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LOW-FLUX NEUTRON IMAGING

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ABSTRACT

Judicious use of scintillation screens greatly improves the capabilities for low-flux neutron imaging. Room temperature, cooled $^6\text{LiF-ZnS(Ag)}$ and gadolinium oxysulfide ($\text{Gd}_2\text{O}_2\text{S:Tb}$) were evaluated for direct exposures, and X-ray intensifying screens were evaluated with dysprosium and europium transfer screens. Although gadolinium oxysulfide provides improved resolution, it requires seven times the imaging time of $^6\text{LiF-ZnS(Ag)}$. Studies indicate that use of intensifying screens during transfer processes decreases the flux for a given density by about 30% and provides contrast enhancement. It was shown that cooling of scintillator-film combinations reduces reciprocity failure effects and in these experiments decreased direct exposure times ($\text{Gd}_2\text{O}_2\text{S:Tb}$) by up to 80%.

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Film is a low efficiency recording medium. This fact is recognized in astronomy and techniques for hypersensitization of emulsions (baking, pre-exposure, and bathing in water or ammonia) and techniques for reducing reciprocity failure effects (cooling) have been developed.⁽¹⁾ These techniques can be usefully applied to low-flux neutron radiography where reduction of exposure time is important.

A specially constructed cassette holder and vacuum cassette were built for exposures at a lower temperature as illustrated in Figure 1. The cassette is slid into the forward half of the exposure chamber where it is held in contact with an aluminum plate which is cooled by dry ice. The forward chamber is sealed during exposure and CO₂ from the rear chamber is vented into this region to prevent moisture buildup on the cassette and object during exposure. The mass of the vacuum cassette is kept to a minimum to permit rapid temperature changes. Films are loaded and unloaded at room temperature and allowed to come to equilibrium at approximately -10°C for exposure.

A number of different converters were employed in our investigations of low-flux imaging techniques including ⁶LiF-ZnS scintillators (NE 421 and NE 425*) and a gadolinium oxysulfide scintillator.⁽²⁾ These scintillators with Kodak RP/R film were cooled for studies of the reciprocity failure effect. Exposure curves (Figure 2) were developed using the cooled cassette system with an effective collimation ratio of 27:1 (1.7×10^3 n/cm²-sec). For comparison, Figure 3 is a series of exposure curves for room temperature exposure. It takes one-third the time to reach a density comparable to a room temperature exposure using the ⁶LiF-ZnS(Ag) with the cooled system, while the improvement is a factor of 5 for the gadolinium oxysulfide scintillator.

FIGURE 1. Cutaway Drawing of Dry Ice Box Used to Cool the Film-Scintillator Combination During Exposure

FIGURE 2. Radiograph Density Versus Exposure for Imaging Techniques When the Cassette is Cooled to -10°C During Exposure. (The thermal flux was $1.7 \times 10^2 n/cm^2\text{-sec}$ and the collimation ratio was about 27:1.)

FIGURE 3. Radiograph Density Versus Exposure for Imaging Techniques at a Flux of $1.9 \times 10^3 \text{ n/cm}^2\text{-sec}$ and a Collimation Ratio of 25:1

Reciprocity failure, as measured by the Schwarzschild index (1 for perfect reciprocity), is caused by a regression of sublatent image centers formed at low light levels. Cooling of the emulsion inhibits this regression, thus effectively increasing the speed of the film. There is an optimum temperature between -20°C to -100°C for emulsions used in astronomy; a similar optimum would exist in our case. Although we were probably above the optimum temperature (-10°C), our results indicate the benefit to be achieved by cooling the film-scintillator combination.

By varying the collimation ratio between 15:1 to 40:1 a number of discrete flux levels were established. Exposures at the various flux levels were used to generate exposure curves to study the effect of flux level. Plots of exposure time versus flux level indicated at Schwarzschild index of 0.7 for Kodak RP/R film which is in agreement with the results of Hawkesworth.⁽³⁾

Development of imaging techniques for transfer radiography can be used to extend the usefulness of this technique to lower flux levels. This is important since transfer radiography is the only practical means of examining highly radioactive materials and such developments will permit the use of isotopic sources with their low fluxes. Sandwiching the film between the transfer screen (both Eu and Dy were used) and a CaWO_4 scintillation screen during the transfer process enhances the film response (Figure 4). Further enhancement is achieved by cooling this combination as illustrated for dysprosium on Figure 4.

FIGURE 4. Radiograph Density Versus Flux Level for Europium and Dysprosium Transfer Imaging Using Kodak RP/R Film with and Without a Calcium Tungstate (CaWO_4) Intensifying Screen. (A curve is also shown illustrating the effect of cooling the film-scintillation combination during transfer.)

Optimization of imaging techniques is important for low-flux applications in order to provide reasonable results (time versus quality). Many potential applications for neutron radiography will increase interest as the technique becomes faster and more available to investigators.

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