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EUROPEAN Dosimetry Activities for the ISS

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Abstract

In cooperation with the University of Kiel, the University GH of Siegen, the Physikalisch-Technische Bundesanstalt in Braunschweig, the Atomic Energy Research Institute in Budapest and the Institute for Biomedical Problems in Moscow, DLR performed measurements of the radiation environment inside and outside spacecrafts on numerous missions with the main objective to determine as precise as possible the radiation exposure of the astronauts. This report comprises some selected results of recent manned missions and indicates where improvements should be achieved and closes with the description of future measurements planned onboard the International Space Station (ISS).

KEYWORDS: Life Sciences, Dosimetry, Radiation, Exposure levels.

1. Introduction

Risks from radiation exposures in space activities cannot be eliminated and are treated as an occupational hazard. Highest possible accuracy on information is therefore required concerning the radiation environment for the evaluation of the radiobiological risk and the protective procedures required. Measurements at different locations on MIR and inside the Shuttle on STS76, 81 and 84 to MIR have been performed using several passive detector stacks and an active silicon detector telescope. Based on the data, the contribution of the single radiation components to the radiation exposure (ambient dose equivalents in a small mass element) during these missions were calculated, they range from 0.6 to 1 mSv/d. Those numbers are considered as a conservative estimate of the organ doses which are needed to calculate the radiation risks. For long term missions where the exposures become higher and even limits may be approached a more accurate estimate of the exposure is inevitable. Determination of organ doses will be supported by depth dose measurements in a human phantom exposed inside and outside the ISS. In addition field measurements across and outside the new station are planned to map the new spacecraft ISS.

2. Material and Methods

The contribution of the sparsely ionizing component (photons, electrons, muons, pions and protons) of the radiation field was determined with Lithium fluoride (LiF) TLD chips TLD700 from Harshaw. The fluence of heavy charged particles were measured with plastic nuclear track detectors of different LET thresholds for particle registration. The detector systems used are di-allylglycol carbonate (CR39), cellulose nitrate-Kodak (CNK), cellulose nitrate-Daicel (CND), and polycarbonate (Lexan). Neutron measurements were performed with CR39 and polycarbonate (Makrofol) combined with converter foils and LiF detectors containing mainly the isotop ^{6}Li (TLD600) in combination with such containing only the isotop ^{7}Li (TLD700).

A detector telescope (DOSTEL) using two silicon diodes was developed to deliver time resolved particle count and dose rates as well as linear energy transfer (LET) spectra separately for the contribution of the trapped particles and the galactic cosmic rays. The instrument measures the time profile of dose rate and particle rate as well as LET-spectra in the range from 0.1 to 120 keV/μm water. Dose measurement counts with LET > 120 keV/μm are treated as LET = 120 keV/μm. During the orbit dose rate and particle rate are registered every 90 sec, while LET-spectra from coincident events in both detectors are integrated over periods of half-orbits on the northern and the southern hemisphere separately. These time intervals for the LET-spectra are defined by the count rate minimum at crossings of the magnetic equator. Periods with particle rates exceeding a given threshold are regarded as crossings of the SAA and treated separately. The particle and dose rate are then registered every 20 sec and a separate LET spectrum is integrated for this crossing of the radiation belt.

3. Results

Table I compiles a data set from passive measurement devices for two MIR and a Shuttle to MIR missions, to give an idea of the radiation exposure in the ISS (more data see Badhwar 1997; Benton, 1988; Beaujean 1999, Heinrich, 1989; Reitz 1994, 1996, 1998). Dose and particle fluence increase with decreasing solar activity. Higher measurements in EUROMIR95 compared to STS84 are explained by lower shielding thicknesses around the dosimeter. Whereas in the MIR flights neutron dose equivalents

Table I – Summary of dosimetric data.

Mission	Absorbed Dose (μGy d^{-1})	Neutrons (μSv d^{-1}) (estimate)	GCR particle fluence rate [cm^{-2} d^{-1}] $^{1)}$
MIR92	294 ± 13	68	0.30 ± 0.05
	178 ± 6		0.19 ± 0.03
EURO-MIR95	483 ± 8		1.38 ± 0.05
	236 ± 2		0.74 ± 0.03
	245 ± 8 $^{2)}$	92 $^{2)}$	0.81 ± 0.03 $^{2)}$
STS84	374 ± 8	228	0.58 ± 0.06
	170 ± 3	109	0.46 ± 0.05

1) Number of particles passing through an unit area of a planar surface. Measurements in CND
2) Personal dosimeter readings

were estimated from differences in the TLD600 and TLD700 response, the doses for the STS missions are from neutron recoil measurements in CR39 and Makrofol which give a better measure of the high energy neutron exposure.

Figure 1 (top panel) shows the measured DOSTEL count rate on November 6, 1997 during the NASA6 mission inside MIR. The low peaks occur at high latitude orbit segments, whereas the first three major peaks are due to ascending crossings of the SAA. All minima indicate crossings of the cosmic ray equator. The first phase of the solar particle event (SPE), as measured by the EPHIN instrument on SOHO (Bothmer, 1999), is well detected inside the MIR station.

In order to demonstrate the dosimetric characteristics of the three main radiation contributions including secondary particles, Figure 2 shows the energy deposit distribution of GCR and SAA particles averaged during five quiet days and of the SPE averaged over the available SPE data for orbit segments above 45° latitude on both hemispheres. The peak in the GCR distribution belongs to high energy particles with charge Z = 1. Obviously the SAA and SPE contributions show a different slope compared to GCR due to the different energy spectra of the detected particles. It can be deduced that the SPE contains more high energy particles than the proton radiation belt (harder energy spectrum)

To obtain the dose equivalent contributed by the different radiation types the absorbed dose has to be multiplied by a weighting or quality factor, which considers that the radiation effect not only depends on the absorbed dose, but also on the type and energy of the radiation causing the dose. Dose equivalents were calculated from measurements of LET spectra or absorbed doses and converted into dose equivalent using mean quality factors determined as spectral averages from their known or postulated energy. Dose equivalents were calculated using the quality factor as defined in ICRP Report No. 60, 1991. Table II lists the dose equivalents for the MIR and Shuttle to MIR mission. Dose equivalent rates for the ISS expected to be in the same range.

4. Discussion

The dependence of dose and fluence rate for primary components is quite well understood. TLDs and plastic nuclear track detectors delivered excellent data for absorbed dose and heavy ions, respectively. Such detectors are small and light weighted and need no power. Therefore they can be easily distributed at various places and also at the astronaut's body.

The contribution of the secondary components especially that of neutrons is not very well known. The neutron measurements obtained by passive systems are of limited use, especially considering that the proton response of the used systems is only rudimentary investigated. Due to the higher mass of the ISS the production of neutrons increases substantially, a fact which is calling for improved measurement techniques for neutrons. A more accurate measurement or estimation of the contribution of neutrons to the radiation exposure of astronauts is inevitable.

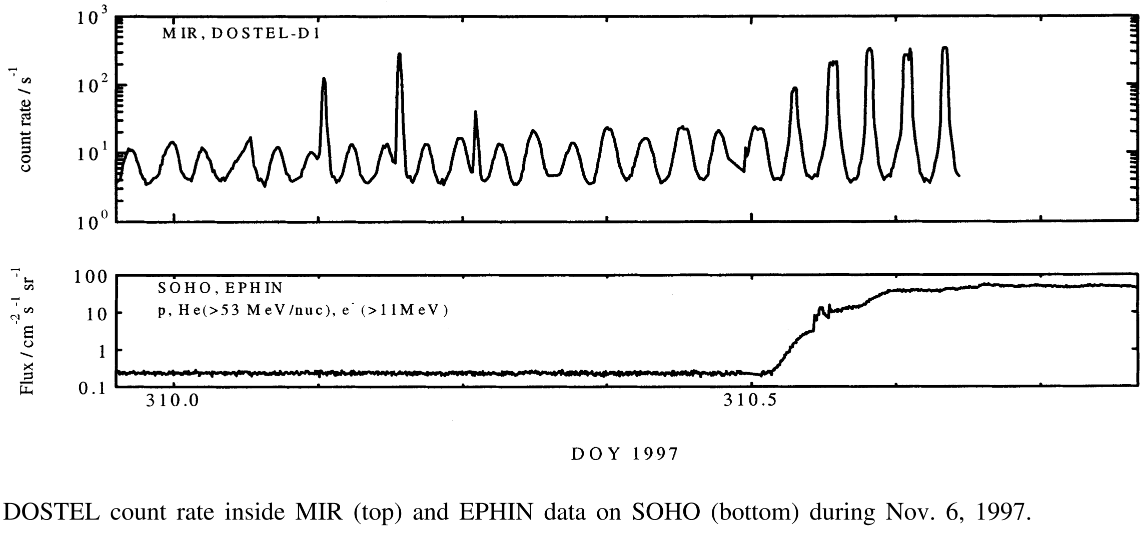

Fig. 1 – DOSTEL count rate inside MIR (top) and EPHIN data on SOHO (bottom) during Nov. 6, 1997.

Table II – Dose rates, mean quality factors and dose equivalent rates. Data for the MIR missions are obtained from passive detectors, for the STS missions data from DOSTEL measurements.

	Mission average			GCR average			SAA average		
	mGy/d	Q	mSv/d	mGy/d	Q	mSv/d	mGy/d	Q	mSv/d
MIR92	306	2.1	640						
EUROMIR94	394	2.0	767						
EUROMIR95									
Ambient max.	510	2.0	1020						
Personal	270	22	600						
STS76	322	2.0	631	141	2.9	418	179	1.2	212
STS81	308	2.1	643	136	3.2	430	172	1.2	214
STS84	365	2.0	716	132	3.3	436	233	1.2	280

The DOSTEL was proven to provide a simple and reliable means to measure absorbed doses and LET spectra in silicon. Uncertainties are found in the treatment of short range particles and the dose conversion from silicon to tissue. Most difficult is the correction due to the different cross sections for nuclear interactions. Especially the dose contribution by neutrons needs to be evaluated.

The calculation of dose and dose equivalents from DOSTEL is in good agreement with those received from measurements with a tissue equivalent proportional counter (TEPC) or with TLD systems. Differences in the response as example of the TEPC and DOSTEL in the low and high energy deposit region and the different neutron response need to be carefully investigated to understand this results. Deficiencies or accident agreements in the measurements are caused mainly by two reasons: the response function of the instrument is not completely known or shielding distributions around the different instruments are different and not known. This calls for a careful calibration of the instruments at ion accelerators or neutron reference fields.

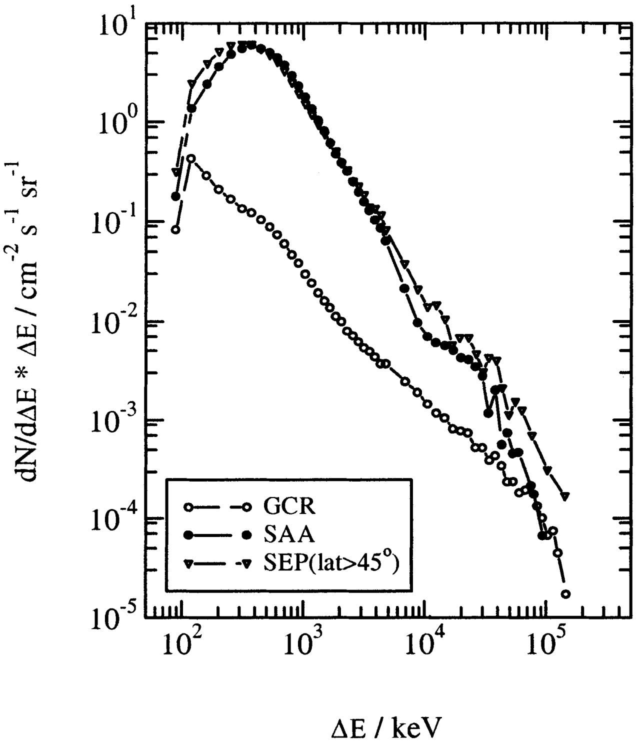

Fig. 2 – Energy deposit spectra for galactic cosmic rays (GCR), for the particles in the South Atlantic Anomaly (SAA) and for the solar particle event (SPE) of Nov. 6, 1997, for inclinations > 45°.

5. Conclusions

Future activities in space radiation dosimetry comprises optimization of well-known detector systems and development of new detector systems, especially for neutrons. Special emphasis is given to clearly establish the characteristics of the measurement devices using different radiation sources, such as heavy ions, protons, electrons and neutrons. Two measurement campaigns were performed at CERN and one with monoenergetic neutrons of different energies at PTB, Germany. A calibration program is planned using heavy ions, protons, electrons and neutrons from different facilities in Europe, Japan and US. A data base consisting of in-flight data, calibration data, instruments and their characteristics shall be established.

Measurements across and outside the new station are planned in the near future. The experiment “Dosimetric Mapping” will be installed as part of the Human Research Facility in the US Lab next year. It consists of nuclear track detector packages, six silicon detector systems and an onboard TLD Reader with 12 thermoluminescence detectors. The hardware for this experiment is already delivered to NASA and ready for flight. A second experiment is planned which measures the depth dose distribution inside a realistic human phantom exposed outside the Russian Service Module. The measurements are used to determine the empirical relations between measurable absorbed doses at the astronauts body and the required tissue absorbed doses which will be needed for risk estimates. Nuclear track detector packages, thermoluminescence dosimeters, up to five small silicon/scintillator sensors and one SRAM sensor are mounted inside the phantom, whereas a tissue equivalent proportional counter, a silicon detector telescope, a passive detector package and a second SRAM sensor will be attached to the phantom. The human phantom is part of the ESA Multi-User Facility MATROSHKA, which will house in their base structure beside the facility electronics the electronics for the experiments. Later on, the facility will be used as part of the Russian radiation monitoring system.

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