A PERSONAL NEUTRON MONITORING SYSTEM BASED ON SOLID STATE
NUCLEAR TRACK DETECTORS

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Presented at the 10th International Congress on
Solid State Nuclear Track Detectors
Lyon, 2-7 July 1979

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ABSTRACT

The use of solid state nuclear track detectors for personal neutron monitoring around high energy particle accelerators has been extensively investigated at CERN. A system based on cellulose nitrate (LR115) as a track detector in contact with different radiators (boron and polycarbonate) has been proposed to replace the NTA neutron film used so far. The holes created in the cellulose nitrate layer by charged particles such as alpha particles and carbon recoils are counted after etching with a microscope connected to an image-analysing computer (Quantimet).

The present paper describes the monitoring system chosen and presents the results of a large series of tests (calibration and field experiments) at CERN. The problems encountered in going from laboratory-scale tests to a large-scale routine use of the neutron monitoring system are discussed. The use of $^6\text{LiF}/^7\text{LiF}$ thermoluminescence detectors in conjunction with the track detector system to select the track detectors that require evaluation is proposed.

KEYWORDS

Personal neutron detectors; solid state nuclear track detectors.

INTRODUCTION

Behind the shielding of the CERN high energy proton accelerators, in particular inside experimental areas, personal neutron exposures may occur. This necessitates the use of an appropriate personal neutron dosimeter covering the wide neutron energy range expected. So far the traditional nuclear emulsion (NTA) has been used at CERN for personnel neutron monitoring in spite of its drawbacks such as poor neutron energy response and fading of the latent tracks limiting the period of use to one month.

For several years new methods for personnel neutron monitoring have been under review at CERN with the hope of replacing the NTA emulsion by a better detector. Methods based on the detection of low energy so-called Albedo neutrons alone do not satisfy our particular requirements since they suffer from too great variations in response as a function of neutron energy and can only be used if the neutron spectrum in which the exposure occurs is known (Höfert and co-workers, 1976).

An attempt to solve this problem at CERN by the use of solid state nuclear track detectors in conjunction with different radiators has been reported elsewhere. (Tymons and Tuyn, 1977; Dutrannois and Tuyn, 1977; Hassib and co-workers, 1977; Dutrannois and co-workers, 1978) whereby for example ^6LiF was used as thermoluminescence detector (TLD) as well as radiator in contact with the cellulose nitrate. Although various other track detector systems were investigated such as spark counting and electrochemical etching of polycarbonate foils, it was finally decided to base the new system on track registration in LR115¹ cellulose nitrate foils. This method avoids the problem of the use of fissile materials in the case of spark counting and the complexity of large-scale electrochemical etching. The present paper reports on our progress made in this field since the last meeting in Neuherberg in 1976. The problems encountered in going from laboratory-scale tests to a large-scale use of the neutron monitoring system are discussed.

EXPERIMENTAL PROCEDURES

The personal neutron dosimeter system chosen consists of a small polycarbonate (Delrin)² cassette containing an LR115 foil in contact with several radiators (Fig. 1). The LR115 foil is composed of a 12 μm red-dyed cellulose nitrate layer on a clear polyester base. Different radiators have been tested such as bismuth for high energy neutron detection through spallation products and boron evaporated on a glass backing for Albedo neutron detection with and without cadmium shields to absorb incoming thermal neutrons. The bismuth radiator was found to be insufficiently sensitive. It was also discovered that the rough surface of the glasses necessary to provide a good fixation of the evaporated boron layer caused damage to the LR115 foil in long-term use. Hence both radiators were abandoned. The latter has however been replaced by a new Kodak product consisting of boron

Fig. 1. Neutron detector holder

¹Trade name Kodak France.

²Trade name Dupont.

loaded plastic (NBA).³ Part of the LR115 foil is in contact with the cassette material, hence the polycarbonate material acts as a radiator for fast neutron detection which is based on tracks formed by heavy recoil nuclei like carbon produced both in the Delrin radiator and the foil itself. These heavy recoil tracks leave visible holes in the cellulose nitrate layer after etching.

The Albedo neutron detection is based on the registration in LR115 of alpha particles arising from the $^{10}\text{B}(n, \alpha)^7\text{Li}$ reaction.

To obtain a personal neutron monitoring system that provides reproducible results the etching procedure in the pilot installation is carried out as follows: after removal from the cassette the LR115 foils are loaded into a jig which accepts up to 88 foils in eight frames. Etching is then made in a bath containing 10 l of 2.5 N NaOH at 50°C for 5.5 hours. The caustic solution is cycled at a rate of 5 l/min from a 70 l container kept within $\pm 0.1^\circ\text{C}$. During etching the jig is slowly rotated (45 minutes per revolution), while the surface of the bath is kept clean by constant overflow. The circulating solution is filtered through a 5 μm nylon filter in order to remove the solid particles and gels created during etching. The flow diagram of the system is shown in Fig. 2 while the system itself is shown in Fig. 3.

After etching the foils are washed for 1 hour in water followed by 10 min washing in a 50% $\text{C}_2\text{H}_5\text{OH}$ solution. Finally they are dried in filtered air at 25-30°C.

It was found that this etching procedure provides clean detector foils without any disturbing surface deposit. Moreover the positioning of the foils and the rotation of the jig ensure a constant bulk etching rate along the surface of the individual foils as well as for all the foils in a given batch.

Fig. 2. Pilot plant flow diagram

³ Trade name Kodak France.

Table 1a: Results of reproducibility tests with thick natural uranium alpha source (3 min. exposure, 18 foils per batch)

Number etched batch	Hole density (holes/cm ²)	σ (%) (stochastic uncertainty for 18 foils)
1	2500	5
2	2639	3
3	2578	5
4	2050	5
5	2056	5

Table 1b: Results of reproducibility tests for 800 mrem PuBe neutron exposures on phantom (14 foils per batch)

Number etched batch	Hole density behind plastic radiator (holes/cm ²)	σ (%)	Hole density behind boron field (holes/cm ²)	σ (%)
1	33	28	2080	39
2	33	32	1619	24
3	25	28	1420	32
4	28	29	570	40
5	14	38	550	66

The stray radiation field exposures around the accelerators took place in different neutron spectra whereby the relative contribution of low energy neutrons could be deduced from the ratio R of the hole density behind the boron radiator B and the hole density behind the plastic radiator C . Typically this ratio was found to vary between 5 for a "hard" spectrum on top of a primary target shielding, to more than a hundred for a "soft" spectrum as found opposite an access labyrinth to a primary beam area.

The hole density behind the plastic radiator is about 200 holes/cm² rem for a hard stray radiation spectrum compared to 30 holes/cm² rem for a PuBe spectrum. These values have to be compared with a background in the unirradiated foils of 11 holes/cm².

Previous results obtained under evaluation conditions (higher magnification, higher etching temperature, different boron radiator) different from the conditions presented above have shown the following two-parameter form:

$$H = \alpha R^{\beta} C$$

where H is the dose equivalent as derived from the hole density C behind the plastic radiator, R the hole density ratio as defined above, and α, β are experimentally determined parameters. For the present evaluation conditions sufficient data are lacking to arrive at a similar fitting form. Moreover the

Fig. 3. Pilot treatment plant (left) and rotating jig (right).

The evaluation of the hole densities behind the different radiators is performed with an automatic scanning microscope equipped with an image-analysing computer (Quantimet). The LR115 foils are mounted in ordinary 35 mm slide holders for routine evaluation. In the past the hole densities were evaluated by scanning 30 fields of 1.2 mm^2 each for the different radiator areas. Such a counting procedure becomes too time-consuming for routine use. Therefore the optical magnification was further reduced such that at present a field of 0.36 cm^2 is scanned. More details on the evaluation method are presented in a separate paper (Dutrannois and Sullivan, 1979) at this conference.

To each batch of LR115 foils to be evaluated, controls irradiated with alpha particles from a thick uranium source and PuBe source neutrons under standard conditions were added to be etched simultaneously. In this way the reproducibility of the system could be controlled.

The dose equivalent received by the foils exposed in the stray fields was determined by the standard CERN four-detector method (CERBERUS) described elsewhere (Höfert and co-workers, 1976). The detectors facing the apparent radiation source were exposed on a phantom made of a slab of tissue-equivalent material.

RESULTS AND DISCUSSION

The data presented in this paper were results obtained with the conditions of readout and etching as described above. Foils coming from the same roll of LR115 were irradiated and treated in five different batches. The results of the reference foil irradiations with alpha particles from a thick uranium source and PuBe neutrons are presented in Table 1 a and b. As can be seen, the hole density for alpha exposure under standard conditions decreased considerably for the last two experiments. This may possibly be explained by variations in the thickness of the LR115 cellulose nitrate layer which is specified to be $12 \pm 1 \mu\text{m}$. The foils irradiated with PuBe neutrons show large variations, between different batches and between foils in the same batch. The latter variations are much more pronounced in foils irradiated under the boron radiator, whereas they are reasonably consistent with the variations expected from a normal distribution under the polycarbonate radiator.

stochastic uncertainties of the hole densities behind the boron loaded plastic radiators of badges irradiated simultaneously at the same position were found to be unacceptably high. It may therefore be considered to abandon the boron radiator and replace its information on the contribution of low-energy neutrons by the information obtained from a pair of $^6\text{LiF}/^7\text{LiF}$ thermoluminescence detectors incorporated in the present pilot project holder. Initially these TL detectors were introduced to provide a flag in case a neutron exposure had occurred such that the LR115 foil should be etched and read. The TL information replacing the hole density behind the boron could easily be incorporated in a similar fitting form.

CONCLUSIONS

The results obtained with the pilot project so far are encouraging. However, more tests are needed to investigate problems like the reproducibility of treatment and variations found in the hole densities behind the boron loaded plastic radiator.

The new badges distributed among a number of individuals working inside as well as outside neutron areas to be worn in parallel with the NTA film will provide the information on the long-term characteristics of the new detector necessary to reach a final decision concerning the replacement of the old NTA film.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to B. Marshall, J.M. Hanon and F. Lehmann, who have provided the data without which this study could not have been made.

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