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Comparison of the response of various TLDs to cosmic radiation and ion beams: Current results of the HAMLET project

P. Bilski [a,*], T. Berger [b], M. Hajek [c], G. Reitz [b]

[a] Institute of Nuclear Physics, Polish Academy of Sciences, Kraków, Poland
[b] German Aerospace Center, Institute of Aerospace Medicine, Cologne, Germany
[c] Institute of Atomic and Subatomic Physics, Vienna University of Technology, Vienna, Austria

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ABSTRACT

HAMLET is an European Commission research project aiming at optimal scientific exploitation of the data produced within the space experiment MATROSHKA. During phase 1 of this experiment a human phantom equipped with several thousands of radiation detectors (mainly TLDs) was exposed outside the International Space Station for 1.5 years. Besides the measurements realized in Earth orbit, the HAMLET project includes also a ground-based program of intercomparison of detector response to high-energy ion beams.

Within the paper, the relative response of main glow-curve peaks of various TLDs (mostly based on LiF) used in frame of the MATROSHKA experiment by three laboratories (DLR Cologne, ATI Vienna and IFJ Krakow) for radiation in space and several ion beams, has been compared. For LiF:Mg,Ti detectors a very good agreement between results obtained by the three laboratories was observed, both for space and accelerator-based exposures. This should be considered a remarkable result, taking into account that the studied TLDs originated from six different batches, manufactured by two producers exploiting different production techniques and were processed by three laboratories, using significantly different protocols (annealing, readout, calibration, glow-curve analysis). Another type of TL detectors, LiF:Mg,Cu,P, was found to show response to cosmic radiation lower than that of LiF:Mg,Ti by 5%–18%.

1. Introduction

Cosmic radiation is one of the main constraints for long duration human space missions. Astronauts working in Low Earth Orbit (LEO) are exposed to a radiation level, which is about hundred times higher than the natural radiation on Earth and will be further increased for travels to Mars. In perspective of the permanent presence of humans in space there is a growing need for reliable estimation of the radiation risk to astronauts.

In response to this need the European Space Agency (ESA) organized the MATROSHKA (MTR) project (Reitz and Berger, 2006), under the science and project lead of the German Aerospace Center DLR. The MTR facility is an anthropomorphic phantom, which mimics a human torso and head, equipped with over 6000 radiation detectors. The majority of them are thermoluminescent detectors (TLD), but also nuclear track detectors and active radiation instruments are used. The facility is dedicated to determine the depth dose and organ dose distribution in the body, for astronauts working at the International Space Station (ISS). MATROSHKA is not only the largest application of TLDs in space measurements, but it is in general the largest international research initiative ever performed in the field of space dosimetry. The project combines the expertise of leading research institutions around the world, thereby generating a huge pool of data of potentially immense value for research.

Aiming at optimal scientific exploitation, the project HAMLET (Human Model MATROSHKA for Radiation Exposure Determination of Astronauts), was funded by the European Commission under the FP7 program, in order to process and compile the data acquired individually by the participating laboratories of the MATROSHKA experiment. Based on the experimental input from the MATROSHKA experiment phases, as well as on radiation transport calculations, a three-dimensional model for the distribution of radiation dose in an astronaut's body will be built up. Further on, the effective dose, as the best available estimation of the radiation risk, will be evaluated.

Up to now three phases of the experiment have been realized: MTR-1 (exposure outside the ISS), MTR-2A and MTR-2B (exposures

* Corresponding author.
E-mail address: pawel.bilski@ifj.edu.pl (P. Bilski).

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inside the ISS – PIRS and Zvezda modules respectively). The exposure times varied between 1 and 1.5 years. The fourth phase – exposure inside the Japanese Experiment Module Kibo, was started in May 2010. The analyses of the MTR-1 data are now completed and partly published (Reitz et al., 2009), while MTR-2A and MTR-2B are still under evaluation.

Besides the measurements in the Earth orbit, the HAMLET project includes also a large program of ground-based experiments. The most important part of this program consists of the investigation of the detector response to a small, well-defined subset of the space radiation environment, available from high-energy particle accelerators. The HAMLET team was granted with a research project by the National Institute of Radiological Sciences, Chiba, Japan, which enabled realization of several measuring campaigns at the Heavy Ion Medical Accelerator, HIMAC (Chiba, Japan).

The goal of this paper is to compare the response of different TLDs used by the HAMLET co-investigators, both to space radiation within the MTR-1 orbital exposure and to various ion beams.

2. Materials and methods

2.1. MATROSHKA-1 experiment

The MTR phantom is made of commercial phantom parts established in the field of radiotherapy. It consists of 33 slices, each with a thickness of 2.5 cm, and contains natural skeletal bones embedded in tissue equivalent plastics (polyurethane). The density of this plastic is modified spatially in order to account for the differences between the lungs compared to other tissues in the human body. In each slice, special channels were made to accommodate polyethylene tubes containing TL detectors at each 2.5 cm. In this way the whole phantom was filled with over 4800 detectors within a 2.5 cm grid. Additionally at positions of some important organs (eye, lung, stomach, kidney and intestines) packages called "organ dose boxes" were placed (Fig. 1a). In these boxes a larger number of TLDs and nuclear track detectors prepared by various co-investigators, were accommodated. The phantom torso was dressed by a travel jacket ("poncho"), in which further packages with detectors (so called "poncho boxes") were located (Fig. 1b). The whole phantom was covered by a carbon fiber container of average thickness $\sim$0.5 g/cm^2, which roughly corresponds to the thickness of a spacesuit (Fig. 1c).

The MTR facility was launched in January 2004 and mounted outside the module Zvezda a month later. The exposure outside the ISS lasted 539 days, whereupon the phantom was transported into the station, passive detectors were dismounted and in October 2005 downloaded to the Earth. The total time spent in space by the detectors of the MTR-1 experiment was 616 days.

2.2. TL detectors

The majority of TLDs used inside the phantom were provided by three laboratories: Institute of Nuclear Physics (IFJ) in Krakow, German Aerospace Centre (DLR) in Cologne and Institute of Atomic and Subatomic Physics in Vienna (ATI). Each of these three participating groups provided TLD types according to their own choice and processed them according to their own procedures. One of the goals of the HAMLET project is to ensure that the results obtained in this way are consistent. Table 1 summarizes the types of detectors used by the three co-investigating laboratories. All groups used ^{7}LiF:Mg,Ti and ^{6}LiF:Mg,Ti detectors and comparison of performance of these TLDs will comprise the main part of this study.

MTS-7, MTT-7, MTS-6 and MCP-7 detectors were manufactured at the IFJ Krakow and have the form of circular pellets with diameter 4.5 mm and thickness 0.6 mm. The remaining TLDs were produced by Thermo Fisher Scientific (Harshaw) and have form of square chips 3.2 × 3.2 × 0.9 mm. MTT-7 detectors are a variant of LiF:Mg,Ti with changed activator concentrations and increased response to high-LET radiation (Bilski et al., 2004).

The selected details of the measurement procedures applied by the three laboratories are compared in Table 2. The gamma calibrations were realized in terms of absorbed dose in water.

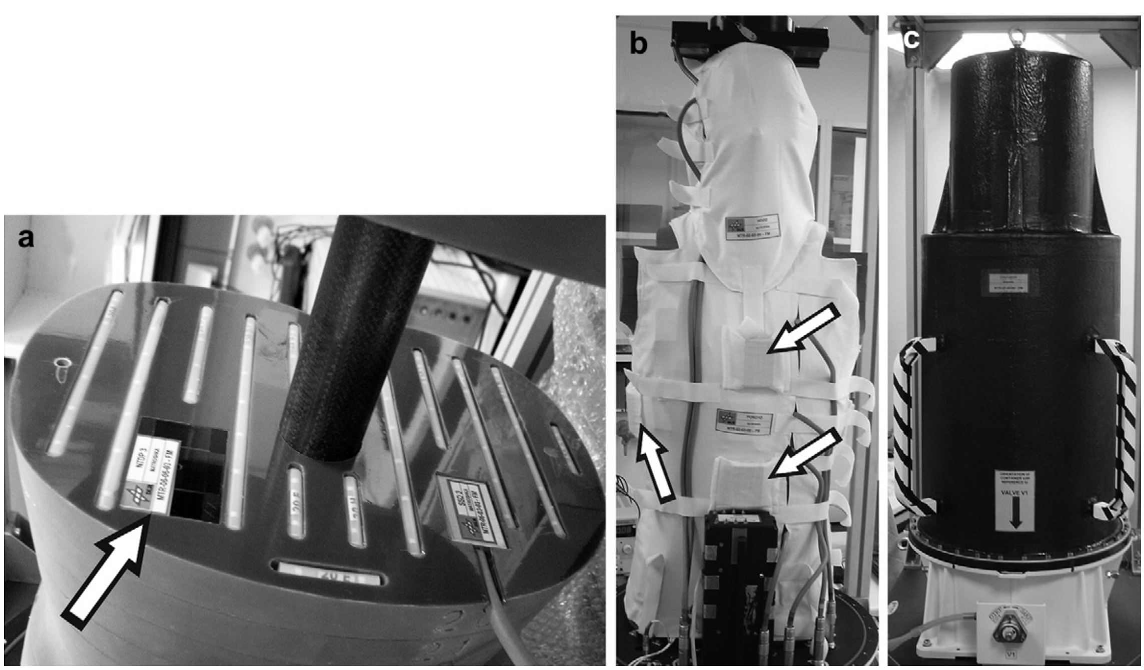

Fig. 1. The MATROSHKA phantom. Arrows indicate locations of detector packages. a) View of one of the phantom slices (#20) showing polyethylene tubes with the integrated TLD detectors and an "organ dose" package ("stomach"). b) The phantom torso dressed by the "poncho". c) The phantom covered by the container.