Improvement on sensitivity for the track - etch neutron radiography

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One of the main restrictions to the employment of the track-etch neutron radiography technique, is the low-intrinsic optical contrast achieved in the recorded image that leads to a poor sensitivity to discern thickness changes of the materials. The sensitivity is determined by measuring the light transmitted through the images and for such purpose, conventional analog optical microphotometers are typically employed. In the present work a digital system has been employed to measure the light transmitted and a significant improvement in the sensitivity was achieved.

The use of solid state nuclear track detectors(SSNTD) to record neutron radiography(NR) images is a well known technique. The radiography is obtained by irradiating a sample in an uniform neutron beam and a converter screen transforms the transmitted neutron intensity into ionizing radiation which is able to cause damages into the detector. Usually boron based converter screens are used, and in which case, alpha particles and lithium ions cause the damages. By means of a chemical etching the latent damages are enlarged and are called tracks and, they form a two-dimensional image which is visible by the naked eye. The insensitivity of the SSNTD to visible light, beta and gamma radiations, the high resolution achieved in the image, the feasibility of stopping the development at intermediate stages are some of their attractive characteristics for radiography purposes [1]. One of the main disadvantages of the track detectors is the low-intrinsic optical contrast achieved in the recorded image. Conventional analog optical microphotometers are typically employed to determine light transmission through the recorded image and the light intensity is evaluated in an optical density(OD) scale ranging from 0 to about 2 corresponding to the unattenuated light beam and to a transmission of 1% respectively [2]. In this case, the resulting sensitivity to discern thickness changes of the materials is relatively poor, limiting the employment of the track detectors for radiography purposes [3].

In the present work a digital system to measure the light transmission through the images has been employed. In this case the light intensity is evaluated in a gray level scale ranging from 0 to the darkest pixel to 255 to the brightest one and a significant improvement in the sensitivity was achieved.

Data acquisition and analysis

The track detector CR-39, 500µm thick, manufactured by Pershore Mouldings(England) was used to record the images. The converter screen is a plastic backing, single coated with a natural boron layer having 106µm and 65µm thickness respectively, produced by Kodak Pathè(French). During irradiation, the detector and the screen are kept in a tight contact, inside an aluminum cassette and the damages are induced by the products of the nuclear reaction $B^{10}(n,\alpha)Li^{7}$ (α - 1.47MeV and Li - 0.84MeV) with an intrinsic registration efficiency of about 100% [4].

The chemical etching was performed in a KOH(30%) aqueous solution at a constant temperature of $70^{o}C$ [2]. The system to measure light transmission was developed at the Research Reactor Center – CRPQ of IPEN-CNEN/SP and consists of two main parts. The first is an old standard photo enlarger in which a divergent light beam, after pass through a set of lens, impinges perpendicularly the detector and the transmitted intensity is projected on a lusterless white screen. The second part is a digital capture system where an analog video camera captures the image and a capture frame grabber, installed in a standard computer, converts it to the digital form. Its main characteristics are shown in Table I.

TABLE I. MAIN CHARACTERISTICS OF THE PHOTO ENLARGER DIGITAL CAPTURE SYSTEM

Projected image size	8cm x 10cm
Video camera	Javelin model JE8242
Capture frame grabber	Pixelview
PC	Pentium IV processor – 1024GB Ram
Software for image processing	Image-Pro plus

The sensitivity has been determined for two materials, Plexiglas and iron. The samples have been radiographed in a NR facility installed at the radial beam-hole 08 of the 5MW pool type IEA-R1 Nuclear Research Reactor of the IPEN-CNEN/SP, with a thermal neutron flux of about 10^{13} n/s.cm^{2} near the reactor core. The main characteristics of the neutron beam at the sample irradiation position are listed in Table II [5].

TABLE II. CHARACTERISTICS OF THE NEUTRON BEAM AT THE SAMPLE IRRADIATION POSITION

Neutron flux (n.s^{-1}.cm^{-2})	1.75x10^{6}
Collimation ratio (L/D)	70
n/γ ratio (n/cm^{2}.mRem)	>10^{5}
Beam diameter (cm)	20
Mean Energy (meV)	7

In order to evaluate the sensitivity, the etching time and the neutron exposure interval for which the recorded images exhibit the best intrinsic contrast must be determined. This was performed by means of the curves that relate gray level(GL) and neutron exposure(E) as functions of the etching time(t_e). For such purpose several strips of the CR-39, in the interval $2x10^{7}$ n/cm^{2} < E < $2x10^{10}$ n/cm^{2}, were irradiated. The resulting gray level intensities as functions of the exposure for three different etching times, 10, 25 and 65 minutes are shown in Fig 1. The best contrast was achieved for t_e = 25 minutes in the exposure interval $6x10^{7}$ < E < $4x10^{9}$ n/cm^{2} (indicated by arrows), since this curve exhibits the highest slope and the highest relative dynamic range [3]. In this interval there is a nearly logarithmic relationship between grey level(GL) intensity and neutron exposure(E) given by:

$$GL = K \cdot \log(E) + cte \qquad (1)$$

where K is the slope and "E = φ.t" (t is the irradiation time and φ is the neutron flux) [6].
Theoretically the relationship between the transmitted " φ(x)" and the incident " φ_o" neutron fluxes by a sample, with thickness "x" and effective total macroscopic cross section " Σ_{eff} " obeys the following exponential law [7]:

$$\varphi(x) = \varphi_0 . e^{(-\Sigma_{eff} \cdot x)} \qquad (2)$$

By combining (1) and (2) the grey level intensity as a function of the sample thickness, is given by the following linear function:

$$GL(x) = GL_0 - C \cdot x \qquad (3)$$

where "GL_o" is the gray level intensity for the direct neutron beam and C = 0.43.K.Σ_{eff}.

The sensitivity is expressed as the minimum detectable thickness, and it is obtained from the derivative of (3) as:

$$\Delta x = -\frac{\Delta(GL)}{\ } C \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where “Δ(GL)“ is the minimal discernible grey level intensity in the image.

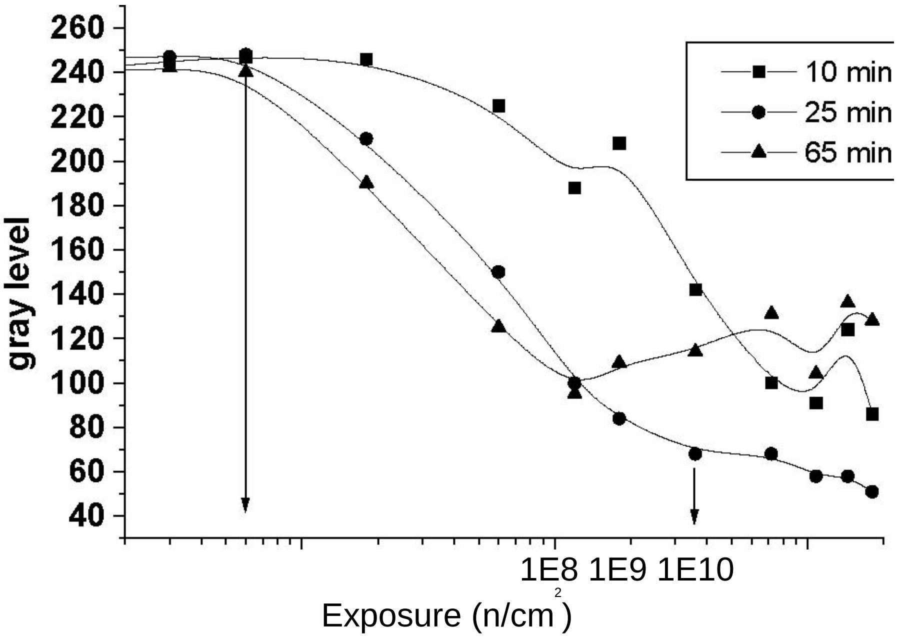

Fig. 1. Behaviour of the grey level intensity readings as functions of the neutron exposure for three etching times.

The samples are step wedges with thicknesses varying from 2 mm to 12 mm which were fixed on the outside face of the aluminium cassette. The sample to detector distance was about 1mm and the radiographs were obtained in the etching time and neutron exposure interval for which the highest contrast is achieved. The Fig 2 shows the radiographic image of the step wedges, captured by the digital system. The behaviour of the grey level intensity (including the detector background) as functions of the sample thicknesses, are shown in Fig 3. Each grey level has been obtained by averaging the intensities of about 1700 individual pixels and the error bars correspond to the uncertainty of the mean.

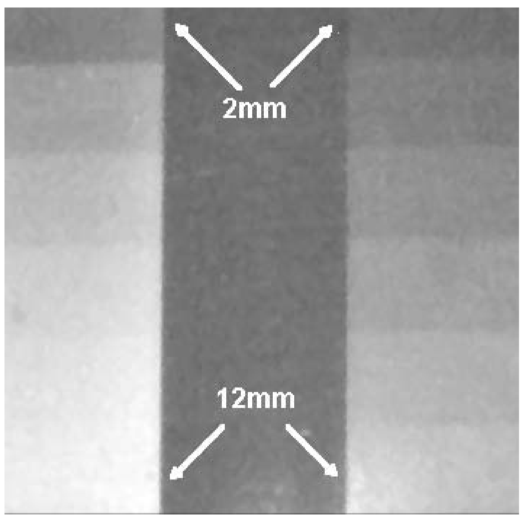

Fig. 2. Digital radiography of the step wedges: Plexiglas(left), iron(right).

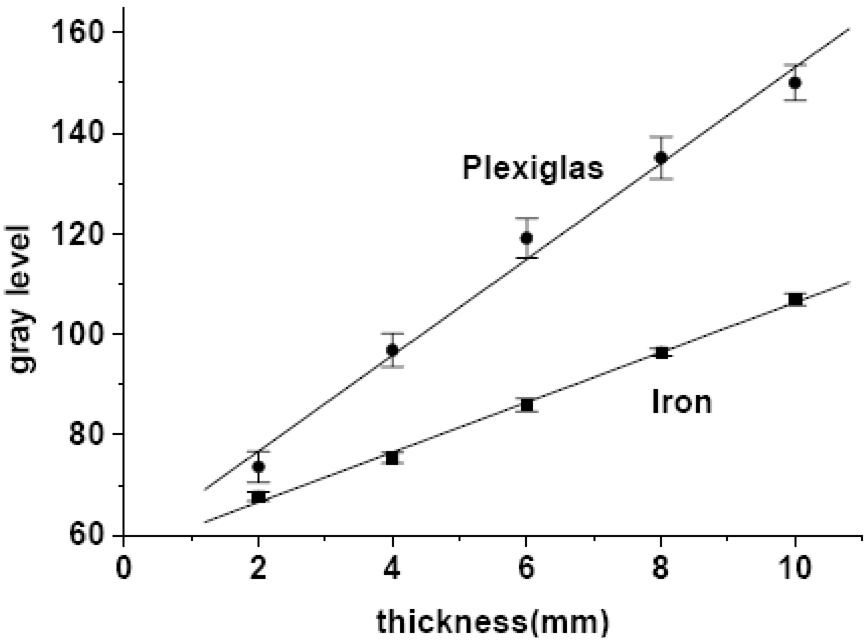

Fig. 3. Behavior of the gray level intensities as functions of the sample thickness.

The expression (3) has been fitted to these data and the sensitivity evaluated by (4). For the present digital system the minimal discernible grey level intensity is $\Delta(GL) = 2.5$ and, the obtained results are shown in Table 3. The uncertainties in these results have been determined by the standard propagation method applied to (4). In order to compare the potential of the present system the sensitivity has been evaluated, according to the same procedures, by using a microphotometer with a light beam size of 3µm(width) by 700µm(length) [3] to analyze the light transmission. The results are also presented in Table 3 and as can be seen the sensitivity provided by the digital system is better. Such improvement can be attributed to the smaller uncertainties and to the higher linearity in the light transmission readings provided by the digital system.

TABLE III. COMPARISON OF THE SENSITIVITY FOR PLEXIGLAS AND IRON FORTHE DIGITAL SYSTEM FOR THE CONVENTIONAL ANALOGMICROPHOTOMETER

	Δx(mm)	
	Plexiglas	Iron
Digital system	0.26±0.01	0.50±0.02
Microphotometer	0.47±0.01	0.75±0.03

Conclusion

The use of the proposed system to evaluate light transmission through the images recorded in the track detectors has demonstrated to be an important tool to improve the sensitivity of the neutron radiography technique. The rapid data acquisition is an important characteristic of this system. As mentioned before each grey level intensity and its corresponding uncertainty are evaluated by averaging the intensities of about 1700 individual pixels in an area corresponding to about 0.4 cm^2 of the image. This procedure takes some few seconds. For the microphotometer the reading procedure takes about 30 minutes in an area approximately 200 times smaller [3]. The main limitation of the present digital system is the low resolution achieved in the image. In radiography studies, resolution is usually defined as the distance that must separate two objects before they can be distinguished from each other [8]. For the same radiography conditions, the microphotometer is able to provide a resolution of about 20µm [3], while the present system provides about 150µm. This value is the pixel size in the digital image, which is limited by the capture frame grabber employed.

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