3º Congresso Geral de Energia Nuclear

22 a 27 de abril de 1990

ANAIS - PROCEEDINGS

# CHARACTERISTICS OF SOME TRACK DETECTORS FOR NEUTRON RADIOGRAPHY

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## ABSTRACT

The track etching method has been employed for neutron radiography purposes, by making use of a cold neutron beam obtained at the IEA-R1 Nuclear Research Reactor.

The films used were the Solid State Nuclear Track Detectors CN-85, CR-39, MAKROFOL-E and LR-115, with a natural boron converter screen.

In order to obtain mean track diameter of about 3 µm with a minimum overlapping between them, adequate conditions for etching and exposure times of about 30 minutes and 3 hours, respectively, were evaluated. For such conditions exposures of $10^9$ n/cm$^2$, which corresponds to $10^7$ track/cm$^2$, were achieved.

Neutron radiographs of several materials were performed and the best results in terms of optical contrast were obtained for the films CN-85 and CR-39.

## INTRODUCTION

Neutron radiography is a relatively recent nondestructive testing technique. Its applications vary enormously, but chief among them are: ceramic capacitors, aircraft turbine blades, highly radioactive materials, hydrogen--rich substances such as oils, adhesives, water, explosives, rubbers etc. Basically, it is very similar to the conventional X and gamma-ray radiographic techniques. A collimated neutron beam impinges the sample which modulates its intensity and a combination between a film and a converter screen is used as the image detector (Berger 1965; Matfield 1971; Domanus et al., 1981; Domanus 1986).

Track etching registration is a very important method employed in neutron radiography. Charged particles coming from a converter screen will give rise to latent tracks in plastic films SOLID STATE NUCLEAR TRACK DETECTORS-SSNTD, which after chemical etching become easily visible, forming a neutronic bidimensional image of the sample. The film insensitivity to visible light, gamma and beta radiations and the small track dimensions that can be achieved by chemical etching, provide versatility and applicability to the method with potential to obtain high resolution radiographs (Khaddury 1976; Durrani et al., 1975; Fantini 1986; Pugliesi et al., 1987). Although low optical contrast is obtained in these films, several techniques have been developed to improve it (Hawkesworth 1977; Lferde 1984).

The objective of this work is to give continuity to the neutron radiography program developed in the Nuclear Physics Department of the IPEN-CNEN/SP and to determine adequate etching and exposure times for the SSNTD : CN-85, CR-39, MAKROFOL-E and LR-115.

## EXPERIMENTAL PROCEDURES

The experimental arrangement is in the beam-hole 3 of the IEA-R1 Nuclear Research Reactor, in which a Beryllium Filter Time of Flight Neutron Spectrometer is installed (Pugliesi.; 1988). A cold neutron beam emerges from this beam-hole and its main characteristics are shown in table 1.

The radiography chamber is an aluminum sheet in a "L" format in which the converter screen and the film are in close contact maintained by another aluminum sheet with 1-mm thickness. The sample is attached in this chamber and the assembly positioned in the neutron beam as shown in figure 1. The converter used is a natural boron screen manufactured by KODAK PATHE FRENCH. The isotope boron-10 has a high absorption neutron cross section and a natural abundance 19.6%. The films, chemical reagents as well as etching temperatures presently employed (Fleischer et al., 1985) are shown in table 2.

The first step of this work was to determine adequate etching times, for which the mean track diameter is about 3 μm, the same mean silver grain sizes existing in some standard X-ray emulsions, to obtain nearly the same film resolution (Matsumuto et al., 1986).

For this purpose, the radiography chamber was positioned, without sample, in the neutron beam with each respective film-converter screen assembly and one-hour exposures were carried out. This time was chosen in a such way to

Table 1 - Neutron beam characteristics

| Neutron Flux $n/cm^2 \times s$ | Cadmium Ratio | Beam Geometrical Unsharpness | n/γ-ratio $n/cm^2 \times mRem$ |
|---|---|---|---|
| $10^5$ | 200 | 30 | $2 \times 10^5$ |

Table 2 - Etching conditions

| | CN-85 | CR-39 | MAKROFOL-E | LR-115 |
|---|---|---|---|---|
| Chemical Reagents | NaOH-10% | KOH-30% | *PEW | NaOH 10% |
| Etching Temperatures ( °C ) | 60 | 70 | 70 | 60 |
| | *PEW: 45g water; 40g ethanol; 15g KOH | | | |

Table 3 - Adequate conditions

| | CN-85 | CR-39 | MAKROFOL-E | LR-115 |
|---|---|---|---|---|
| Etching times (min.) | 19 | 40 | 9 | 19 |
| Exposure times (hour) | 3.1 | 2.4 | 3.5 | 3.6 |

highly enriched boron-10, used by the author, in comparison with natural boron used in this work.

The resolution of the method for thin samples(2-mm thickness)is about 70μm mainly provided by the beam geometrical unsharpness, since the film-converter screen intrinsic resolution is about 3 μm. This low intrinsic resolution is very important if an intense neutron beam is available, for which geometrical unsharpness as high as 250 is possible.

REFERENCES

01- Berger, H. (1965).- Neutron Radiography. Methods, Capabilities and Applications. Elsevier Publishing Company.

02- Domanus, J.C., Matfield, R.S. (1981).- Neutron radiography handbook. D. Reidel Publishing Company.

03- Domanus, J.C. (1986).- Euratom neutron radiography working group. Proceedings of the Second World Conference on Neutron Radiography 339-347. Paris, FRANCE, June 16-20.

04- Durrani, S.A., Khan, H.A. (1975).- Solid state track detectors for neutron image recording, Radiography with neutrons (Hawkesworth M.R., ed.), BNES, London 71-77.

05- Fantini, M. (1986).- Advances and possibilities of cellulose nitrate detectors in corpuscular imaging. Proceedings of the Second World Conference on Neutron Radiography 635-638. Paris, FRANCE, June 16-20.

06- Fleisher, R.L. Price, P.B., Walker, R.M. (1985).- Nuclear tracks in solids-principles and applications. Berkeley, Cal.

07- Hawkesworth, M.R. (1977).- Neutron radiography: Equipment and Methods. Atomic Energy Review 15 (2) 169-219.

08- Khaddury, I.Y. (1976).- A neutron facility on the IRT-2000 reactor. In solid state nuclear track detectos. Proceedings of the 9th International Conference, Neuherburg/Munchen, 761-769.

09- Lferde, M., Lferde, Z., Monnin, M. et al., (1984).- Neutron radiography with track detectors. Nuclear Tracks and Radiation Measurements, 8(1-4), 497-499.

10- Matfield, R.S. (1971).- Neutron radiography. ATOM, monthly bufletin of the United Kingdom Atomic Energy Authority number 174, April.

11- Matsumoto, G., Murata, N., Suzuki, S., Matsumoto, M., Ohkubo, K., Ikeda, Y. (1986).- Track-etch neutron radiography with a new boron carbide converter. Nuclear Technology, 72, 201-211.

12- Pugliesi, R., Moraes, M.A.P.V. de (1987).- Aspectos qualitativos da neutrongrafia pela técnica do registro de traços. Ciência e Cultura, 39, (8), 772-774.

13- Pugliesi, R., Moraes, M.A.P.V. de, Yamazaki, I.M., Acosta, C. de F. (1988) Neutronradiography Experiments at the IEA-R1 Nuclear Research Reactor. Proceedings of the Third International Conference on Nuclear Data for Science and Technology, 1095-1097. Mito, JAPAN, 30/05-03/06.

assure a low track density, to prevent any overlapping between tracks. After exposure the films were chemically etched for different time intervals and the track diameters evaluated using an optical microscope. The experimental data were fitted by straight lines, as shown in figure 2, using the least square method. The evaluated etching times are shown in table 3.

The second step was to determine adequate exposure times for the same film converter screen assemblies. These times are those for which track overlapping are minimum, otherwise the resolution of the method would be worse. By making use of the SSNTD-MAKROFOL-E, the track overlapping behaviour was analysed, in a 370 $\mu m^2$ arbitrary area, in the microscope. Photographs of the track image in the microscope screen are shown in figure 3. The adequate exposure time is achieved for track density of about $0.08/\mu m^2$ which corresponds to 30 tracks in the area read. Exposures from 2 to 4 hours for each film-converter screen assembly were carried out. After chemical etching, the track yield was determined using the microscope. The experimental data as well as the straight lines obtained by the fitting method are shown in figure 4. The evaluated exposure times are shown in table 3, and correspond to exposures (neutron per square centimeter) of about $10^9$ n/cm$^2$.

It is necessary to consider, for sample analysis, its neutronic transmission, which will increase the exposure time to obtain the same track density. With this information, several radiographs were obtained and the results are shown in figure 5. These photographs were obtained without contrast improvements.

## CONCLUSIONS

Good contrast of the images, the smallest holes of the cadmium test piece, the internal structures of the objects as well as the powder graininess in the projectiles can clearly be seen in figure 5.

The good optical contrast is attributed to the low energy of the cold neutron beam ($E < 5$ meV), the film insensitivity for gamma and beta radiations and its low track background.

The best results were obtained with the films CN-85 and CR-39 due to their transparent background to visible light. A comparison between their values for etching and exposure times demonstrates maximum variations of about 30 minutes, which is not so high as to compromise their employment, although these exposure times are intrinsically high for technological goals. However, by cooling the beryllium filter, or alternatively by using two converter screens, lower exposure times can be readily achieved.

By taking into account the track yield as a function of the exposure time, the ratio "track per neutron" can be easily calculated and values of about $6 \times 10^{-3}$, $7 \times 10^{-3}$, $9 \times 10^{-3}$, were obtained for Makrofol-E and LR-115, CN-85 and CR-39, respectively. From these values it is clear that CR-39 presents the greater sensitivity for the 1.47 MeV alpha particle emitted from the $^{10}B$ reaction with neutrons, and this may be attributed to the fact that its bondings are stronger than those of the others films (Matsumoto et al., 1986).

The present "track per neutron" values are smaller than those obtained by Matsumoto for CA80-15 (similar to CN-85): $6.16 \times 10^{-2}$. This can be explained considering the greater effectiveness of the boron carbide converter screen

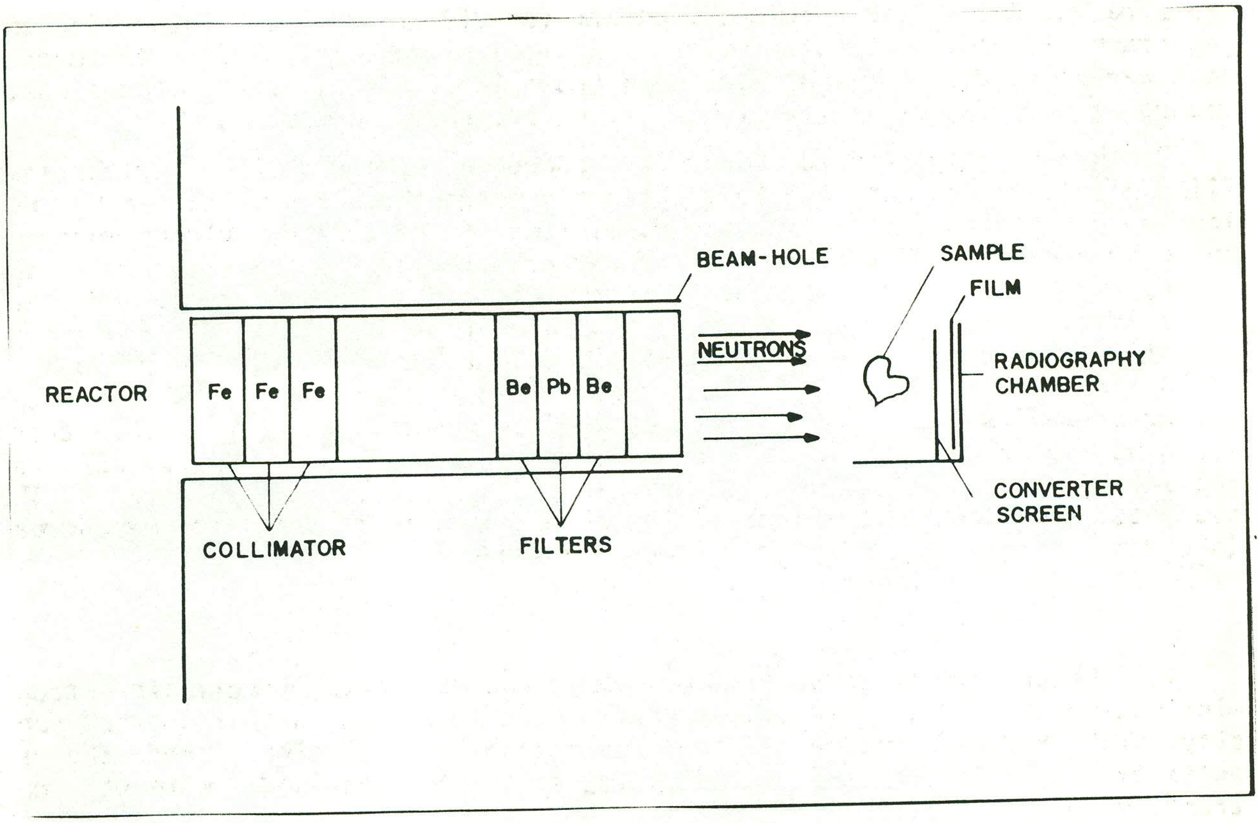


Figure 1-Schematic diagram of the experimental arrangement

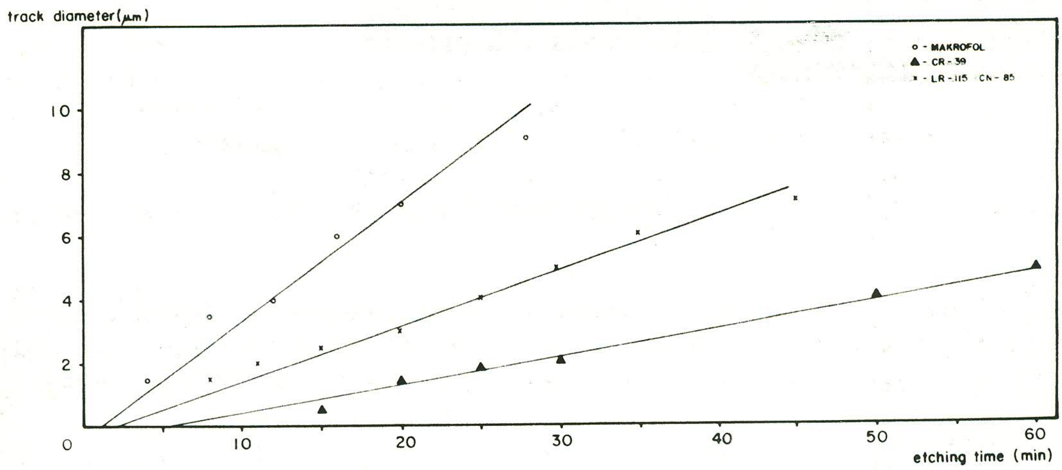


Figure 2-Track diameter growth evaluation

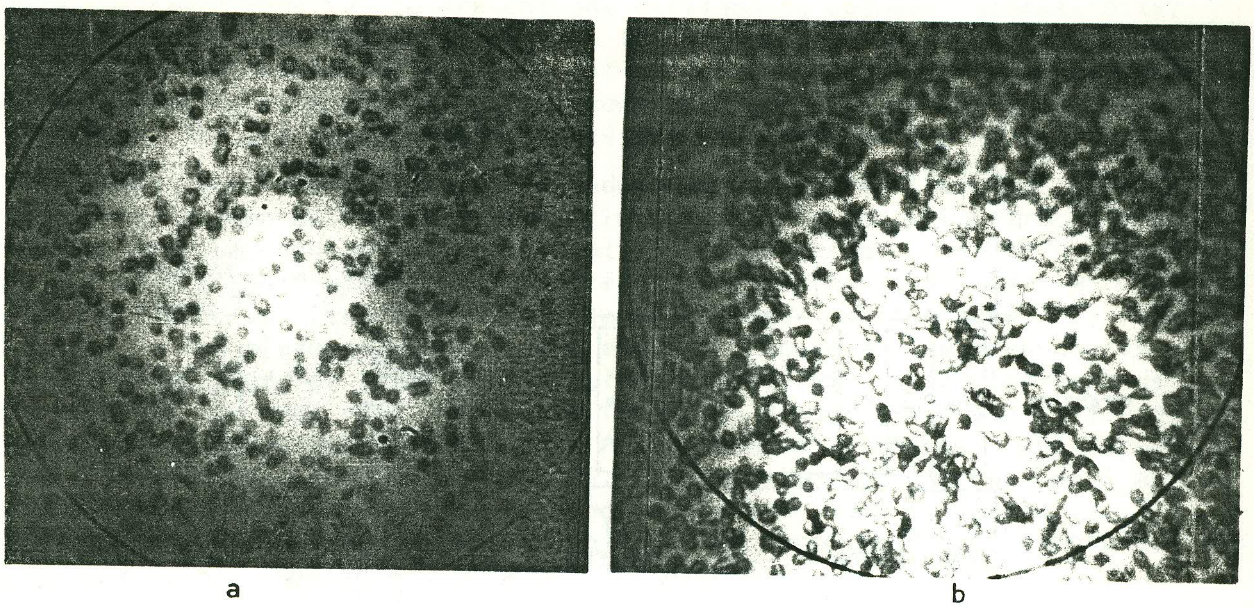


Figure 3- Track overlapping behaviour to different exposure times.
a) good expore time b) poor exposure time

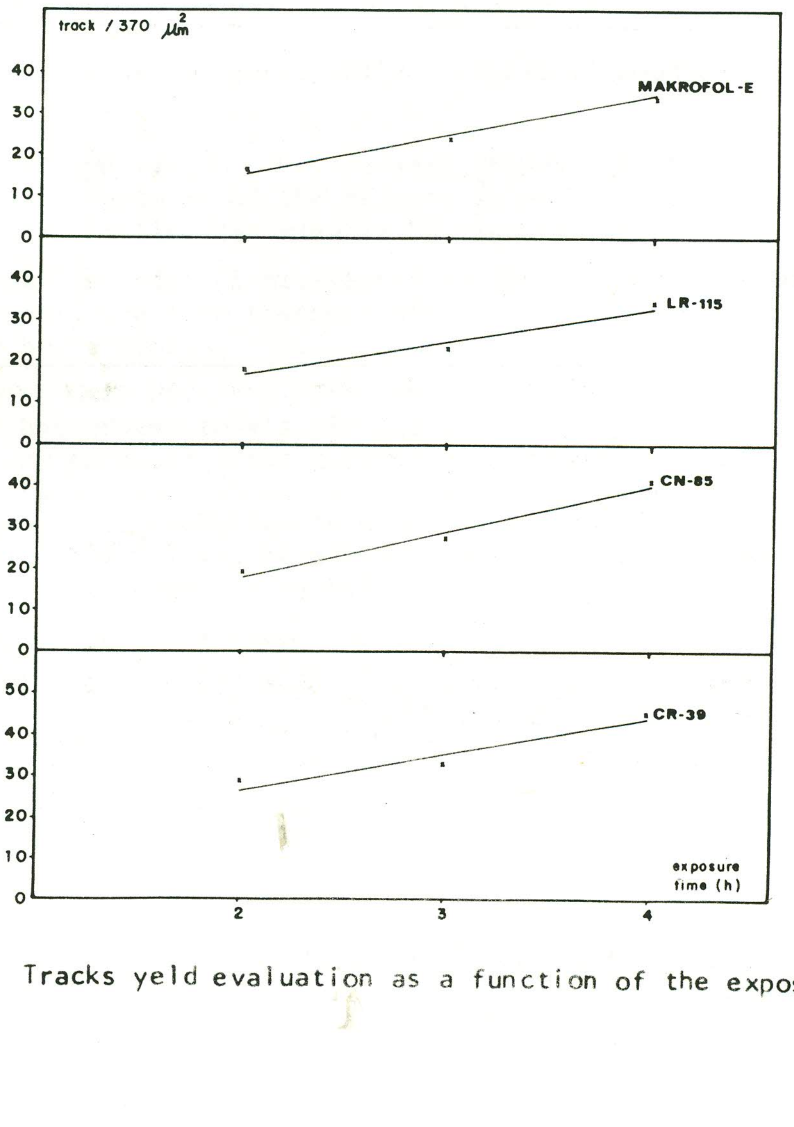


Figure 4- Tracks yeld evaluation as a function of the exposure time

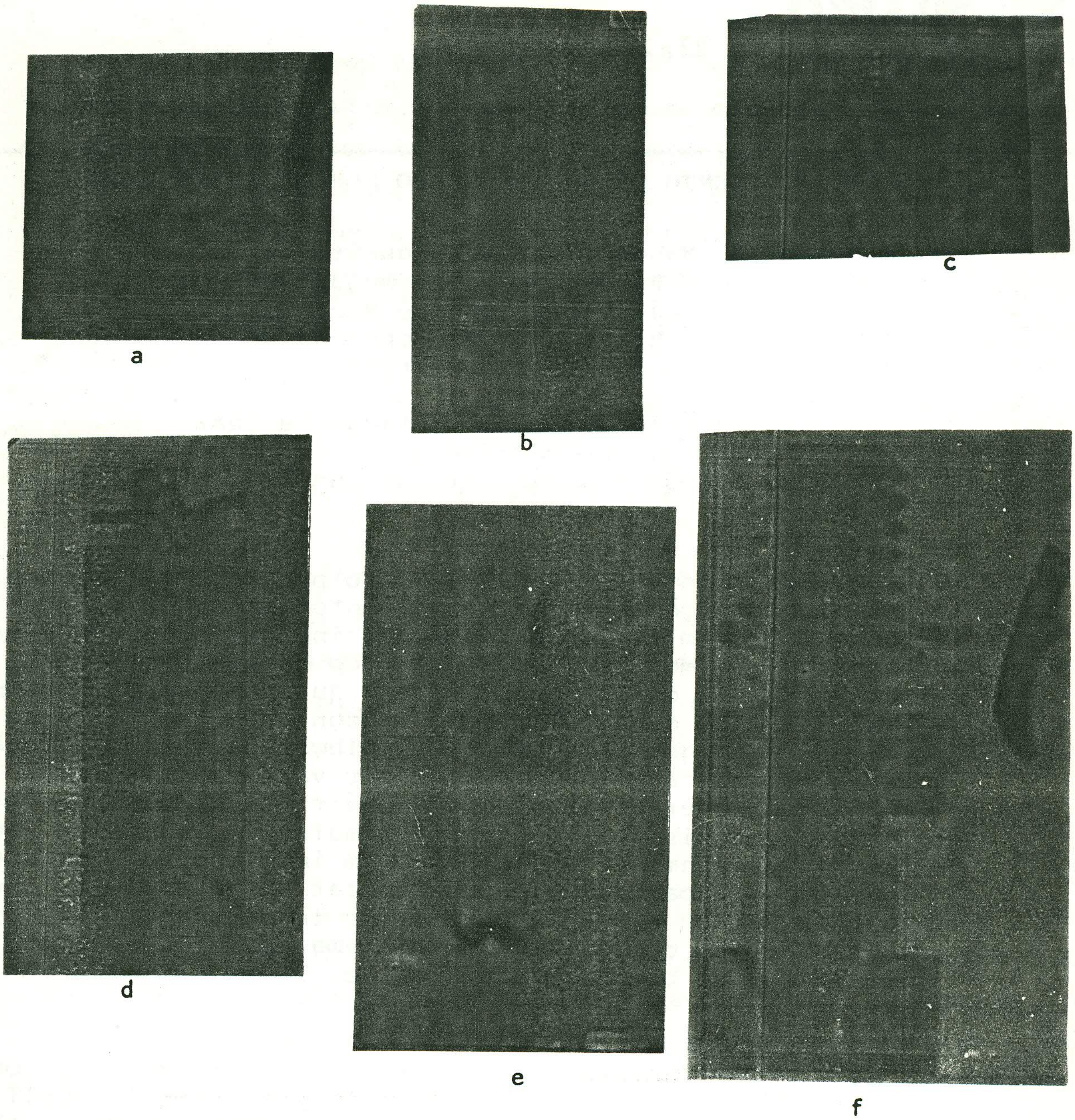


Figure 5- Neutron radiographs of some materials for CR-39 (a,b,c,d) and CN-85 (e,f).

a) brass padlock; b) rifle projectiles; c) cadmium test piece; d) gas lighter; e) revolver projectile; f) iron screw with a 2 mm hole in its upper part; copper wire with a cadmium test piece.