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Letters to the Editors

A Polaroid Film Method for Transfer Neutron Radiography*

Although the use of Polaroid film to record neutron images has been reported by a number of investigators,[1-3] each of these reported techniques has required that the film itself be exposed to the neutron imaging beam. There are a number of situations in which this would be undesirable.[4] For example, if the inspection object were highly radioactive, even a brief exposure of the film near the object might cause sufficient film fogging to obliterate the desired neutron image. A Polaroid technique suitable for use under these conditions is described in this note.

The neutron-image-detection method described makes use of a screen of potentially radioactive material. Materials such as rhodium, silver, indium, dysprosium and gold have been used in these neutron radiography studies because each of these materials has a reasonably large cross section for a convenient half-life activity. The metal screen itself is exposed to the neutron imaging beam after the beam has passed through the inspection object. The screen becomes active proportional to the neutron intensity in each area of the image. This radioactive image can be made visible by allowing the screen to decay on photographic film and then developing the film.

This method for neutron radiography has been termed a transfer technique[4] and has been successfully employed for neutron radiographic inspection.[5]

It was in connection with this last mentioned study[5] that it was deemed desirable to investigate the possibility of using a transfer neutron radiographic method with Polaroid film. This inspection application involved highly radioactive irradiated reactor fuel specimens. The use of a transfer neutron radiographic inspection to examine these specimens nondestructively has proven to be valuable. One problem is that alignment difficulties, that is, placing the object in the neutron beam in such a position as to reveal the desired information, did frequently take some time. This had been checked by obtaining an image on a silver screen and transferring it to a fast X-ray film such as Kodak Type KK. Silver was used because, with its short half-life (the half-life of Ag^{108} is 2.3 min.), the film can receive the needed exposure within 7 minutes and then be developed.

Since this image was desired only to check alignment and not for a high-quality inspection, the use of a fast Polaroid technique appeared to have advantages. This can be accomplished by placing the radioactive image-carrying screen next to Polaroid film. One way in which this can be done easily is to employ individual 4 × 5 Polaroid Packets. The 3000 speed film is available in this form as Polaroid Type 57. In its simplest form the radioactive screen can be placed on the paper covered packet and allowed to decay, all under normal lighting conditions. A small weight can be used to obtain reasonable screen-film contact. Development of the image can be accomplished using an attachment made for light cameras, Polaroid Land Film Holder, No. 500.

Using this approach, silver screens were unusable in our neutron intensity (10^7 n/cm^2 - sec), since they did not become sufficiently active to expose this film. Rhodium screens yielded reflection densities in the mid-portion of the useful range of the Polaroid print[6] with neutron exposures of about $4\frac{1}{2}$ minutes and decay times of $4\frac{1}{2}$ minutes or longer (the half-life of Rh^{104} is 4.4 minutes). Other screen materials with longer half lives were not investigated for this application.

Some improvement in the Polaroid print density was obtained if the radioactive screen was placed on the Polaroid Packet on the side normally used away from the camera lens. In this manner the

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[1]S. P. WANG, C. G. SHULL and W. C. PHILLIPS, *Rev. Sci. Instr.*, 33, 126 (1962).
[2]H. G. SMITH, *Rev. Sci. Instr.*, 33, 128 (1962).
[3]H. BERGER and I. R. KRASKA, *Nondestructive Testing*, 21, 181 (1963).
[4]H. BERGER, *Nondestructive Testing*, 20, 185 (1962).
[5]H. BERGER and W. N. BECK, *Nucl. Sci. Eng.*, 15, 411 (1963).

[6]J. W. DUTLI and J. F. TORBERT, *Nondestructive Testing*, 13, No. 3, 23 (1955).

radiation from the screen had to penetrate only the black paper cover before reaching the radiation-sensitive material. If the screen was placed on the lens side of the packet, the radiation had to penetrate both the paper cover and the print paper before reaching the "negative material". The speed factor increase was relatively slight. Even when combined with the use of a lead screen on the opposite side of the film packet to serve as a back screen intensifier, the combined increase in speed was less than a factor of 2.

Although this Polaroid Packet method offered a great improvement over the previous X-ray film method in that a Polaroid neutron radiograph was available for viewing within 10 min. after the neutron exposure started, further increases in speed were desired.

Speed improvements can be obtained by opening the packet and inserting a fast fluorescent X-ray screen facing the radiation-sensitive material. The light emitted from this screen when the radioactive foil is placed on the packet intensifies the image sufficiently so that, with a rhodium screen, the image can be obtained in a total time of about 3 minutes, approximately split between neutron exposure and decay time.

This inconvenience of opening the packet before and after the radioactive screen exposure[a] to place and remove the fluorescent screen (it must be removed before the print can be developed) can be eliminated by using special Polaroid radiographic packets made to be used with X-ray fluorescent screens (Polaroid Type 3000X). Cassettes and developing apparatus for these radiographic packets are commercially available.[b] This radiographic Polaroid equipment has been described in the literature.[7]

The high-contrast resolution observed on these Polaroid radiographic prints is in the order of 0.020 in., as determined by neutron radiographs of of a cadmium test piece containing 0.020 in. holes whose spacing continually decreases.[8] Holes separated by about 0.020 in. could be resolved. In terms of radiographic contrast sensitivity, thickness changes in the order of 8 to 10 per cent were detectable in natural uranium in the thickness range of $\frac{1}{2}$ to 1 in. These capabilities are quite suitable for alignment procedures. Our experience has shown that the convenience of the Polaroid method has proved to be very useful.

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[7]J. A. REYNOLDS, *Nondestructive Testing*, 11, No. 1, 24 (1952).

[8]H. BERGER, *J. Appl. Phys.*, 34, 914 (1963).

[a]Another alternative approach is to perform the Polaroid exposure in the dark with the packet open. This permits the placing of the radioactive transfer screen immediately in back of the radiation sensitive material.

[b]Available from the Picker X-Ray Corporation, White Plains, N. Y.

The Effects of Coherent Scattering on the Thermalization of Neutrons in Beryllium

The problem of the effects of coherent neutron scattering on the neutron spectrum in finite assemblies has been studied theoretically[1,2,3,4] and experimentally.[5] We have obtained data on the time-dependent spectra in beryllium metal at 30 C by the phased-neutron-chopper/linear-electron-accelerator technique. We observe prominent crystalline effects at the Bragg energies of 0.022 eV and 0.0067 eV.

The primary neutrons are obtained from the RPI linear electron accelerator operated at 7 kW of electron beam power and 45 MeV; photo-neutrons are produced by electron converted bremsstrahlung in a thick water-cooled tungsten target. These neutrons are incident on a beryllium assembly, 4.31 in. $\times$ 11.9 in. $\times$ 12.0 in. (buckling $\sim 0.073/\text{cm}^2$), density approximately 1.7 g/cm^3, having a 0.5 in. $\times$ 0.5 in. reentrant hole to the center of the assembly from which the scalar neutron flux is extracted. The experimental set-up is shown in Figure 1. A mechanical disk chopper consisting of B^{10}-steel 3/4 in. thick, 1% by weight of B^{10}, samples the

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[2]G. DESAUSSURE, "The Neutron Asymptotic Decay Constant in a Small Crystalline Moderator Assembly," *Proc. of the Brookhaven Conf. on Neutron Thermalization, IV*, 1158-1174 (1962).

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[4]S. S. JHA, *J. Nucl. Energy Part A: Reactor Science*, 12, 89-92 (1960).

[5]E. G. SILVER, "Experimental Investigation of Persisting Changes in the Thermal Neutron Decay Constant in Finite Media of Ice and Beryllium as a Function of Temperature and Buckling," *Proc. of the Brookhaven Conf. on Neutron Thermalization, III*, 981-996 (1962).