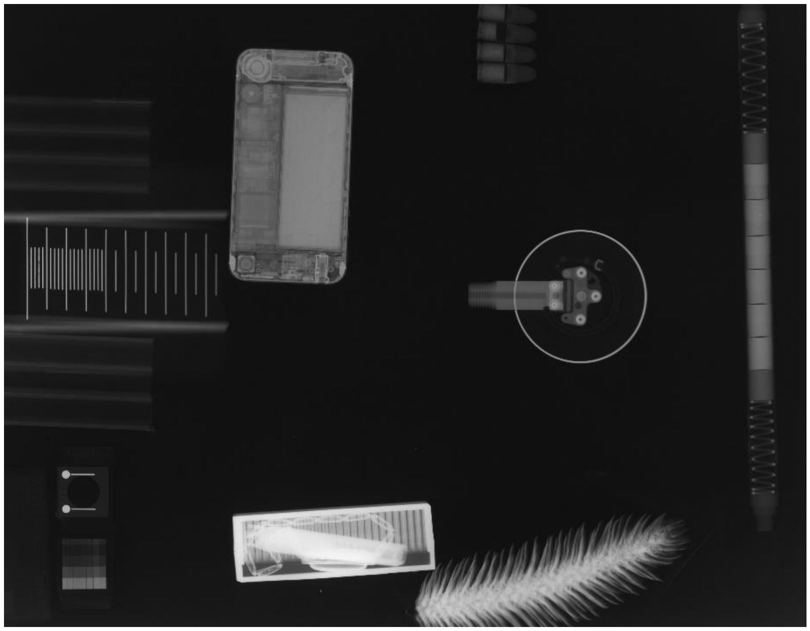


Figure 2: This image features the LD Device located off to the left side



The optical density results are then found:

Optical Density Results:

- Figure 1 (Mystery Box): DB (Max) at 0.60, DB (Min) also at 0.60, resulting in ΔDB of 0. The DL (Max) is 1.66, DL (Min) is 1.64, with ΔDL being 0.02. DT and DH values are 1.67 and 2.00, respectively.
- LD Device (Figure 2): DB (Max) is 0.71, DB (Min) is 0.70, yielding a ΔDB of 0.01. DL (Max) stands at 2.05, DL (Min) at 2.01, with a ΔDL of 0.04. The DT value is 2.06 and DH is 2.46.

Following the methodologies outlined in Tables 3.2-3.4 of the Lab Manual, calculations were made for several parameters:

- Effective thermal neutron content of the beam (η)
- Scattered neutrons (S)
- Holes on the sensitivity indicator (H)
- Smallest gap on the sensitivity indicator (G)
- Gamma rays (γ)
- Pair production (P)

The calculated parameters for each image category are as follows:

Parameters for Each Image Category:

- For Figure 1 (Mystery Box): The effective thermal neutron content (η) is 69.00%, the holes on the sensitivity indicator (H) and smallest gap on SI (G) are both 7, with scattered neutrons (S) at 0%, gamma rays (γ) at 1.50%, and pair production (P) at 1%.
- For the LD Device (Figure 2): The effective thermal neutron content (η) is slightly higher at 69.51%, holes on SI (H) and smallest gap on SI (G) remain at 7, scattered neutrons (S) increase to 0.41%, gamma rays (γ) are at 2.03%, and pair production (P) is at 1.63%.

Discussion:

1. **Mystery Box Analysis (Figure 1)**: The mystery box contains a lighter and a watch, with a Beam Purity Indicator (BPI) of 297 pixels. By measuring the box dimensions as 1146 by 978 pixels and assuming its thickness as 1 inch, a conversion factor of 297 pixels/inch is obtained, translating to physical dimensions of 3.86 inches by 3.29 inches by 1 inch, or 12.7 cubic inches. The accuracy hinges on the image resolution, potential blurriness, and the estimated error in the box's thickness, leading to an approximate uncertainty of about 12.7± 0.033 inches (assuming a 1/32-inch uncertainty for the thickness and an error of 1 pixel = 1/297 inch for the width and height)
2. **Resolution and Contrast Considerations**: The depth of an object affects its resolution in neutron radiography; objects further from the imaging plane appear blurrier due to increased neutron scatter. Contrast varies with material composition; for instance, metal ores show up dimly, while organic materials like a rat carcass appear brighter. This contrast is not directly proportional to material density.
3. **Sensitivity Indicator and Internal Structures Analysis**: The gaps on the sensitivity indicator and the intricacies of electronic components, such as PCB layouts and finer circuitry, are well-captured. The internal mechanisms of the watch and the pinecone's structure are distinctly visible, demonstrating the technique's resolution capabilities.
4. **Material Impact on Imaging**: Generally, plastics, polymers, and organic materials result in brighter images, while metals and composites, such as PCBs, appear dimmer. This is evident in both images, with their respective parameters (η, H, G, S, γ, P) further supporting these observations.
5. **Exposure Time and Converter-Film Separation Effects**: A higher exposure time darkens the image due to increased neutron penetration. An increased converter-film distance results in blurriness due to neutron scatter, emphasizing the need for minimal separation for clearer images.

6. **Neutron Sources and their Implications**: Reactor-based neutron sources offer high flux, reducing image development time. However, the associated costs and maintenance requirements are considerable drawbacks.

7. **Applications in Non-Destructive Testing**: Neutron Radiography (NR), though somewhat costly, serves as an effective non-invasive and non-destructive testing method. A primary application in nuclear operations, especially relevant to components like the Risø fuel pin, is the examination of spent nuclear fuel and other reactor parts. This analysis is crucial for detecting any failures or manufacturing defects, and for overall quality control. In practical settings like the McMaster Reactor, NR is employed to inspect plane turbines, enabling the identification of potential failures, cracks, or defects. Addressing these issues pre-emptively is vital, as they can lead to costly and dangerous situations if left undetected until operational in the field.

8. **Gamma Radiation and Imaging Artifacts**: The presence of lead discs in the BPI can create artifacts in the image due to gamma radiation obstruction. Sources of gamma rays include the beam, core, neutron scattering, and pair production.

9. **Analysis of Figure 1 (Mystery Box) - Radiation Characteristics**:

    - The value of DL being greater than DB indicates that gamma radiation is less prevalent compared to neutron radiation in the image. This is inferred because lead (represented by L in the measurements) is more effective at blocking gamma rays, while boron (B) primarily blocks neutrons.
    - The similarity of DT and DL, along with DL being greater than DB, supports the conclusion of minimal gamma radiation presence. If significant gamma radiation were present, lead would have blocked more, leading to a higher differential.
    - The observation of DH being higher than DT aligns with expectations, as the hole in the setup allows for unobstructed radiation, hence the higher value.
    - A low ΔDL suggests that the amount of gamma radiation scattering is minimal. This indicates a clear image with less interference from scattered gamma rays.
    - The near-zero value of ΔDB implies that the neutron beams used were well-collimated. This is evidenced by the neutrons primarily impacting either the upper or lower boron disc, and not both, due to their specific angle of entry. Similarly, the minimal value of ΔDL reinforces this point, indicating minimal scattering.
    - A higher value in pair production indicates the presence of gamma radiation with energy above 1.22 MeV, which is the minimum energy threshold required for pair production to occur. This aspect is crucial for understanding the energy levels involved in the radiographic process.

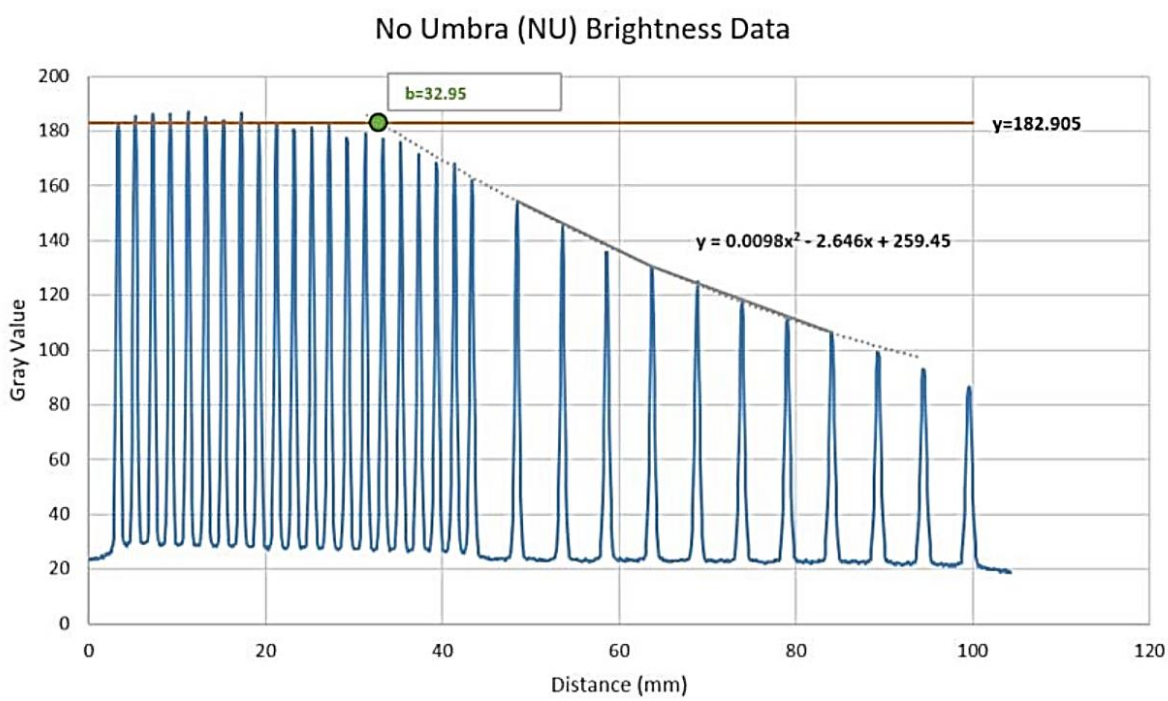
10. **Image Quality Classification**: Both images fall under Category I, indicating high resolution and accurate neutron radiation measurement.

11. **Comparative Analysis of Gamma and Neutron Radiography**: Each method has its strengths; gamma radiography excels with denser materials, while neutron radiography is superior for organic materials and plastics. Equipment configuration and radiation sources play crucial roles in their effectiveness.

12. **Material Comparison for Neutron Radiation Blocking**: Magnesium offers slightly better neutron radiation blocking than aluminum and doesn't become radioactive post-exposure, unlike aluminum.

13. **Image Analysis Using ImageJ (Figure 2)**: Utilizing ImageJ to analyze the No Umbra device in Figure 2, a 'b' value of 32.95 mm is deduced. The rod's thickness is measured at 0.79mm, resulting in an L/D ratio of 41.7, showcasing the method's precision in measuring dimensions.

    The L/D ratio in neutron radiography, representing the distance between the neutron source and the object (L) relative to the collimator diameter (D), significantly influences image quality. A higher L/D ratio generally yields sharper and higher resolution images due to better beam collimation, but it can also increase geometric unsharpness and reduce the field of view. Additionally, higher ratios may necessitate longer exposure times. Balancing this ratio is essential for optimizing image sharpness and detail while considering practical limitations.



Conclusion:

Throughout this laboratory experiment, neutron radiography was employed to effectively capture images of a variety of objects, including a Beam Purity Indicator (BPI), a Sensitivity Indicator (SI), a mystery box, and a No Umbra (NU) device. The clarity and differentiation of materials observed in these images, particularly the BPI and the distinct features within the SI, led to their categorization as Category I under the ASTM E545 standard. This classification is indicative of the highest resolution, primarily attributed to the quality of neutron radiation used in the imaging process.

The contents of the mystery box, notably a watch and a lighter, were distinctly visible in the neutron radiographs. Additionally, the analysis of the NU device revealed an L/D ratio of 41.7, affirming the high resolution and contrast of the images produced in the lab.

These findings underscore the effectiveness of neutron radiography as a superior imaging technique, especially compared to other methods. It demonstrated a particular proficiency in visualizing organic and plastic materials, while effectively minimizing the interference from metal objects, a task that poses challenges in X-ray imaging.

In summary, the lab successfully highlighted the unique advantages of neutron radiography, showcasing its potential as a valuable tool in material analysis and scientific research where other imaging techniques might be less effective.