1st International Workshop on Space Radiation Research and
11th Annual NASA Space Radiation Health Investigators' Workshop
Arona (Italy), May 27-31, 2000

Measurement of the Depth Distribution of Average LET and Absorbed Dose Inside a Water-Filled Phantom on Board Space Station MIR

T. Berger[1,2], M. Hajek[1,2], W. Schöner[1], M. Fugger[1], N. Vana[1,2], M. Noll[2], R. Ebner[1], Y. Akatov[3], V. Shurshakov[3], V. Arkhangelsky[3]

1. *Atominstitute of the Austrian Universities ATI, Vienna (Austria)*
2. *Austrian Society for Aerospace Medicine ASM, Vienna (Austria)*
3. *Institute of Biomedical Problems IMBP, Moscow (Russia)*

Abstract

The Atominstitute of the Austrian Universities developed the HTR-method for determination of absorbed dose and "averaged" linear energy transfer (LET) in mixed radiation fields. The method was applied with great success during several space missions (e.g. STS-60, STS-63, BION-10 and BION-11) and on space station MIR in the past 10 years. It utilises the changes of peak height ratios in LiF thermoluminescent glowcurves in dependence on the LET. Due to the small size of these dosemeters the HTR-method can be used also for measurements inside tissue equivalent phantoms. A water filled phantom with a diameter of 35 cm containing four channels where dosemeters can be exposed in different depths was developed by the Institute for Biomedical Problems. This opens the possibility to measure the depth distribution of the average LET and the dose equivalent simultaneously. During phase 1 dosemeters were exposed for 271 days (05.1997-02.1998) in 6 different depths inside the phantom, which was positioned in the commander cabin. In phase 2 dosemeters were exposed in 2 channels in 6 different depths for 102 days (05.1998-08.1998) in the board engineer cabin, following an exposure in different channels in 3 different depths for 199 days (08.1998-02.1999) in the Modul KWANT 2.

KEYWORDS: Space Radiation, MIR, Phantom, LET.

1. Introduction

Concerning the life on the International Space Station ISS and the possibility of a future flight to Mars the accurate estimation of radiation risk for the astro- and cosmonauts is of great importance. The radiation field in space consists of the Galactic Cosmic Rays (mainly protons, and HCP up to iron ions) and the emission of particles by the sun (protons, electrons and He nuclei). At the orbit of the Space Station MIR ~ 380 km the main part of the primary radiation field is due to the GCR and the trapped protons of the South Atlantic Anomaly. Measurements on Space Station MIR showed, that the ratio of dose equivalent from GCR to protons is about 3/2:1 [1]. Interaction of this radiation field with the hull of the spacecraft results in a complex secondary radiation field consisting of charged particles, neutrons, gamma- and X-rays, bremsstrahlung as well as π- and m-mesons. A considerable component of that field are particles with a high linear energy transfer resulting in very high biological effectiveness. For the estimation of organ doses and thus the radiation risk measurements in phantoms are essential. The aim of the project Phantom 1-3 was to measure the depth distribution of absorbed dose and 'averaged' LET in dependence on the position of the phantom inside the Space Station MIR and on the positions of the dosemeters inside the phantom (perpendicular and parallel to the hull of the spacecraft). By evaluating of the 'averaged' LET it is further possible to obtain information about the depth dependence of the dose equivalent and so the biologically relevant dose.

2. Theoretical Background

For the evaluation of the 'averaged' LET of the complex mixed radiation field in space the HTR – method was used. Developed at the Atominstitute of the Austrian Universities the method utilizes the different LET - efficiency of the main peak of LiF glowcurves compared to the high temperature peaks. This effect was calibrated in various radiation fields [2]. Applying the HTR - method it is possible to obtain information about the biologically relevant dose equivalent. Measurements were successfully performed in several space missions [3, 4], in aircraft [5, 6, 7] and in therapeutic proton beams [8]. The results obtained with measurements using LiF TLD´s are also in good agreement with French-Russian tissue equivalent proportional counter (TEPC) measurements (CIRCE, NAUSICAA) and LET spectrometer measurements by the Space Radiation Analysis Group (JSC NASA) [2, 9].

3. Measurements

A water filled phantom with a diameter of 35 cm was developed by the Institute of Biomedical Problems in Moscow. This phantom consists of 4 channels which are positioned in right angle in one plane inside the phantom. In these channels dosemeters of the types TLD 600 (^{6}Li enriched) and TLD 700 (^{7}Li enriched) were exposed in different depths. Due to their small dimensions TLD´s are very suitable for measurements inside phantoms.

Table I – Project Phantom.

Project	Duration	Dosemeter inside Phantom (days)	Position on board Space Station MIR
Phantom 1	May 1997 - February 1998	271	➢ Commander Cabin
Phantom 2	May 1998 - August1998	99	➢ Board Engineer Cabin
Phantom 3	August 1998 - February 1999	15	➢ Board Engineer Cabin
		170	➢ Modul Kwant 2

During Phases 1 and 2 of the Phantom project dosemeter packages (4 × TLD 600, 4 × TLD 700) were exposed in 6 different depths in 2 channels (channels number 2 and 4) perpendicular to the hull of the spacecraft. In Phantom 3 dosemeters in 3 different depths in the 2 channels (channels number 1 and 3) parallel to the hull of space station MIR were exposed. Therefore the depth distribution and the 'averaged' LET under changing shielding conditions was measured due to the different locations of the phantom and the different positions of the dosemeters inside the phantom (perpendicular and parallel to the hull of MIR).

4. Results

The dosemeter were evaluated using the HTR – method.

Figure 2 and Figure 3 show the summary of the depth distribution of absorbed dose for projects Phantom 1-3. In Figure 2 a stronger decrease in absorbed dose for Phantom 1 and 2 is due to the nearer position of the dosemeters in channel number 2 to the hull of the spacecraft. During the duration of Phantom phase 1 and 2 absorbed dose rates are almost independent of the position of the phantom. The dose rate for Phantom 3 is lower in channels number 1 and 3. This can be explained by the different shielding condition of phase 3 (Modul Kwant 2) and the changed position of the dosemeters within the phantom (parallel to the hull of the spacecraft). The difference in TLD – 600 and TLD 700 could be explained by the thermal neutrons which are detected by TLD – 600 over the $^{6}Li(n,\alpha)^{3}H$ reaction.

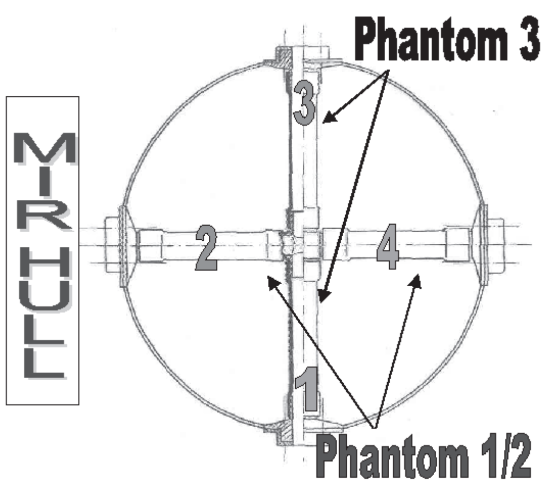

Fig. 1 – Position of dosemeters inside Phantom.

The 'averaged' LET evaluated with the HTR – method can be seen in Figure 4 and Figure 5.

The evaluation is based on the LET calibrations with ions of different LET. Whereas the "averaged" LET for TLD – 700 shows no significant change by increasing depth for all 3 Phantom exposures, the 'averaged' LET for TLD – 600 is increasing with increasing depth. This is due to the increasing part of thermalized neutrons inside the phantom. Although the absorbed dose decreases, the dose equivalent rate remains almost constant over the whole depth of the phantom.

Phantom 1: TLD – 600: 776 ± 29 μSv/d and TLD – 700: 574 ± 60 μSv/d;
Phantom 2: TLD – 600: 770 ± 28 μSv/d and TLD – 700: 535 ± 40 μSv/d;
Phantom 3: TLD – 600: 730 ± 40 μSv/d and TLD – 700: 436 ± 35 μSv/d.

The difference in Phantom 1 / 2 to Phantom 3 is due to the different shielding conditions and the changed position of the dosemeters inside the phantom.

5. Discussion

Thermoluminescent dosemeters of the types TLD – 600 and TLD – 700 were used for position sensitive measurements of absorbed dose and the 'averaged' LET inside a water filled phantom on board space station MIR. The absorbed dose rates change due to the different positions of the channels inside the phantom and due to the different locations of the phantom on board space station MIR. While the 'averaged' LET evaluated for TLD – 700 is almost constant for each channel, the 'averaged' LET for the TLD – 600 increases with increasing depth due to high efficiency to thermalized neutrons. The accurate interaction processes of radiation with LiF is not completely understood up to now. Further investigations using the concepts of microdosimetry and the evaluation of the specific energy distribution in connection with the HTR – method are under progress to gain better understanding of the theoretical background of the different 'LET

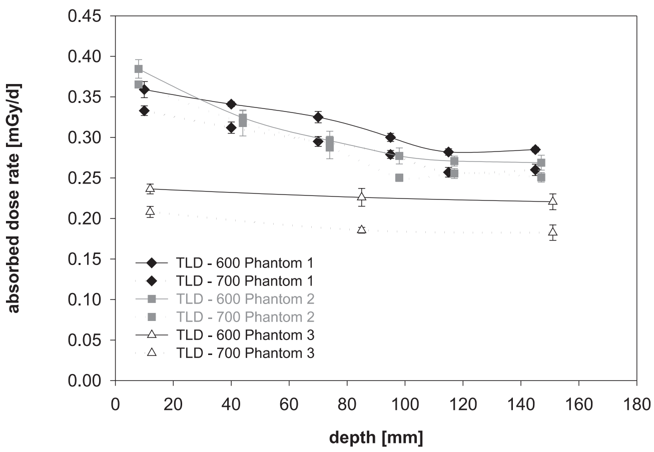

Fig. 2 – Depth distribution of absorbed dose rate: Phantom 1 / 2: Channel 2, Phantom 3: Channel 1

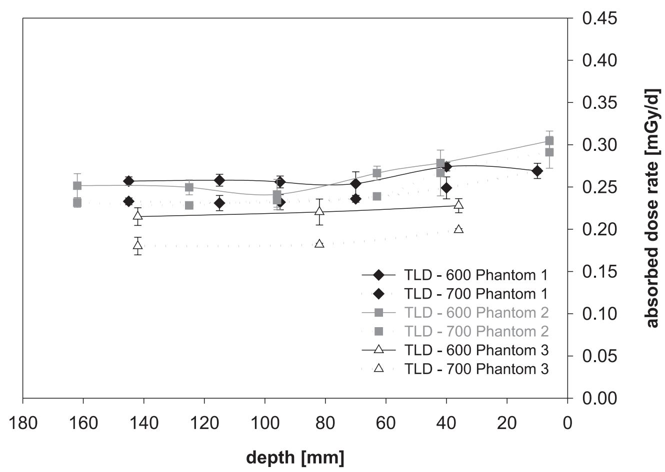

Fig. 3 – Depth distribution of absorbed dose rate: Phantom 1 / 2: Channel 4. Phantom 3: Channel 3

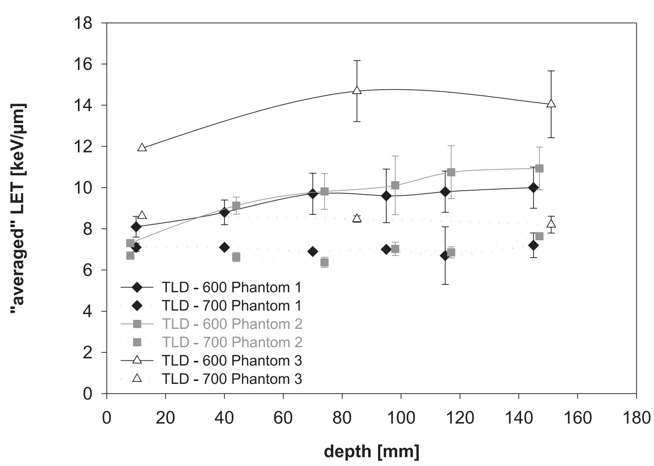

Fig. 4 – Depth distribution of 'averaged' LET: Phantom 1 / 2: Channel 2, Phantom 3: Channel 1.

dependency' of the peaks of LiF glowcurves. Nevertheless, using the LET evaluation with the HTR – method the results obtained in space up

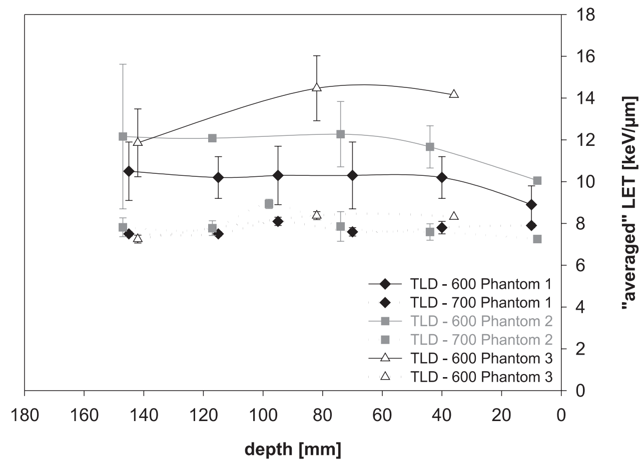

Fig. 5 – Depth distribution of 'averaged' LET: Phantom 1 / 2: Channel 4, Phantom 3: Channel 3

to now agree very well with results using other methods and therefore the dose equivalent rates in the phantom experiments show no significant change over the depth.

REFERENCES

[1] Cucinotta FA, Wilson JW, Williams JR, Dicello JF. Analysis of MIR-18 results for physical and biological dosimetry: radiation shielding effectiveness in LEO. Rad Meas 2000: 32; 181-191.

[2] Schöner W, Vana N. Measurement of the "Average" LET and Determination of the Quality Factor in Mixed Radiation Fields Using the HTR-method with LiF-TLDs – A Critical Discussion. Proc. IRPA Regional Congress on Radiation Protection in Central Europe, Budapest 1999.

[3] Vana N, Schöner W, Fugger M, Akatov Y. DOSIMIR – Radiation Measurements Inside the Soviet Space Station MIR – First Results. Proc Intern Space Year Conference 1992. ESA ISY-4; 193.

[4] Schöner W, Vana N, Fugger M, Akatov Y, Arkhangelsky V. Measurements of Absorbed Dose and Average LET with TLDs During Space Missions. Proc. 3rd Workshop on Radiation Monitoring for the International Space Station. Budapest 1998.

[5] Noll M, Schöner W, Fugger M, Vana N, Brandl H. Dose Measurements in Mixed Radiation Fields with TLDs Under Consideration of the Peak Height Ratio. Radiat Prot Dosim 1996: 66(2); 119-124.

[6] Noll M, Vana N, Schöner W, Fugger M. Determination of Average LET and the Equivalent Dose in Aircraft Using the HTR-method. Proc. International Congress of IRPA9 1996: 2; 253-255.

[7] Noll M, Vana N, Schöner W, Fugger M, Brandl H. Dose Measurements in Mixed (n,g) Radiation Fields in Aircraft with TLDs Under Consideration of the High Temperature Ratio Radiat Prot Dosim 1996: 66; 119-124.

[8] Noll M, Böck E, Schöner W, Egger P, Wolf C, Rüdiger H, Vana N. Correlation of the LET-dependent TL-Response of LIF:Mg, Ti TL-Dosemeters and Gentoxic Endpoints after Proton Irradiation. Appl Radiat and Isotopes 2000: 52(5); 1135-1138.

[9] Badhwar G, Golightly M, Konradi A, Atwell W, Kern W, Cash B, Benton E, Frank A, Scanner D, Keegan R, Frigo L, Petrov V, Tchernykh I, Akatov Y, Shurshakov V, Arkhangelsky V, Kushin V, Klyachin N, Vana N, Schöner W. In-Flight Radiation Measurements on STS-60. Radiat Meas 1996: 26(1); 17-34.