COMPARISON OF ALBEDO DOSIMETERS AND NUCLEAR TRACK DETECTORS FOR NEUTRON MONITORING

E. Piesch, and B. Burgkhardt
Health Physics Division
Karlsruhe Nuclear Research Center, Fed. Rep. Germany

1. Abstract

The albedo neutron dosimeters so far used in personal dosimetry provided oversensitive indications of intermediate and thermal neutrons. Therefore, correction factors dependent on the location had to be used to assess the dose equivalent (Harvey[1], Hoy[2]). An albedo dosimeter tested at the Karlsruhe Nuclear Research Center showed promising results in measuring the dose equivalent of fast neutrons[3 4]. Intercomparison measurements with nuclear track detectors were performed to indicate the dosimeter response, influence of the energy dependence and of the direction of the radiation incidence on the dosimeter reading.

2. Dosimeter and Radiation Sources

In a LiF-albedo dosimeter the thermal neutrons moderated and backscattered in the body of the wearer are detected by the ^{6}Li (n,α)-reaction. If a pair of dosimeters is used, the neutron fraction of the reading is obtained from the difference in readings between a TLD-6oo dosimeter (neutron + γ-dose reading) and a TLD-7oo dosimeter (γ-dose reading).

Albedo dosimeters so far have been used preferably for the detection of intermediate and thermal neutrons. The detection response to fast neutrons is approximately 5 % of the response to thermal neutrons, but still 5o % of the γ-response. In this way, a LiF-albedo dosimeter is capable of detecting the dose equivalent of neutrons and of gamma rays over a dose range between 2o mrem and more than 1ooo rem.

The following dosimeters were used for intercomparison measurements (cf. Table 1):

- Albedo neutron dosimeter according to Harvey: Absorption of incident thermal neutrons by means of a boron capsule[1]. A pair of Harshaw ribbons of $3 \times 3 \times 1$ mm^3 size were used.
- Single albedo dosimeter: Separate measurement of incident neutrons (D_2) outside the boron capsule and neutrons backscattered from the body (D_1) within the boron capsule by means of one pair of dosimeters each[4].
- Albedo dosimeter system: Reduction of the influence of the body by wearing a dosimeter belt with one single albedo dosimeter each on the front and back of the body[3 4]. A functional relationship found

Detector	Energy	response
Kodak NTA Film	> o.7 MeV	$2\cdot 1o^4$ tracks/cm$^2\cdot$rem$^+$)
^{237}Np+Makrofol E (4o µg/cm^2)	> o.75 MeV	4 tracks/cm$^2\cdot$rem $^+$)
^{232}Th+Makrofol E (o.o5 mm foil)	> 1.2 MeV	37 tracks/cm$^2\cdot$rem $^+$)
Albedo Dosimeter Harvey	n_{th}, n_i	< 1o R/rem
Single Albedo Dosimeter	and > 1oo keV	o.5 R/rem
Albedo Dosimeter System	-14 MeV	o.54 R/rem

$^+$) Fluence-Dose conversion factor for track detectors $2.86 \cdot 10^7$ n/cm^2 $\cdot$ rem

Tab.1: Neutron detector characteristic

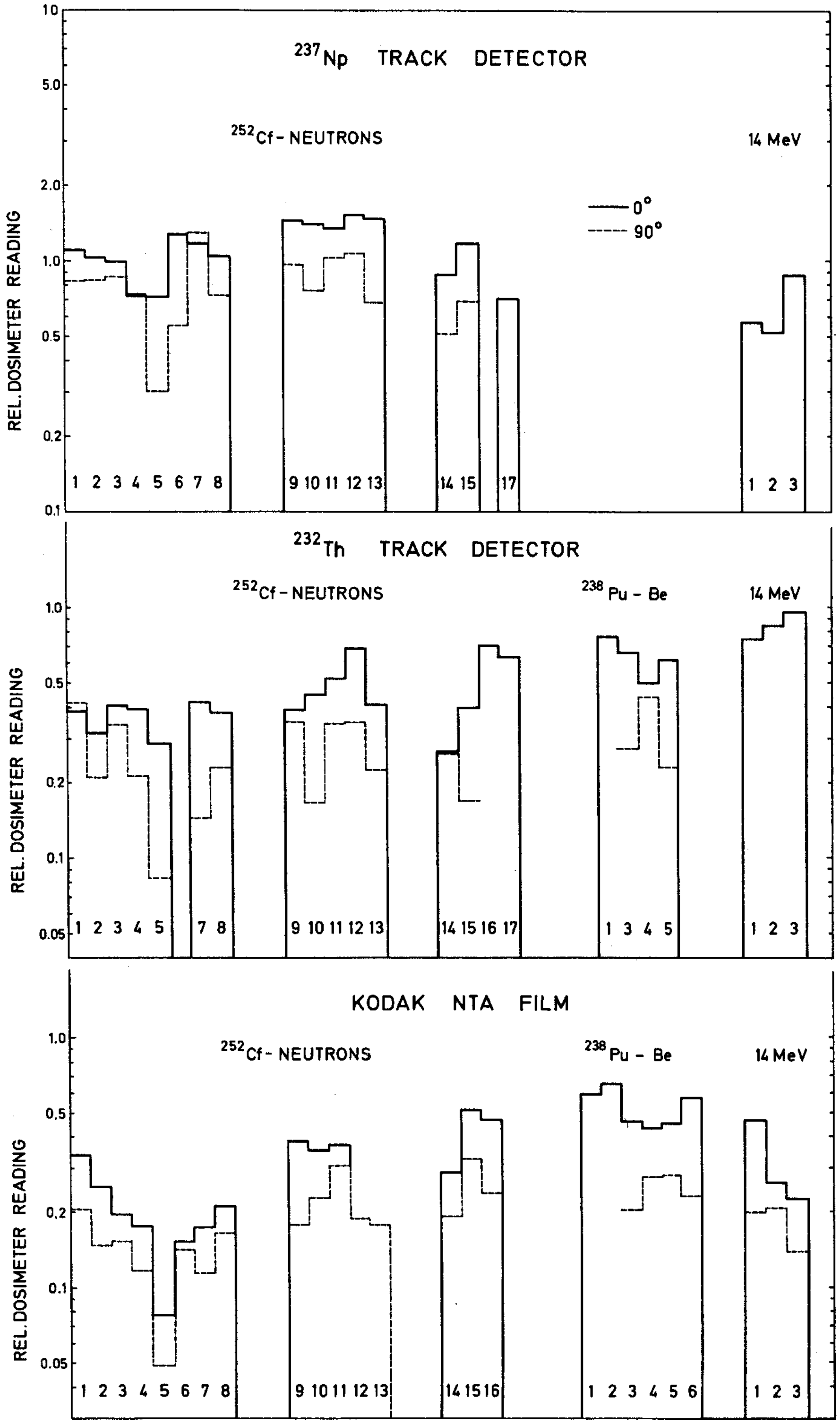

Fig.1: Relative dosimeter reading of nuclear track detectors after phantom irradiations with ^{252}Pu-Be- and 14 MeV neutrons

Position No.	Source	Distance source-detector
1	^{252}Cf in air	
2	+ 5 cm Pb	
3	+ 5 cm Al	
4	+ 5 cm Fe	2 m
5	+ 16 cm Fe	
6	+ 5 cm PVC	
7	+ 11 cm PVC	
8	+ 5 cm Concrete	
	^{252}Cf in air	
9	8 cm wall distance	
1o	1 m	1 m
11	2 m	
12	3 m	
13	4 m	
	^{252}Cf behind water layers of	
14	4 cm	
15	12.5 cm	2 m
16	43 cm	
17	51 cm	
1	^{238}Pu-Be in air	1 m
2		2 m
3	in a small room:	1 m
4		2.3 m
5		2.2 m
6		3.6 m
1	14 MeV in air	2o cm
2		3o cm
3		54 cm
4		1 m
5		1.5 m
6	behind concrete (4o cm)	2 m
7		3 m

Tab.2: Sources and exposure positions

experimentelly between D_1 and D_2/D_1 is used for correction:

$D_n = k \times D_1$

- Kodak NTA Type A nuclear emulsion welded in aluminium-plastic foil for the detection of fast neutrons > o.7 MeV.
- ^{237}Np + Makrofol for the detection of fast neutrons > o.75 MeV and
- ^{232}Th + Makrofol for the detection of fast neutrons > 1.2 MeV by counting of fission fragment tracks.

The exposures were performed with a human phantom (water bottles of 2o cm diameter, 4o cm height) at 1.4 m above ground with radiation incidence from the front, the sides and the back (0°, 90°, 180°, 270°). The respective dose equivalent were measured with an Anderson-Braun type rem-counter at the point of exposure of the phantom. In the case of 14 MeV neutrons also activation and threshold detectors were used. The rem-counter and the nuclear track detectors were calibrated in free air with an Am-Be-source of known source intensity.

Table 2 contains further details about the exposure positions. Irradiation with a ^{252}Cf-source of 1 mg was performed in free air and behind shieldings of PVC, concrete, aluminium, iron and lead. The source was set up at distances between 8 cm and 4 m from a concrete wall (wall effect), the distance of the detector remaining constant, or was suspended into a water tank of 6o cm diameter directly opposite the detector to generate water layers of different thicknesses ranging between 4 and 51 cm.

Irradiations with ^{238}Pu-Be neutrons were performed in free air and in a small chamber of 2 x 3 m^2, the source being located in one corner of the room. 14 MeV neutrons were used for irradiation in free air and behind a wall, respectively. Exposures in a heavy water moderated power reactor (Obrigheim Nuclear Power Station) were performed directly on top of the reactor core outside the biological shield. Exposures in the FR 2 research reactor were performed in accessible places between the concrete and paraffin shields for inpile experiments in horizontal beamholes.

3. Measured Results for Fast Neutrons

3.1 Nuclear Track Detectors

Figure 1 is a diagram of the reading of nuclear track detectors referred to the reading of the rem-counter for various exposure conditions. Due to fading within two weeks, the results obtained with the nuclear track emulsion are below of 6o %. An iron shield of 16 cm reduces the average neutron energy of the fission spectrum from 1.9 MeV to 0.88 MeV[5]. Here the NTA-film had higher fading and lower response, thus indicating only 25 % of the free air exposure. Because of the fading, the energy threshold of the NTA film is higher than in the ^{232}Th-detector. The reading of the ^{232}Th-detector for fission neutrons is lower by a factor of 2, while for 14 MeV neutrons it is only slightly higher than for Pu-Be

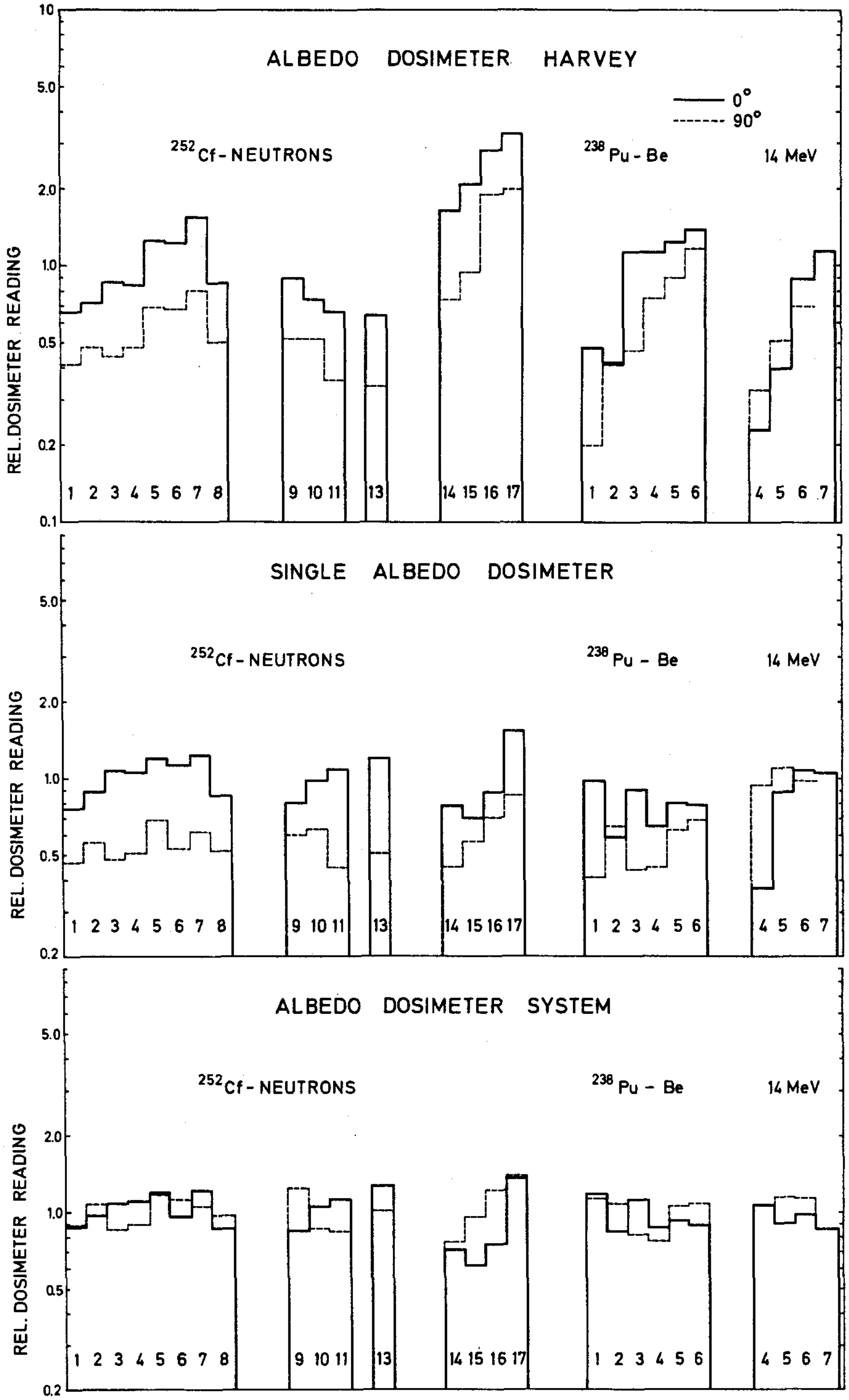

Fig.2: Relative dosimeter reading of albedo neutron dosimeters after phantom irradiations with ^{252}Cf-, ^{238}Pu-Be and 14 MeV neutrons

neutrons despite the high (n,f)-cross section, due to the fluence-dose conversion factor.

The deviation of the ^{237}Np reading from the reading of the rem-counter is between +50 % and -3o %. For 14 MeV neutrons, the deviations are larger because of the fluence-dose conversion factor. For radiation incidence under 90° nuclear track detectors in most cases indicate between 75 % and 45 % of the reading obtained by incidence upon the front.

3.2 Albedo Neutron Dosimeter (see Figure 2)

Because of its oversensitivity to thermal and intermediate neutrons, the albedo dosimeter according to Harvey indicates up to a factor of 6 more than the rem-counter. However, a modification of the fission neutron spectrum by 5 cm of shielding results in deviations only within ± 30 %. In single albedo dosimeters the energy dependence and the influence of scattered thermal neutrons from the environment are reduced. For front incidence a deviation in readings for fission neutrons is found to be within ± 40 %. For 14 MeV neutrons different correction factors were used[4]. As in nuclear track detectors, dosimeter readings between 75 % and 45 % of the reading obtained in free air were found for radiation incidence under 90°. The albedo dosimeter system reduces the influence of the direction dependence to approximately ± 15 % for radiation incidences under 0°, 90°, 270° and 180°. The total influence of the error due to energy and direction dependence of the dosimeter reading accordingly is ± 30 % for a dosimeter belt with two albedo dosimeters.

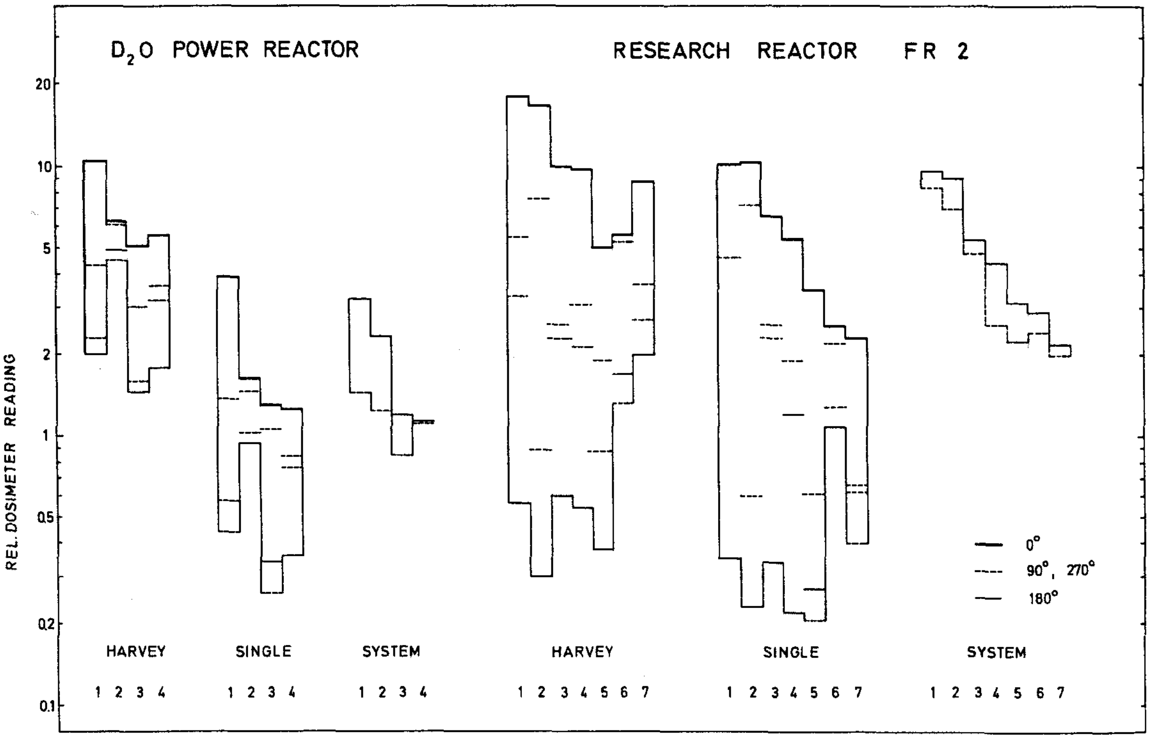

Fig.3: Relative dosimeter reading of albedo neutron dosimeters at reactor sites after phantom irradiations for different directions of radiation incidence

4. Results Measured at Reactor Sites (see Figure 3)

Chiefly thermal and intermediate neutrons are encountered near reactors, which requires correction factors to be applied in the evaluation of albedo dosimeters which depend on the location[1,2]. The dosimeter reading varies by up to a factor of 2 in the case of incidence on the front near a power reactor and by a factor of up to 4 when measured near a research reactor. Harvey dosimeters have maximum sensitivities of 5 and 9 R/rem, respectively. In single albedo dosimeters this value is reduced to 2 and 5 R/rem, respectively. In albedo dosimeter systems the dosimeter reading shows a maximum variation of a factor of 2.5 except for the first two irradiation positions in the FR 2 research reactor. The maximum sensitivity is 2.5 R/rem. The albedo dosimeter system has the advantage of a non-directional dose reading for all radiation incidences between 0° and 180°. However the more unfavorable conditions existing near beamholes of research reactors are in no way representative for a personnel monitoring at reactors.

5. Summary

Because of the sometimes relatively high dose fraction of intermediate neutrons, location dependent correction factors must be taken into account in personnel monitoring at reactors by means of albedo dosimeters (corrections by up to a factor of 5). Because of the energy threshold, nuclear track detectors cannot be used for this purpose. In extreme cases, corrections by up to a factor of 10 are required near beamholes. This must be anticipated also in the energy range of intermediate neutrons from the calculated response of the dosimeter reading (see[4], including results from[6]).

Albedo neutron dosimeters can be applied preferably to personnel monitoring near neutron sources in the range of energy between some 100 keV and 14 MeV. The readings are comparable to those obtained from a ^{237}Np detector with respect to energy and direction dependence, while ^{237}Th and the NTA-film show more unfavorable results because of the energy dependence and the energy dependence plus fading, respectively. For 14 MeV neutrons, ^{238}Pu-Be neutrons and ^{252}Cf-neutrons, a maximum deviation of ± 30 % was ascertained for the albedo dosimeter system, which is due to influences of scattered radiation, the neutron spectrum, and differences in the direction of radiation incidence between 0° and 180°. Compared with nuclear track detectors, albedo dosimeters have the advantage of a broader range of measurement (between 20 mrem and in excess of 1,000 rem), higher measuring accuracy (± 3 %), no energy threshold (with a detection of the correct dose > 100 keV), simple evaluation and simultaneous indication of the gamma dose.

Acknowledgments

We wish to thank Mr. J. Vaane for giving us the opportunity to performe irradiations in the laboratories of the European Institute for Transuranium Elements at Karlsruhe. We gratefully acknowledge the assistance of Mrs. B. Baur and Mrs. I. Hofmann in the careful evaluation of the detectors.

References

1 Harvey, J.R.: Report RD/B/N 827, 1967, Report RD/B/N 1547, 1970
2 Hoy, J.E.: Health Physics 23, 385, 1972, Report DP-1277, 1972
3 Piesch, E., Burgkhardt, B., Vaane, J.: Report KFK 1666, 1972
4 Piesch, E., Burgkhardt, B.: IAEA-Symposium on Neutron Monitoring 1972
5 Makra, S.: Private communication
6 Alsmiller, R.G., Barish, J.: ORNL-4800, p. 67-69, 1972