Radiation Physics, II. Riga 1964

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Personnel Dosimetry Technique Using Nuclear Emulsions for Monitoring Fast Neutrons

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Translated at CERN by J. Rice
and revised by N. Mouravieff
(Original: Russian)

(CERN Trans. 66-3)

Geneva
March, 1966

66/270/5/p/mm

Personnel Dosimetry Technique Using Nuclear Emulsions for Monitoring Fast Neutrons

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For exact measurement of the absorbed dose in neutron fields with an unknown spectrum, it is necessary for the energy dependence of the response of the radiation detector to have the same character as the response of the tissue to the neutron energy. Of the known methods for personnel neutron dosimetry the emulsion technique proposed in Ref. 1) most fully satisfies this requirement. This method uses as a detector thinly-laminated nuclear emulsions, placed in a packet of alternating layers of hydrogenous radiators and absorbers. The emulsion records the recoil protons generated both in the emulsion itself and in the hydrogenous radiators surrounding it. This method is based on the fact that the alternation of radiators and absorbers of a fixed thickness ensures that the number of the tracks of recoil protons generated in the emulsion is proportional to the absorbed dose in rad, independently of the neutron energy. Such a packet can serve as a personnel fast-neutron dosimeter.

At the JINR high-energy laboratory this technique has been used for more than three years. Recoil protons are recorded by "K" type (20 μ) nuclear emulsion applied to a 130 - 140 μ triacetate backing. The characteristics of the neutron film badge with this emulsion are given in Ref. 2). Details of the thickness of the raw materials, from which the badge is prepared, and the order in which they are arranged, are found in Table 1.

Arranged in the order mentioned, the badge (Fig. 1) is mounted in a standard IFK holder in addition to a RM-5-1 type X-ray film. The position of the neutron film badge and of the compensating gamma-radiation filter is shown in Fig. 2.

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Table 1

Material	Thickness of 1 layer mg/cm^2	Number of layers
Cardboard	58	1
Aluminium	27.5	3
Triacetate film	17.2	2
Aluminium	27.5	1
Black paper	6.6	2
Backing for emulsion (triacetate film)	17.2	1
Emulsion	6.9	1
Triacetate film	17.2	1
Black paper	6.6	2
Aluminium	27.5	1
Triacetate film	17.2	2
Aluminium	27.5	3
Cardboard	58	1

The additional error arising from the use of other thicknesses of the raw materials was found by calculation. It has been found that a change in the thickness of the aluminium foil of from - 10% to + 20% leads to a change of not more than ± 5% in the number of tracks in the emulsion when this is irradiated by neutrons of more than 7 MeV, but the number of tracks is not affected when the neutron energy is lower.

A change of ± 10% in the thickness of the triacetate film gives rise to a change of ± 10% in the number of tracks in the emulsion for neutron energies higher than 3 - 4 MeV. This means that more attention must be given to the choice of the triacetate film than to the choice of the aluminium foil.

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1. CALIBRATION OF NEUTRON FILMS

The proportionality factor between the number of tracks per unit area of the emulsion and the dose can be determined by calibrating the dosimeters in a known neutron flux. For calibration we used a calibrated Po + Be or Pu + Be neutron source with a yield of 1 to 10 $\times$ 10^6 neutrons/sec. The calibration of the neutron sources was carried out by comparing them with a N-26 Ra + Be source the neutron yield of which was known to within $\pm$ 2%. The comparison was done by the method of activating manganese in an aqueous solution $KMnO_4$ [3]. The precision of the comparison of the neutron yield was $\pm$ 7%.

The effective energy (for dose effect) of the Po + Be neutron source, considering the first collision [4,5], is equal to 4.1 MeV. Our calculations were based on the spectrum of the Po + Be source, as obtained by Medvetski [6]. This leads to the following average absorbed dose per 1 neutron from the Po + Be source (for first collisions): 4.3×10^{-9} rad/neutron $\times$ cm^{-2}.

We assume the relative biological effectiveness to be equal to 10. The choice of this value is justified by the fact that the neutron spectrum in our case was near to the evaporation spectrum for which an estimate of the RBE value gives the value 9 [using the relation RBE = f(E) from Ref. 7)]. The neutron flux [calculated for first collision [8]], which corresponds to the value of the maximum permissible dose per week and per month when RBE = 10, is the following:

100 mrem	2.3×10^6 neutron/cm^2
450 mrem	1.03×10^7 neutron/cm^2 .

Since the calculation of the neutron film takes into account only first collision doses, the calibration must be done in such conditions that the collision is guaranteed to be single. Then when individual dosimeters are worn, the neutrons subjected to multiple scattering in the human body give an additional contribution (build-up factor) in the number of recoil protons recorded, which guarantees the approximation to the real

value of the dose on the surface of the body (taking into account the contribution of multiple scattering). Carrying out the calibration on the basis of the curve of multiple collisions in the absence of a phantom would lead to errors. On the other hand constant use of a phantom when calibrating is inconvenient. Therefore we carried out another experiment for comparing the increase in the response of the neutron packet in the presence of a polyethylene phantom and with known values of the build-up factor.

The experiment showed that the number of tracks in the emulsions as a result of multiple scattering in the phantom was on an average 25% higher than without a phantom. The values of the build-up factor, determined by calculation and experimentally, are given in a number of papers[9-12]. According to these data, the value corresponding to a neutron energy of 4.1 MeV is B = 1.2 to 1.5, which overlaps (1.25 times) the increase in the number of tracks obtained in our experiment. This confirms the validity of the method adopted by us for calibration in air using the curve of first collisions for calculating the calibration constant, the value of which is given below.

We made the calibration in air far from scattering objects at a distance of 20 to 40 cm from the source. The neutron film badges were arranged in such a way that their plane was perpendicular to the incident neutron flux. For transfer from perpendicular to isotropic radiation the coefficient 0.75 is introduced, which is determined experimentally in Ref. 2). The diagram in Fig. 3 shows the reproducibility of the calibration results.

2. CHEMICAL PROCESSING AND SCANNING OF THE EMULSION

The film was processed by a standard method, developed at NIKFI (Motion Picture and Photography Scientific Research Institute) for thin layers of emulsion. The neutron film badges had to be taken apart and the emulsions had to be processed under diffused non-actinic yellow-green illumination with No. 117 or 118 light filters and no more than a 25 W bulb.

Direct rays from the lamp must not fall on the film. After a neutron film badge had been taken apart the number of the corresponding holder was written on the emulsion with a metal stylus. The emulsion films marked in this way were fitted into the slots of the developing rack (Fig. 4). Together with these "real" films we developed six calibration and 2 - 3 background films.

The chemical processing of "K" type (20 μ) emulsion on a triacetate base is carried out in the following steps:

1. Saturation in distilled water at a temperature of 18 - 20°C for 5 minutes.
2. Developing in an amidol developer*) composed of the following:

Amidol	3 g
Anhydrous sodium sulphite	12 g
Water to	1 litre
Temperature of developer	20 ± 0.5°C

   Developing time is 5 minutes.
3. Rinsing in distilled water for 1 minute.
4. Stop bath of 1% solution of acetic acid at 13 - 15°C for 5 minutes.
5. Rinsing in distilled water for 1 minute.
6. Fixing in 40% solution of sodium hyposulphite at 13 - 15°C. Duration of fixing equals twice the clarification time (roughly 20 to 25 minutes).
7. Washing by decantation. The first decantations are done in adequately filtered tap water and the later ones in distilled water. The washing time is roughly equal to or more than the fixing time.
8. Drying in a dust-free place without forced-air circulation.

Scanning of the emulsion is done on a MBI-3 microscope with a magnification of 950 (black tracks on a light background) or on a "lumipan" microscope, with which it is possible to observe light tracks on a dark background, which is more convenient. In either case we used an immersion

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*) Amidol developer quickly oxidizes, therefore it is prepared immediately before use.

objective 60 and an eyepiece × 10, the diameter of the range of vision being 150 μ. The film with the emulsion was placed in the microscope in a special holder, shown in the diagram in Fig. 5. Counting of the tracks is done through a cross-section 0.15 × 15 mm (the area of the cross-section being 0.0225 cm^2) by shifting the microscope stage lengthwise. The length of the cross-section is read along the vernier in the microscope stage. The thickness of the developed film after drying is 10 μ. Scanning in depth with such a thickness is still necessary, but it does not increase the scanning time significantly, provided the film can be moved in the horizontal and vertical directions simultaneously. The smallest length of track which can still be identified is about 3 μ (three or four grains placed in one straight line). The number of tracks being observed can be conveniently recorded, without leaving the microscope, by means of an electromechanical counter.

When calculating the dose from the number of tracks in the cross-section of the "real" emulsion we deducted the number of tracks in the cross-section of the background emulsion. As background we took the average number of tracks from several cross-sections in each background film.

The dose can be calculated by means of the formula

$$D = A(N - N_{\Phi}) \qquad (1)$$

where N is the number of tracks in the cross-section of "real" film;

N_{Φ} is the average number of tracks in the cross-section of background film;

D is the dose in rem;

A is the coefficient determined from Po + Be calibration, and is equal to 0.45 rem/N_{cal};

N_{cal} is the number of tracks in the cross-section, corresponding to the monthly maximum permissible dose, multiplied by the coefficient 0.75, allowing for isotropic radiation when the holder is being worn (A is on the average equal to 0.005 rem/track).

The use of fast-neutron radiation monitoring under our conditions showed that on the average 20 - 40% of those working in an area where there is a possibility of neutron radiation, receive less than 0.1 of the maximum permissible fast-neutron dose. In that case increased measuring errors may be tolerated in order to save time spent on scanning. If in the first 3 mm of a standard 15 mm cross-section not a single track was detected, the scanning was stopped.

In the register of individual radiation exposures a radiation dose of 0.01 rem was then recorded as most probable. This value was determined in the following way.

108 films with no tracks in a 3 mm cross-section were scanned over the whole length of 15 mm. The average number of tracks in the cross-section was

$$N_{av.15\ mm} = \frac{\sum_i N_i\, n_i}{\sum_i n_i}\ , \qquad (2)$$

where N_i is the number of tracks in the cross-section;
n_i is the number of cross-sections with N_i tracks.

According to Eq. (2) we get:

$$N_{av.15\ mm} = 3\ .$$

The average number of background tracks in a cross-section of 15 mm

$$N_{av.bg} \geq 1\ .$$

Consequently, the average number of tracks in a 15 mm cross-section, due to the "real" neutron radiation, is equal to

$$N_{av.re} \leq 2\ .$$

This number of tracks corresponds to a dose of the order of 0.01 rem ± 100%.

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The total amount of time spent in the various operations necessary for this method of personnel monitoring is shown in Table 2*).

Table 2

Operations	Total time in hours
Preparation of holder (checking, adjusting and numbering)	4 hours
Preparation of the films (cutting, etc.)	1
Loading holders and neutron badges	6
Unloading holders and marking films	6
Calibrating reference films	3
Putting films into developing racks	2
Chemical processing of films	2
Scanning with microscope	120
Calculating dose and filling in dosimetry cards	6
Preparation of working space, adjustment of microscope, etc.	10
Total	160 hours or 27 working days

Joint Institute of Nuclear Research
of the USSR Academy of Science

*) The table shows the calculation of the time spent by one qualified laboratory assistant on the various operations in connection with the processing of 500 neutron film dosimeters.

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REFERENCES

1) J. Cheka, Nucleonics 12, 6 (1954).

2) L.S. Zolin, V.N. Lebedev and N.I. Salatskaya, Atomic Energy 13, 467-471 (1962).

3) V.A. Davidenko and A.M. Kucher, Atomic Energy 2, 334-336 (1957).

4) G. Hurst, R. Ritchie and V. Mills, Data of the International Conference on the Peaceful Uses of Atomic Energy (Geneva 1955) Vol. 14, Fizmatgiz, M. 265 (1957).

5) NBS Handbook 75 (1961).

6) L. Medvetski, Atomic Energy 13, 583-587 (1962).

7) W.S. Shyder, Selected topics in radiation dosimetry. International Atomic Energy Agency, Vienna 617, (1961).

8) W.S. Shyder and J. Neufeld, Brit.J.Radiol. 28, 312 (1955).

9) W.A. Mills and G.S. Hurst, Nucleonics 12, 4 (1954).

10) T.A. Barr and G.S. Hurst, Nucleonics 13, 2 (1955).

11) G. Goldstein, Principles of reactor shielding, Gosatomizdat M (1961).

12) M.I. Shal'nov, Neutron tissue dose, Gosatomizdat M (1960).

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FIGURE CAPTIONS

Fig. 1 : External view of neutron film badges.

Fig. 2 : Arrangement of the neutron film in a standard IFK holder:
1. Body of the holder; 2. Cover of the holder; 3. Neutron film; 4. Type "K" nuclear emulsion for recording neutrons; 5. Lead 0.75 mm thick; 6. Aluminium 0.5 mm thick; 7. Type RM-5-1 X-ray film.

Fig. 3 : Reproducibility of the calibration in time. δ constant calibration in relative units. The size of the error, indicated in the figure, characterizes the statistical accuracy of the results.

Fig. 4 : Developing rack.

Fig. 5 : Film holder for MBI-3 microscope:
1. Frame of the holder; 2. Glass; 3. Slot for film.

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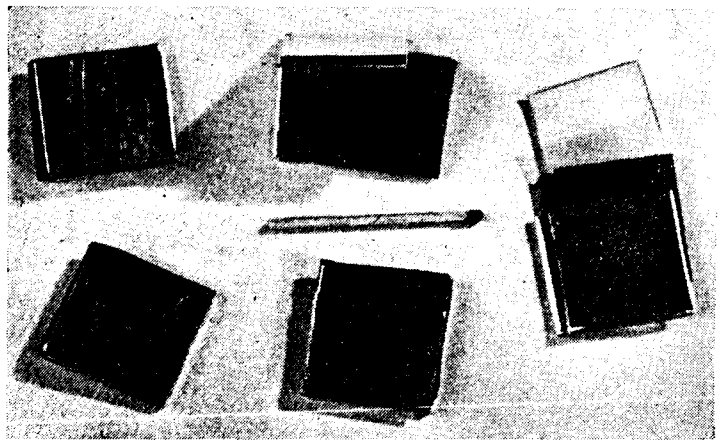

Fig. 1

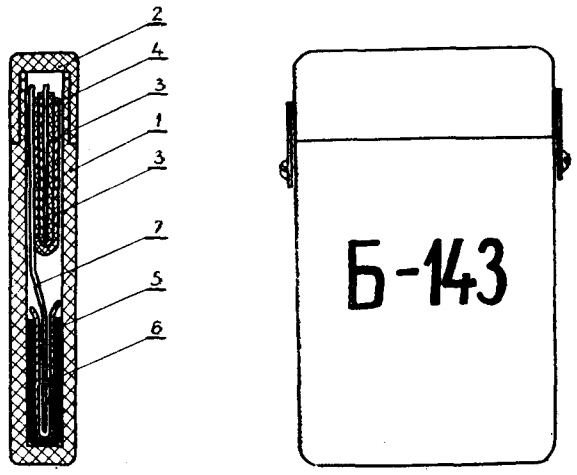

Fig. 2

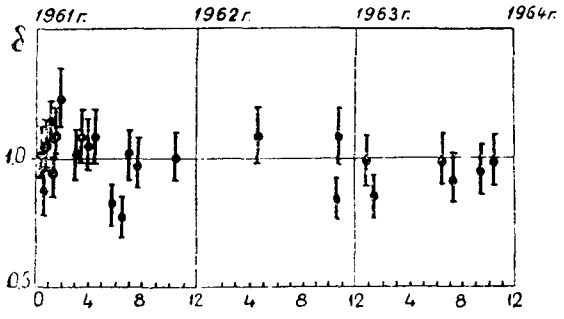

Fig. 3

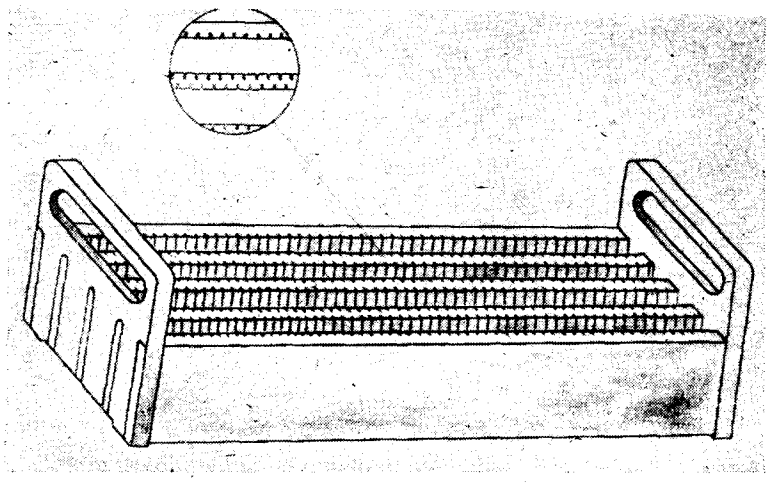

Fig. 4

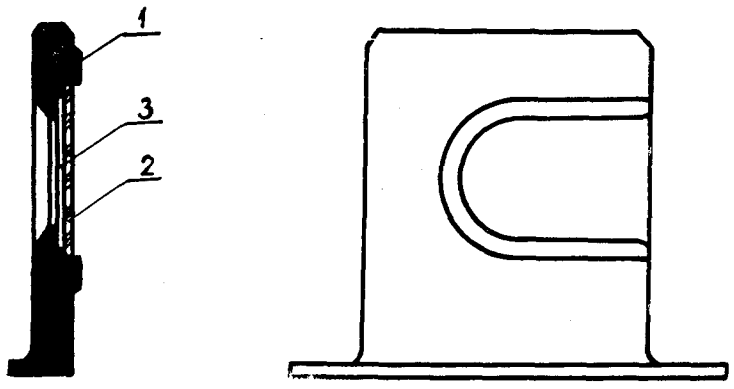

Fig. 5