DETERMINATION OF THE AVERAGE LET AND THE EQUIVALENT DOSE IN AIRCRAFTS USING THE HTR-METHOD

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ABSTRACT

Measurements of the average LET and the equvialent doserate in high altitude aircrafts were performed with TLDs using absorber material of varying thickness. Besides these TLD-packets Bonner spheres were used.
The determination of the equivalent doserate was carried out with two methods. With the Bonner spheres calibrated for their neutron energy dependent response the equivalent doserate induced by neutrons and gammas is measured with TLD-600 and TLD-700 in pair use.
In addition the high temperature region of the TLD-700 is analysed. Using a LET calibration of the HTR (high temperature ratio) the quality factor and the average equivalent dose can be determined in dependence on the absorber thickness. The deviation in the equivalent doserate of the two methods is discussed. Furthermore the results of two different flight periods are shown.

INTRODUCTION

Interest in radiation protection measurements in mixed (n,γ)-fields as they occure in high altitude aircrafts has increased with improved knowledge of the biological effectiveness of some of the components. The mixed radiation field induced by solar and galactic cosmic radiation consists of a broad spectrum of different particles (protons, neutrons, electrons, gamma-quants,..) with varying energy and LET. Beside absorbed dose measurements particular investigations for the evaluation of the LET-spectrum of the mixed radiation field have been made using LET-spectrometers (1). Furthermore increased efforts are made concerning neutron dosimetry in aircrafts (2) because about half of the equivalent dose is caused by neutrons of various energies. Since most of the applied systems are very complex, unwieldy and heavy, especially for radiation protection purpose investigations based on TLDs are of particular interest.
TLDs are mainly used to obtain the absorbed dose of the ionising component of the mixed radiation field (3, 4). Analysing the high temperature region (5) the average LET can be evaluated in addition. Beside determination of the equivalent dose using the high temperature ratio (HTR), the neutron induced equivalent dose was measured with a calibrated neutron detector.

MEASUREMENTS IN AIRCRAFTS

Measurements in aircrafts were performed during two different flight periods. Flight period 1 covers three flights Köln - Washington - Köln (exposure time: 60.25 h), during flight period 2 the dosemeters were exposed on four flights the same distances (exposure time: 108 h). For both periods the latitude was between 32 - 52°N in 10 - 11 km altitude.
For flight 1 a standard packet (3mm poystyrol), a standard packet with 20 mm polystyrol in addition and a Bonner sphere with 25 cm diameter was used. Since a dependence of the equivalent dose on the absorbing layer was measured, for flight 2 a second Bonner sphere with 12 cm diameter was used to evaluate the depth dependence in more detail. Each packet included TLD-600, TLD-700 and TLD-200, the two spheres only TLD-600 and TLD-700. During flight 2 labor-made single crystals with different magnesium content were exposed in one of the standard packets.

DETERMINATION OF THE EQUIVALENT DOSERATE CAUSED BY NEUTRONS

For tissue equivalent dose measurements of the neutron dose a neutron detector consisting of TLDs embeded in the centre of a Bonner sphere with 25 cm diameter was used. This sphere enables nearly neutron energy independent measurements in the energy region between approximately 0.025 eV and 10 MeV. In the centre of the moderator sphere a special inset containing the TLDs was developed to improve neutron shielding of the TLD-700 particular against thermal neutrons: TLD-700 situated in the centre of the compartment are surrounded by TLD-600.
To determine the equivalent dose caused by neutrons in mixed (n,γ)-fields the pair method is applied to discriminate between the neutron- and the γ-component (6). TLD-700 were used to measure the γ-dose. The TLD-600 glowcurve is caused by composition of the γ- and the thermal neutron component. Therefore the glowcurve caused by neutrons can be obtained by subtraction of the γ-fraction of the total glowcurve. The calibration of the neutron detector is described in more detail elsewhere (7). Analysing the peak 5 maximum of this neutron glowcurve and using the energy dependent calibration the neutron induced equivalent dose can be determined.

The neutron equivalent doserate measured in the aircraft with the calibrated neutron detector was 3.7 ± 0.5 μSv/h for flight 1 and 2.6 ± 0.4 μSv/h for flight 2. For the calculation a mean calibration factor of 1473 ± 221 cts/mSv was used. The total equivalent doserate is obtained by addition of the absorbed doserate measured with TLD-700. This gives a total equvialent doserate of 5.7 ± 0.5 μSv/h (flight 1) and 3.9 ± 0.4 μSv/h (flight 2).

DETERMINATION OF THE TOTAL EQUIVALENT DOSERATE

The absorbed dose in the aircraft was measured with TLD-700 and TLD-200. Table 1 shows the dependence of the absorbed doserate on the layer thickness. Measuerments of period 1 indicated that the dose increases with absorber thickness. The more detailed measuements of period 2 however shows a maximum at 6 cm depth. This function of the dose is the result of the production of secondary protons by neutrons penetrating the absorbing material. This is also indicated by the dependence of the neutron flux on the absorbing layer (table 1). For flight 2 two identical standard packets were used which show a discrepance in the absorbed doserate. This can be due to a different positions of the packets with different shielding thickness or material in the aircraft.
Furthermore the absorbed doserate was measured with labor made single crystal exposed in packet 1 during flight 2. Crystal E (280 ppm Mg, 11.5 ppm Ti) gives a doserate of 1.83 ± 0.07 μGy/h, crystal F (150 ppm Mg, 11.5 ppm Ti) 1.73 ± 0.11 μGy/h and crystal I (410 ppm Mg, 28.8 ppm Ti) 2.06 ± 0.05 μGy/h. These values are in good agreement with the doserate obtained with TLD-700.

	absorbed doserate [μGy/h]		thermal n-fluence [n/cm²s]	
	flight 1	flight 2	flight 1	flight 2
packet 1	1.50 ± 0.09	1.32 ± 0.07 2.20 ± 0.06	0.61 ± 0.20	0.35 ± 0.08 0.23 ± 0.05
packet 2	1.69 ± 0.04	-	0.56 ± 0.05	-
sphere 1	-	1.50 ± 0.10	-	0.71 ± 0.02
sphere 2	2.00 ± 0.03	1.09 ± 0.05	0.44 ± 0.05 0.49 ± 0.03	0.35 ± 0.06

table 1: Dependence of the γ-doserate (measured with TLD-700) and the thermal neutron flux on the absorbing layer. For calculation of the neutron flux the peak 5 maximum was analysed after subtraction of the γ-component, the calibration factor is $3.03 \cdot 10^{-3}$ cts/ncm².

In addition the total equivalent doserate was evaluated applying the HTR-method. This method compares the high temperature region of the glowcurves with a Co-60 irradiation, normalized on the peak 5 maximum. Since this ratio correlates with the distributaion of the energy deposition, a LET-calibration allows the determination of the average LET of unknown mixed radiation fields (5). The method was used to evaluate the average LET of the measurements in the aircraft.
The increase of the high temperature region of TLD-700 is shown in figure 1. According to the measurements of the neutron flux, an increase of the LET respectively the equivalent dose with absorber thickness was obtained for both periods (table 2).

	HTR		$LET_{average}$ ICRP 26 [keV/μm]		$Q_{average}$		H [μSv/h]	
	flight 1	flight 2	flight 1	flight 2	flight 1	flight 2	flight 1	flight 2
packet 1	4.4 ± 0.8	1.57 ± 0.1	18.0 ± 3.6	8.7 ± 0.3	4.1 ± 0.4	2.4 ± 0.2	8.3 ± 1.6	3.1 ± 0.3
packet 2	3.2 ± 0.6	-	15.0 ± 2.3	-	3.5 ± 0.8	-	7.4 ± 1.5	-
sphere 1	-	2.81 ± 0.3	-	16.3 ± 1.7	-	3.7 ± 0.6	-	5.6 ± 0.9
sphere 2	6.6 ± 1.8	1.71 ± 0.1	25.4 ± 7.1	9.5 ± 0.6	5.4 ± 1.3	2.5 ± 0.3	15.4 ± 4.6	2.7 ± 0.3

table 2: Evaluation of the average LET and the equivalent doserate using the HTR-method. If measurements were made using two equal packets for one flight the mean value is given. The increase of the high temperature region of the TLD-700 glowcurves is shown for both flights in figure 1. $LET_{average}$ is only meaningfull using ICRP 26 because ICRP 60 demands the assessment of the various components of the mixed radiation field.

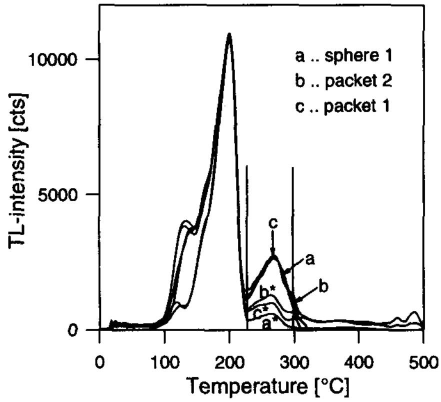

figure 2: Comparision of the TLD-700 glowcurves obtained during flight 1 (a, b, c) with the corresponding Co-60 calibration (a*, b*, c*). Glowcurves are normalized on peak 5 maximum.

DISCUSSION

Comparision of the neutron equivalent doserate of the two flights shows that flight 2 gives only about 70% of the doserate obtained on flight 1. This situation can also be seen by comparing the results of the HTR-method. The values differ between flight 1 and 2 about a factor of 2 to 5 depending on the absorber thickness. Part of this discrepance can be explained by the lower neutron flux during flight 2 (table 1). This indicates that the particle spectrum must have changed quite significantly in this short period between flight 1 and 2. A further indication of this variance of the particle specturm is given by analysis of the dependence of the equivalent dose on the absorbing layer. Flight 1 shows an increase of the equivalent doserate with absorber thickness whereas on flight 2 packet 1 with 1.5 mm absorber and sphere 2 with 12 cm absorber give the same equivalent doserate, only at 6 cm depth a maximum occurs. This discrepancy can be caused by a differing neutron and proton spectrum during each flight. A direct correlation of the results obtained with the HTR-method and the variation of the solar activity was found comparing measurements performed in 1989 and the flights in 1995. In 1989 (route: Köln - Aschchabad, altitude: 10 - 11 km, latitude: 40 - 55 °N) an absorbed doserate of 2.3 ± 0.2 µGy/h, a neutron flux of 0.17 ± 0.05 n/cm²s and an equivalent doserate of 5.2 ± 0.22 µSv/h were measured. If these values are compared with the results of the two flights in 1995 a decreased absorbed doserate and an increased neutron flux is determined. In correlation to these results in 1989 a solar maximum reduced the primary proton and neutron component compared with the situation of 1995 (minimum solar acitivity).

CONCLUSION

The deviation of all the investigated parameters compared with former measurements correlates with the variation of the solar activity. Furthermore the differences of the parameters between flight 1 and 2 explained by a variing particle spectrum shows the sensitivity of the HTR-method. It can be seen that the composition of the mixed radiation field in aircrafts changes significantly with the solar acitivity. Since these variations cannot be predicted continous measurements of the absorbed dose and the LET are proposed.
Using TLD-700 not only the absorbed doserate can be determined but also the evaluation of the average LET is possible. The differences in the equivalent doserate dependence on the absorber thickness for the two flights show that further efforts have to be made to obtain the depth dose in more detail. Measuerments with more Bonner spheres of different diameters are planned.

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