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PERSONAL FAST NEUTRON MONITORING BY USE OF KODAK NTA FILMS

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BUDAPEST

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Summary

Investigations in connection with routine dose measurements for personal fast neutron monitoring are reported. The energy and angular dependence as well as the fading of the Kodak NTA track film applied in the measurement have been evaluated. The film permits to cover doses and energies from 0,05 to 10 rem and from 0,5 to 14 MeV, respectively, provided the gamma dose does not exceed 1 R. Experiences in fast neutron dose measurements, performed at the Institute routinely since 1964, are discussed.

Introduction

Routine fast neutron monitoring of persons working with nuclear reactors, accelerators and radioactive neutron sources is performed nowadays almost exclusively by the use of nuclear emulsion track films. Though the track film method has considerable limitations as regards the ranges of both energy and dose, and the error of the measured values may be in some cases as high as 100 %, its use has become general because of its sensitivity, simplicity and last but not least owing to the low cost involved [1 - 5].

The Kodak NTA track film produced in the U.S.A. which consists of about 30 μ thick nuclear emulsion on celluloid backing of 3 x 4 cm size, in paper cover, is a satisfactory personal dosimeter and is used at our Institute currently for the routine fast neutron monitoring of the personnel.

Method of track counting

The hydrogen nuclei in the emulsion and its environment are recoiled upon elastic collision with the incident fast neutrons. The recoiled protons ionize the emulsion along their tracks and produce thereby a latent picture which can be developed so that the tracks become visible when sufficiently enlarged.

Neutrons which have the same energy distribution produce in the emulsion a track density (track/unit surface) proportional to the absorbed dose.

The energy dependence of the dose to density ratio is determined by two energy dependent coefficients, namely, the track production probability and the dose equivalent per unit neutron fluent (neutrons/cm^2).

The energy dependence of the track production probability was evaluated for the dosimeter arrangement used in our measurements by the method of Cook and Deme [6, 7]. In our dosimeter a PVC foil is used as radiator in addition to the paper covering provided by the manufacturer. The PVC covering protects the film from humidity and if one welds a safety pin into it the film dosimeter can be worn pinned onto the dress.

The following data were used in the calculation:

emulsion thickness	9,7 mg/cm^2
paper thickness	23,6 "
PVC thickness	26,0 "
hydrogen content of emulsion	$9{,}7 \cdot 10^{18}$ H atoms/mg [8]
hydrogen content of paper	$3{,}7 \cdot 10^{19}$ H atoms/mg
hydrogen content of PVC	$2{,}9 \cdot 10^{19}$ H atoms/mg
miniumum detectable energy	0,5 MeV.

The detection of neutrons with energies below 0,5 MeV becomes uncertain, since the protons produce at such low energies very short tracks of about 1-3 grains which cannot be clearly distinguished from the background.

The calculated curves are shown in Fig. 1. The total response is composed of three contributions.

1/ The protons recoiled in the emulsion are detected in the form of tracks, thus the number of tracks produced by neutrons with energies above the threshold energy of 0,5 MeV is proportional to the proton scattering cross section.

2/ Out of the protons recoiled in the paper radiator only those are detected which transfer energies above 0,5 MeV to the emulsion. The number of protons produced in the thick radiator adjacent to the emulsion depends on the range of the recoiled protons. If the radiator ceases to be of saturation thickness for the recoiled protons, the number of protons decreases with increasing neutron energies.

3/ The effect of the second, i.e. the PVC radiator, is felt only at neutron energies which are high enough to energize the protons to an extent that after slowing down they can still transfer an energy above 0,5 MeV to the emulsion.

Since the value of the dose equivalent is of practical interest, the energy dependence of rem-dose per unit neutron fluent was also calculated using the values of maximum permissible flux [9]. The variation of the value of track density/rem with energy is shown in Fig. 2.

The points marked next to the solid curve represent the values obtained in measurements which have been performed to check the predicted energy dependence. In these measurements the monoenergetic neutrons with energies from 2 to 5 MeV were produced in Van de Graaff accelerator by $D/d,n/^{3}H$ reaction. The neutron flux was measured by energy independent "long counter" [10] which had been calibrated with standard neutron sources. 14 MeV neutrons were produced by $T/d,n/^{4}He$ reaction in a cascade neutron generator. Most of the irradiations, for the routine calibrations as well as for the investigations to be described in the following, were performed with Po-Be neutron source.

The perpendicular lines at the experimental points shown in the figure indicate the triple statistical error of the measurement.

As apparent from the figure, the energy dependence of the response is considerable, especially at the low energy end. For routine personal dosimetry it seems to be inadequate to evaluate the neutron energies from the length and the angular distribution of the tracks.

For neutrons of unknown energy, assuming a medium response of the dosimeter, the equivalent dose can be determined to $\pm$ 70 % accuracy in the range of neutron energies from 0,8 to 14 MeV. When the neutron source is known, and in practice it is usually so, the average energy of the incident neutrons can be evaluated by known methods [10].

All this applies, of course, to the ideal case of neutron incidence normal to the plane of the film. In Fig. 3 the angular dependence of the track film irradiated by Po-Be neutrons is to be seen. It is apparent that for parallel incidence only about half of the tracks can be detected for the same dose on the same surface area as compared with normal incidence. The angular dependence varies with the energy. The effect was observed to increase with decreasing energies [11] and the author of this report suggested that in order to avoid an underestimation of the dose, a correction factor of 0,75 should be applied in the calibration, if the film had been exposed to neutrons of other than normal incidence.

A large error may be caused in the evaluation of the dose if the neutrons are incident from the rear side of a person. Measurements performed on a water phantom have shown that in such cases the dose measured is only about 1/10 of the value measured at the front exposure.

Phantom measurements were performed also to determine the difference between the dose evaluated from surface measurement and the average neutron dose absorbed in the body. For a broad beam of normally incident Po-Be neutrons the average value of the absorbed dose is half that measured on the surface. The backscattering effect of the body increases the track density by about 20 % relative to that of the film exposed in free air.

The minimum detectable dose by NTA film depends on the magnitude of the scanned surface area and varies from 20 to 100 mrem in the different reports. Considering the maximum permissible dose rates, the reported values seem to be safe enough. The maximum detectable dose is 10 to 20 rem which cannot be extended since at higher track densities the picture gets too intricate for satisfactory scanning.

For the detection of neutrons doses exceeding 10 rem, emergency dosimeters are used [12]. In these dosimeters the fast neutron dose is measured independently of the gamma radiation and without any limitation on the maximum detectable dose.

The neutrons are frequently accompanied by gamma radiation. The incident gamma rays blacken the film. This is manifested by little dark spots appearing on the enlarged picture. It has been found in our experiments that these background spots considerably interfere with the counting of neutron tracks, if the dose of the incident hard gamma rays is higher than 500 mR. At a dose of 5 R, for instance, the number of detectable tracks is reduced by about 50 %. At 20 R the tracks cannot be isolated from the background at all. Since the emulsion is more sensitive to soft gamma rays, their interference is even more inconvenient.

The fading of the latent picture may also substantially impair the reliability of the scanning [13]. The fading of the grains forming the tracks is due to the ambient humidity and temperature. It has been observed that in an atmosphere of about 100 % rel. humidity at room temperature half of the tracks disappeared in about a week. This effect can be reduced if the irradiated films are kept in a refrigerator. In this case the fading was observed not to exceed 10 % over a month. The PVC covering was also found to reduce the fading.

Some authors [14] proposed the dessication of the films and polyethylene covering in order to protect the tracks from fading. This method was tested and the results are shown in Fig. 4. A set of films was kept in exsiccator for a few days before covering them with polyethylene foils. After irradiation the films were stored at room temperature in an atmosphere of 50-70 % rel. humidity. It is apparent from the figure that over a period of 2 weeks there is not any appreciable difference between the fading observed in the dessicated and polyethylene covered films and that of the control set treated in the usual way. The PVC foil, however, proved more convenient to handle, than polyethylene.

The fading was investigated under different conditions /e.g. in winter in open air and in heated premises/. The irradiated films were worn for this experiment for two weeks by persons working far from neutron sources. The fading of tracks proved to be, on the average, 35 %. Thus, if the time of the exposure is not known, the fading may be responsible for an underestimation of the absorbed dose by about 20 %.

Routine monitoring and experience

The routine fast neutron monitoring of 50-60 persons in periods of two weeks started in our Institute in 1964.

The films are developed in always freshly prepared solution composed of

boric acid	35 g
sodium sulphite anhyd.	16 g
potassium bromide	0,8 g
amidol	3,5 g
per litre of water.	

The developing does not affect the film sensitivity, therefore a calibration set is prepared only, if a new batch of films is started /the thickness of the emulsion may vary per batch/.

The films are scanned by Zeiss "Lanameter" projection microscope, magnifying the films by a factor of 1000. A 100 x 100 μ^2 field of the film is visible on the screen. 1,5 cm length of this field is scanned by the continuous traverse of the stage in one direction. This method reduces the error due to edge effect as compared with the discrete field technique [15]. The scanning of each film takes about 10-15 minutes. The background is 2 tracks/1,5 cm^2 on the average. If the number of tracks at the scanned surface is ≤ 5, the dose is below the minimum detectable value. For tracks exceeding 5, for better accuracy, such surface areas are scanned which are twice or several times as large as the usual area. In this manner it is possible to evaluate 50 mrem on an area of 3 mm^2 to $\pm$ 10 % accuracy. In Fig. 5 the track abundance on films exposed to 50 mrem from Po-Be source is shown, as evaluated from the scan of 65 mm^2 surface of 25 films.

The films are numbered with a deep printer and the identification number is unambiguously visible on both the paper cover and the developed film to avoid any possible confusion.

Three years' experience proved that the radiation protection at our Institute is satisfactory also as regards fast neutrons. Detectable doses but never exceeding the maximum permissible level have been found in a few cases only. It is of interest to note that detectable body burdens were found only on persons working with the accelerators or neutron generators and never on the personnel of the research reactor. For this reason the sensitivity of the film to the moderated fission neutrons emerging from the horizontal channel of the WWRS-type reactor was investigated in special measurements. In this set of experiments the films were placed on the external shield of the horizontal channel /the most probable place for exposure/ and left there for various times when the channel was kept open.

It was found that the films can be evaluated to about 400 mrem and the response is linear and not appreciably different from that obtained in the case of Po-Be neutrons. At higher doses than 400 mrem the interference with the gamma background / $>$1R/ presents considerable difficulties in the evaluation.

Since the measurements performed at various spots adjacent to the reactor showed the fast neutron to gamma dose ratio to be less than 1, the fast neutron dosimeter is scanned only if the detected gamma dose exceeds 50 mR per month on the gamma-beta dosimeter [16] of any individual of the reactor personnel.

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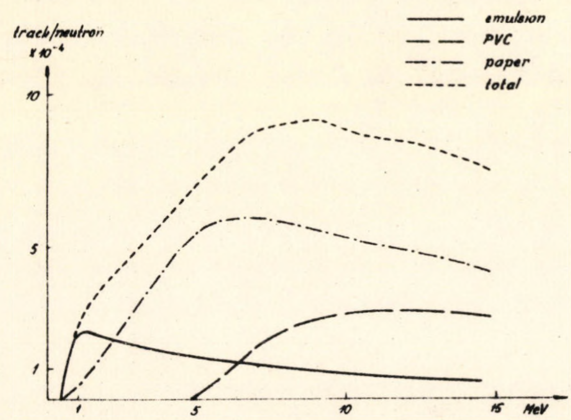

Fig. 1

Probability of track production versus energy

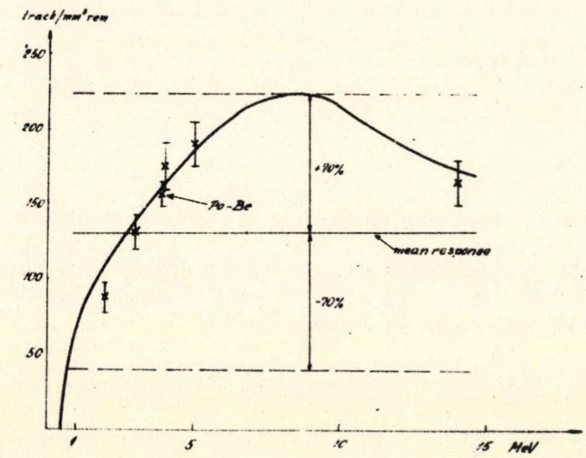

Fig. 2

Energy dependence of dose equivalent response

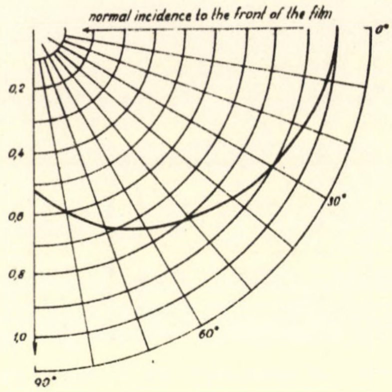

Fig. 3
Angular dependence of track density for Po-Be neutrons

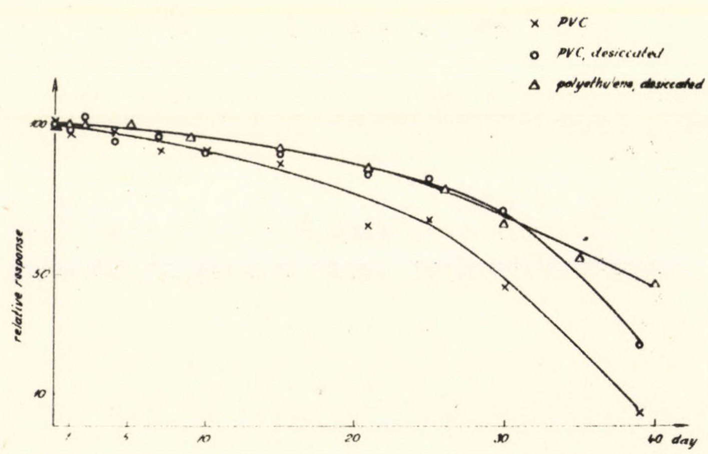

Fig. 4
Fading of track films

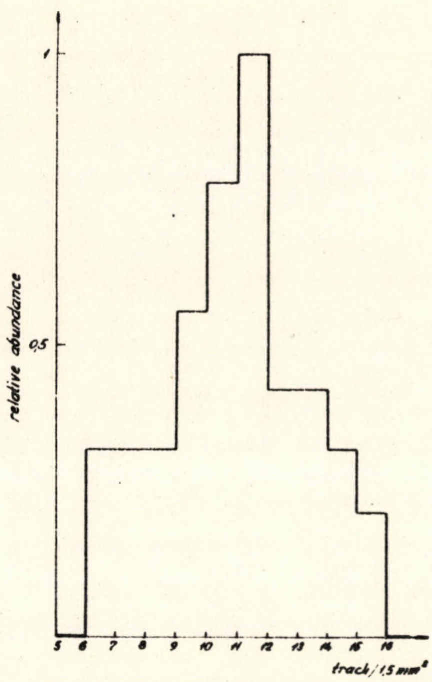

Fig. 5
Distribution of track counts at 50 mrem

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