ROUTINE NEUTRON MONITORING IN THE FEDERAL REPUBLIC OF GERMANY USING A TWO-COMPONENT ALBEDO DOSEMETER SYSTEM

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INTRODUCTION

In personnel monitoring the NTA film was the only applied neutron detector for more than 25 years (1). However, the energy threshold at about 1 MeV, the relatively high fading and the gamma sensitivity allow only a useful application in neutron fields near accelerators. When used in personnel monitoring at reactors and in the fuel element cycle, the NTA film never indicated neutron exposures. This „zero reading" of the NTA film were sometimes taken as an alibi of negligible neutron dose contributions.

Since ten years CR 39 track etch detectors have been improved in the etching technique and dosimetric properties. Commercially available materials, however, have not yet reached the state that materials of constant quality and uniformity in response and background are available for a large scale routine application (2). The energy threshold at about 100 keV, on the other hand, calls for a combination with an albedo detector.

Energy dependence prevented a large scale routine application of albedo dosemeters in the past. This has been overcome by using location and facility dependent calibration factors. In the stray neutron fields of interest a large-scale routine monitoring (3, 4) has been recently realized with a two-component albedo dosemeter by classifying the variety of neutron fields in four types of application areas. Well-known field calibration factors for each type of application area may be applied without the need of knowing more details about the local situation such as the neutron energy spectrum, the shielding and the distance to the source. The calibration factors which may significantly vary with neutron energy in the four areas of application are transferable to other types of TLD systems using the two-component dosemeter capsule. In routine monitoring therefore is in general no need to perform field calibrations at the actual neutron facility of interest.

DOSEMETER SYSTEM

The two-component albedo dosemeter consists of a boron-loaded plastic encapsulation with an albedo neutron detector (i) facing the body of the wearer and an additional thermal neutron detector (a) for field neutrons. For special applications only track etch detectors may be incorporated. The universal albedo dosemeter is applicable for automatic TLD read-out systems of the manufacturers Alnor, Harshaw, Panasonic and Vinten (Fig. 1).

The TLD systems applied make use of TLD cards with four detectors, for instance two pairs of TLD600/700 detectors. The TLD700 detector reading is used to subtract the gamma dose component from the TLD600 reading. An empirical calibration factor N_N corrects for neutron energy dependence of the albedo detector reading $M_n(i)$. The neutron calibration factor $N_N = H_R/M_n(i)$ has been derived from field calibrations using a 30 cm polyethylene sphere as a phantom and reference dosemeter for the measurement of H_R using similar TL detectors in the center of the sphere. In detail, N_N is the product of the relative neutron calibration factor n_N normalized to the calibration factor in a Cf-252 neutron reference field, the relative neutron calibration factor n_{nr} in the neutron reference field normalized to a photon calibration, and the gamma calibration factor N_γ for the TLD reader given by the equation

$$N_N = n_N \cdot n_{nr} \cdot N_\gamma = \left(\frac{N_N}{N_{nr}}\right) \cdot \left(\frac{N_{nr}}{N_\gamma}\right) \cdot N_\gamma = \frac{1}{R_N} \qquad (1)$$

The results of field calibrations in all available types of neutron fields (3) have shown that the variety of neutron fields can be reduced to four typical types of neutron fields in the application areas N1-N4 shown in Fig. 3. Within one area the relative neutron response R_n/R_{nr} can be estimated with a sufficiently low scatter of about a factor of two which in general is acceptable in personnel dosimetry. At least in N1 and N2, constant response values may be used . In N3 and N4, the relative albedo response R_N/R_{nr} increases with the reading ratio of the albedo detector (i) and the thermal neutron detector (a). This ratio and the calibration curve may be used to estimate the actual albedo response in personnel monitoring. Behind heavy shieldings fission neutrons as well as 14 MeV neutrons may result in the same albedo response (area N1). There is the strong decision in neutron monitoring to use the albedo dosemeter in one field of application only.

DOSIMETRIC ASPECTS OF ALBEDO NEUTRON DOSIMETRY

In routine monitoring the two-component albedo dosemeter turned out to be of sufficiently low energy and angular dependence. On the basis of calibration factors derived from Fig. 3, routine application does not need further investigation of workplace dependent calibration factors. The calibration factors are applicable in similar stray neutron fields and also transferable to other TLD systems as seen in Tab. 1 for different neutron fields. Only in cases of higher neutron exposures it may be useful to improve the dose estimation by an actual field calibration.

Within personnel monitoring the albedo dosemeter should indicate the angular dependent dose quantity H'(10), in particular for an radiation incidence from the front half space. Also in the extreme case of lateral exposures the albedo detector still overestimates H'(10). On the basis of field calibrations, the uncertainty of the albedo dosemeter reading due to energy dependence is comparable with that of the reference dosemeter. With respect to other „rem-meters", the sphere of 30 cm diam. offers the lowest energy dependence, i.e. overestimation in stray neutron fields (4). Field calibration factors are conservative with respect to the dose estimation within personnel monitoring, because the reference dosemeter overestimates the dose equivalent H'(10) for frontal exposures below 1 MeV due to its energy dependence and for other directions of the radiation incidence due to its isotropic response.

However, the application of albedo dosemeters in routine personnel dosimetry requires

(a) the use of the personal dosemeter in only one field of application,
(b) the need to apply once established field calibration factors for each type of application area N1 - N4, which are applicable for TLD systems from different manufacturers,
(c) the side correct attachment of the dosemeter encapsulation on the body.

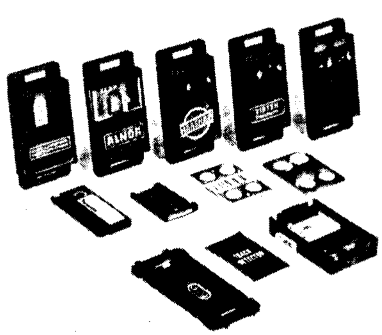

Fig. 1 Universal albedo dosemeter type Alnor, Harshaw, Panasonic, Vinten

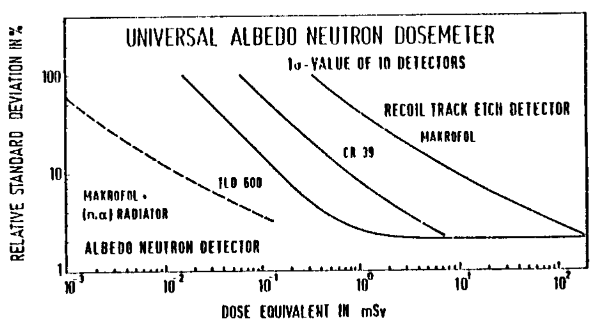

Fig. 2 Random uncertainty of albedo TL and track etch detectors

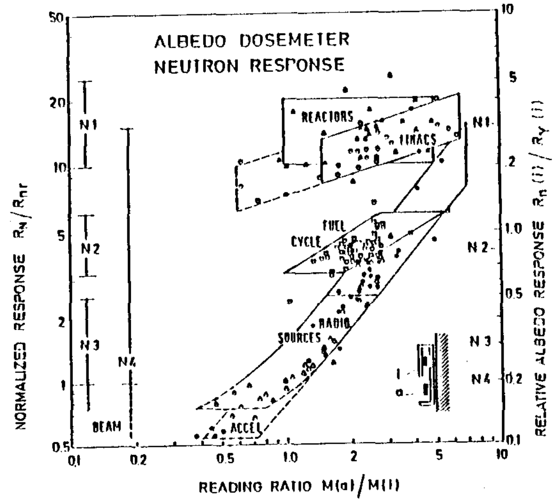

Fig. 3 Relative neutron response R_N of the albedo TLD system Alnor normalized to R_{nr} of a Cf-252 scatter free reference field vs. the reading ratio $M_n(a)/M_n(i)$ for different areas N1 to N4

DOSIMETRIC PROPERTIES AND APPLICATION

As shown in Tab. 2, albedo dosemeters covers a dose range which is sufficient for routine and accident exposures in mixed photon/neutron fields. In the case of criticality, the calibration factors are well-known, the component of thermal neutrons are identified separately and the reading ratio M(a)/M(i) indicates changes in the shielding/scattering conditions during the exposure. These results have to be completed by other measurements such as Na-24 in blood, P-32 in hair, by the chromosome aberration technique, for instance

The effect of body-to-detector distance is comparable with other photon dosemeters. With respect to gamma discrimination the dose equivalent of neutrons and gamma rays in total may be estimated accurately enough.

Tab. 1 Relative neutron response of different albedo TLD systems in stray neutron fields

RELATIVE NEUTRON RESPONSE $R_n(i)/R_n(i,Cf\text{-}252)$					
	ALNOR (KFK)	HARSHAW (MPA)	PANASONIC (GSF)	VINTEN (KFK)	R_{mean} $\pm\Delta R$
Cf-252[1]	1	1	1	1	1
Reactor beam	4.0	3.94	4.3	3.55	3.83 ± 12%
Power plant	13.3	14.8	14.9	14.3	14.0 ± 13%
Fuel element storage[2]	3.2 ± 18%	4.25 ± 21 %	3.1 ± 21 %	-	3.52 ± 15 %
RELATIVE ANGULAR RESPONSE Rn(i,90°)/Rn(i,0°)					
Cf-252[1]	0.62	0.63	0.59	0.55	0.60 ± 6%
Power plant	0.56	0.52	0.53	0.54	0.54 ± 4%

1) Stray neutron field of source in 2.5 m distance and 1.25 m above floor. Field calibration includes room scattered neutrons

2) Mean value and maximum scatter for 12 to 20 calibration results

In special cases, the albedo dosemeter allows the combination with track etch detectors in order to detect separately neutrons above 5 MeV. The TL detectors, on the other hand, may be replaced by gamma insensitive $^{10}B(n,\alpha)$ track etch detectors resulting in a lower detection limit (Fig. 2).

Tab. 2 Dosimetric properties of albedo dosemeters in stray neutron fields N1 to N4

Dose range photons/neutrons (N1-N4)	0.03 mSv to 10 Sv/(0.02-0.10) mSv to (3-50) Sv
Random uncertainty/gamma discrimination	$\sigma_n < 5$ % for 10 mSv/$\sigma_{n+\gamma} < 20$ % for $H_\gamma/H_n \leq 10$
Indication of H'(10)	conservative in front half space (including 90°)
Energy and angular response R_n (front half space)	within factor 2 N1, N2: constant R_n values N3, N4: calibration curve (see Fig. 3)
Systematical uncertainty of field calibration	conservative albedo response $R_n(i)$, overestimation ≤ 50 % due to energy dependence of 30 cm sphere
Detector-body distance effect	within ± 10 % for distance up to 4 cm
Scatter in the response curves (Table 1)	within ± 15 % for TLD systems Alnor/Harshaw/Panasonic/Vinten

Within a governmental supported research program four official dosemeter services make use of different automatic TLD systems of the manufacturers Alnor, Harshaw, Panasonic and Vinten. As the result of the joint calibration program and the long-term application in routine monitoring (4), the albedo dosimetry systems have been found to be adequate dosemeters for the estimation of the neutron and photon dose equivalent. Within routine monitoring the lower detection limit and the uncertainty of neutron dose measurement have been found to be comparable with those of photon dosemeters. Since 1986, the universal two-component albedo neutron dosemeter is the official neutron dosemeter in the Federal Republic of Germany which replaces the neutron film dosemeter (NTA film) used so far. Neutron albedo dosemeters are applied routinely if the neutron dose rate at workplaces exceeds 20 % of the photon dose rate and/or if there is a risk for an overexposure due to neutrons.

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