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Dy-IP characterization and its application for experimental neutron radiography tests under realistic conditions

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Abstract

Imaging plates containing Dy for neutron radiography have been designed, fabricated and tested experimentally. Using the imaging plates combined with the developed NR system and the honeycomb collimator, quantitative neutron radiograph, which is free from scattered neutron and γ-ray, has been obtained. Application has been conducted for the post-irradiation examination for the nuclear fuel pin.

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Keywords: Neutron radiography; Imaging plate; Honeycomb collimator; Quantitative analysis; Nondestructive testing; Post-irradiation examination

1. Introduction

A wide dynamic range is required for the quantitative nondestructive analysis in the neutron radiography (NR) using digital imaging systems. Photo-stimulated luminescence (PSL) based on BaFBr:Eu is a suitable radiation-photon converter for NR imaging. In addition, elements such as lithium, gadolinium (Gd) and dysprosium (Dy) are used as neutron-charged particle converter in the neutron imaging plate. The neutron signal without any background from other sources should be obtained in an environment of heavy gamma fields. However, the PSL material is in principle very sensitive to X- and γ-rays too. The detector response of the transmitted neutron should be evaluated quantitatively using some technical procedures while the response of γ-ray must be diminished. As reported previously [1], several

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procedures can be applied to erase γ-ray disturbance. A conventional method to avoid γ-ray fogging is an indirect NR technique using X-ray film and Dy metal sheets. This technique has been applied to an IP and Dy sheet combination [2]. In addition, the background term due to scattered neutrons from the sample as well as surroundings should be removed from neutron detection by additional technique such as honeycomb-like neutron collimators [3].

Based on these experiences [1–3] and some considerations, new imaging plates have been designed, fabricated and examined in comparison to the existing NR systems. An important application of this method would exist for the post-irradiation examination of nuclear fuel pins. The present report is concerned to some results using the new IP and the technical procedures involved.

2. Experiments

2.1. Devices: imaging plate, honeycomb neutron collimator and test samples

(1) *New IP containing Dy*: The γ-ray fogging is diminished by the indirect imaging technique using the Dy-containing imaging plate. The indirect technical procedure is based on the rather long half-life of Dy-165. The imaging plate consists of a (Dy_2O_3 + BaFBr:Eu) layer and the plastic supporting sheet. The neutronic characteristics of various converters and related materials are listed in Table 1. Specifications of the Dy-IP are shown in Table 2.

(2) *Honeycomb collimator* [3]: Position-controlled honeycomb-like collimator improved the option for quantification of IP image by removing the background of scattered neutrons from the sample and irradiation room.

(3) *Test samples*: Test stepwedge samples of graphite, iron, titanium, cadmium and dysprosium have been used for the evaluation of neutron transmittance and attenuation coefficient. Sharp edge sample of cadmium has been used for the evaluation of the spatial resolution of the NR image system. In addition, the post-irradiation nuclear fuel pin has taken the NR image as an application of the present Dy-IP NR system.

Table 1
Nuclear data of Gd, Dy and Eu

(1) *Gd-IP(BAS-ND)*: Direct method
Gd-155/157(n,γ/IC)Gd-156/158
σ_c(Gd-155) = 61,000 b
σ_c(Gd-157) = 240,000 b
(2) *Dy-IP: Direct method*
Dy-164(n,γ)Dy-165/165 m
σ_c(Dy-164 → Dy-165) = 1000 b
σ_c(Dy-164 → Dy165 m) = 1700 b
(3) *Dy-IP*: Slow indirect method
Dy-165(β decay, 2.33 h)Ho-165
(4) *Activation of PSL(BaFBr:Eu)*
Eu-151(n,γ)Eu-152(β, 9.32 h)Gd-152
σ(Eu-151 → Eu152) = 8700 b

Table 2
Specifications of Dy-IP

Coating	Thickness: 6 μm, material:PET
PSL + converter	Thickness: 150 μm, PSL material: BaFBr(Eu)
	Converter material: Dy_2O_3, molar ratio: Ba/Dy = 1/1
Supporter	Thickness: 188 μm, material: PET + ferrite

2.2. Experimental procedures

The new IP has been tested by the conventional neutron radiographic experiments using the TNRF I and II facilities at JRR-3M in JAERI. Application experiment of Dy-IP to the post-irradiation examination has been performed using the NEURAP setup in the NEUTRA facility at SINQ in PSI [5].

The NR imaging procedures using the Dy-IP are shown schematically in Fig. 1. As demonstrated in the figure, just after the neutron exposure of 10^9 n/cm^2, the direct image has to be removed by lighting eraser. Then, the PSL material of the IP is inherently exposed in an auto-radiographic mode by the radioactive Dy-165 decay. After