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RFP-1778

January 13, 1972

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RESPONSE OF FILM/CONVERTER COMBINATIONS
TO 14.3 MeV NEUTRONS FOR FAST
NEUTRON RADIOGRAPHY

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Printed in the United States of America

Available from the

National Technical Information Service

U. S. Department of Commerce

Springfield, Virginia 22151

Price: Printed Copy \$3.00; Microfiche \$0.65

January 13, 1972
Publication Date

RFP-1778
UC-4 CHEMISTRY
TID-4500 - 56th Ed.

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Prepared under Contract AT(29-1)-1106
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Albuquerque Operations Office
U. S. Atomic Energy Commission

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RESPONSE OF FILM/CONVERTER COMBINATIONS TO 14.3 MeV NEUTRONS FOR FAST NEUTRON RADIOGRAPHY

Dennis G. Vasilik, Richard L. Murri, and Estevan S. Salazar

Abstract. The direct method for producing radiographic images with neutrons of approximately 14.3 MeV is considered. The source of neutrons is a sealed-tube neutron generator which has a yield of about 6.36×10^{10} n/sec. In the direct method, X-ray film is placed between calcium tungstate (CaWO_4) fluorescent screens. A hydrogenous converter screen is used to stimulate light emission in the fluorescent screens by means of recoil hydrogen atoms. The response of Kodak Royal Blue film to fast neutrons is discussed for various fluorescent-screen/converter-material combinations. Film exposure density is investigated as a function of both source-object distance and exposure time. Three converter materials investigated include Lucite, Bakelite, and magnesium-phenolic screens. Optimum results are achieved with a film-Lucite combination.

INTRODUCTION

A sealed-tube neutron generator (Kaman Nuclear Corporation, Garden of the Gods, Colorado Springs, Colorado) is used to provide a continuous yield of approximately 14.3 MeV neutrons for fast neutron radiography purposes. The yield was measured by copper foil activation analysis to be 6.36×10^{10} n/sec.¹ The emission is nearly isotropic. The generator is a cylinder 25.4 cm in diameter and 58.96-cm long. In the past few years, image detection methods for 14.3 MeV neutrons have been reported;^{2,3,4,5} however, little experimental data are available which characterize the response of a given film for various exposure times and source-to-detector separations. In particular, the response of Kodak Royal Blue film to fast neutrons is discussed in this paper. The method used is the direct technique, in which X-ray film is exposed to a beam of fast neutrons. The film is placed between calcium tungstate (CaWO_4) fluorescent screens in combination with a hydrogenous converter screen. The converter screen is used to stimulate light emission in the intensifying screens by means of neutron-induced hydrogen recoil atoms. Three converter materials used as screens were Lucite, Bakelite, and magnesium-phenolic.

EXPERIMENTAL METHOD

A sealed-tube neutron generator is used as a source of neutrons generated from $\text{H}^3(\text{d},\text{n})\text{H}^4$ and $\text{H}^2(\text{H}^3,\text{n})\text{He}^4$ reactions. These reactions are produced by deuterium and tritium gases which are ionized by a Penning-ion-gage type

source and accelerated into a grounded target assembly by a potential of 190-200 kV. The target consists of tritium (7 curies) and deuterium absorbed in a layer of titanium. Because of its high speed, Kodak Royal Blue X-ray Film was used for this work. However, any other standard industrial X-ray film could be used for fast neutron radiography.

The films were developed with a Kodak Industrial Film Processor (X-OMAT). The film exposure densities were measured with a Densichron (The Welch Scientific Company, 7300 North Linder Avenue, Skokie, Illinois 60076) transmission densitometer. Each density value was obtained by taking the average of five density measurements per film. The standard deviation is 0.01.

In the direct radiographic method the film is sandwiched between two CaWO_4 scintillator screens. The paper backings used as the base for the CaWO_4 screens provide a hydrogenous material in which recoil hydrogen atoms are generated from neutron collisions. These recoil hydrogen atoms stimulate fluorescent light emission in the CaWO_4 . The resulting image can be further intensified by placing additional hydrogenous converter material next to the film. Figure 1 shows a typical experimental arrangement

Figure 1. Experimental Arrangement for Direct Fast Neutron Radiography.

for detecting a fast neutron image. The screens are held in a blank, spring-loaded aluminum X-ray cassette (Halsely X-Ray Products, Inc., Brooklyn, New York). The screens and film are thereby kept in intimate contact to prevent distortion of the image.

EXPERIMENTAL RESULTS

Film Density as a Function of the Source-to-Film Distance

The response of Kodak Royal Blue film to fast neutrons is shown in Figure 2. X-ray background has been subtracted from the total density to yield this curve. Film density is plotted as a function of the distance from the neutron source to the position of the film. All exposure times were 2 minutes. The three curves correspond to converter screen materials of Lucite, Bakelite, and magnesium-phenolic. The Bakelite and magnesium-phenolic screens are 0.080-cm thick and each is deposited on a 0.24-cm aluminum base. The Lucite is 0.32-cm thick.

Figure 2. Film Density as a Function of Distance from Neutron Source for Kodak Royal Blue Film with Various Conversion Screen Materials, Exposure Time - 2 Minutes.

Figure 2 shows that the Lucite provides the best film density response of the three converter materials for distances less than 3.0 meters from the source. At 3.0 meters, the three converter screens yield about the same film response.

The image recorded by the combination of converter screens and film is a mixture of neutron and X-ray images. The x-rays are caused by neutron activation of the environment in which the generator is housed. Also, x-rays

are produced as a result of the neutron generating reactions. The radiation from the room formed a weak diffuse background and was not a significant problem. X-rays from the generator are, however, emitted very intensely. But, fortunately, they are preferentially emitted along the axis of the generator tube. Therefore, the generator axis was oriented 45° away from the film position and these x-rays were not a significant problem.

Film Density as a Function of Exposure Time

The dependence of the film density on the exposure time is shown in Figure 3. The measurements were taken at 3.6 meters from the neutron source using Lucite as the converter screen material. Curve A is the measured total film density as a function of exposure time. Curve C is an approximation of the x-ray contribution to the total film density. Curve B represents that part of the total film density which is primarily a result of neutron interactions with the film-converter screen assembly. Curve B results when Curve C is subtracted from Curve A.

Figure 3. Film Density as a Function of Exposure Time for Lucite Converter Screen at 3.6 Meters from Fast Neutron Source with Kodak Royal Blue Film.

SUMMARY AND CONCLUSIONS

The two factors which govern film density are beam intensity and exposure time. The experimental data relating these quantities have been presented for Kodak Royal Blue film in combination with three converter materials (Lucite, Bakelite, and magnesium-phenolic). Lucite was shown to provide the best response up to 3.0 meters from the neutron source.

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