Simulations of MATROSHKA experiments at ISS using PHITS

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Abstract

Concerns about the biological effects of space radiation are increasing rapidly due to the perspective of long-duration manned missions, both in relation to the International Space Station (ISS) and to manned interplanetary missions to Moon and Mars in the future. As a preparation for these long duration space missions it is important to ensure an excellent capability to evaluate the impact of space radiation on human health in order to secure the safety of the astronauts/cosmonauts and minimize their risks. It is therefore necessary to measure the radiation load on the personnel both inside and outside the space vehicles and certify that organ and tissue equivalent doses can be simulated as accurate as possible. In this paper we will present simulations using the three-dimensional Monte Carlo Particle and Heavy Ion Transport code System (PHITS) of long term dose measurements performed with the ESA supported experiment MATROSHKA (MTR), which is an anthropomorphic phantom containing over 6000 radiation detectors, mimicking a human head and torso. The MTR experiment, led by the German Aerospace Center (DLR), was launched in January 2004 and has measured the absorbed dose from space radiation both inside and outside the ISS. In this paper preliminary comparisons of measurements outside the ISS will be presented. The results confirm previous calculations and measurements which indicate that PHITS is a suitable tool for estimations of dose received from cosmic radiation and when performing shielding design studies of spacecraft.

1. Introduction

Doses achieved by personnel during space flights depend on solar cycle phase, the spacecraft orbit parameters such as orbit inclination, altitude, space weather parameters, mission duration, and the spacecraft compartment shielding, etc. For Low Earth Orbit (LEO) spaceflight conditions, the dose distribution inside the spacecraft is a result of both primary and secondary space radiation. The primary radiation comes from Galactic Cosmic Rays (GCR), Solar Particles Events (SPE), and particles trapped in the Earth' radiation belts. The secondary radiation is produced by nuclear interactions of the primary radiation with the materials in the spacecraft and biological tissues of the human body. Estimation of the radiation risks for humans on board a spacecraft in a space flight can either be performed using measured data of dose and flux distributions in the spacecraft compartments obtained in real space flight conditions, or by computer simulations. However, complex composition of space radiation and the dynamical nature of energy and angular spectra in habitable compartments of the space stations do not permit obtaining of accurate enough data on radiation conditions based on only dose calculations, but since it is not possible to perform measurements for all possible projectile-target-energy-geometry combinations, computer simulations using particle and heavy ion transport codes are still necessary. It is therefore important to use both measured data and computer simulations when performing the risk estimation for astronauts in space.

This paper describes some preliminary results from simulations of measurements performed with the European Space Agency (ESA) experiment MTR [1], lead by the German Aerospace Center (DLR) in Cologne, Germany, simulating and Extra Vehicular Activity (EVA).

2. MATROSHKA (MTR) Experiment

The ESA supported experiment MTR [1], consists of anthropomorphic phantom containing over 6000 radiation detectors, mimicking a human head and torso. The MTR experiment, which is led by the German Aerospace Center (DLR), was launched in January 2004 and has measured the absorbed dose from space radiation both inside and outside the ISS. In this paper preliminary comparisons of measurements outside the ISS during the time period 26 February 2004 up to 18 October 2005 will be presented. The main goals of the MTR experiment were to measure the depth-dose distribution inside the phantom and provide data to benchmark radiation transport codes.

2.1 Phantom

Phantom RANDO® used in MTR experiment is composed of a real human skeleton, embedded into soft tissue-equivalent material (see fig. 1). The soft tissue material has an effective atomic number (7.6) and mass density (0.997 g/cm^3) which simulates muscle tissue with randomly distributed fat. The material with the lower effective atomic number (7.1) and almost three times lower mass density (0.352 g/cm^3) simulates lungs. The phantom has no arms and no legs and is divided into 33 slices of 2.5 cm in height. The material compositions of RANDO® phantom for soft tissue and lungs are presented in Table 1. The material density of an adult skeleton is equal to 1.3 g/cm^3 according to ICRP reference man [2].

In a regular grid of 2.5 cm inside the phantom, more than 5000 passive thermoluminescent detectors (TLDs) were equipped (see fig. 1b). TLDs were put into the polyethylene tubes separated by the polyethylene spacers. RANDO phantom filled with the detectors was located inside a carbon fiber container with an average mass shielding of ~1 g/cm^2, simulating the shielding distribution of an astronaut's EVA spacesuit. The doses measured by TLDs were calculated according to the procedure shown in [3].

Table 1. Percentage element composition of RANDO® phantom in soft tissue and lungs.

Element	Percentage in soft tissue	Percentage in lungs
Carbon	67.78	70.74
Oxygen	20.31	21.28
Hydrogen	9.18	5.97
Nitrogen	2.50	1.9
Antimony	0.22	0.1
Density [g/cm^3]	0.997	0.352

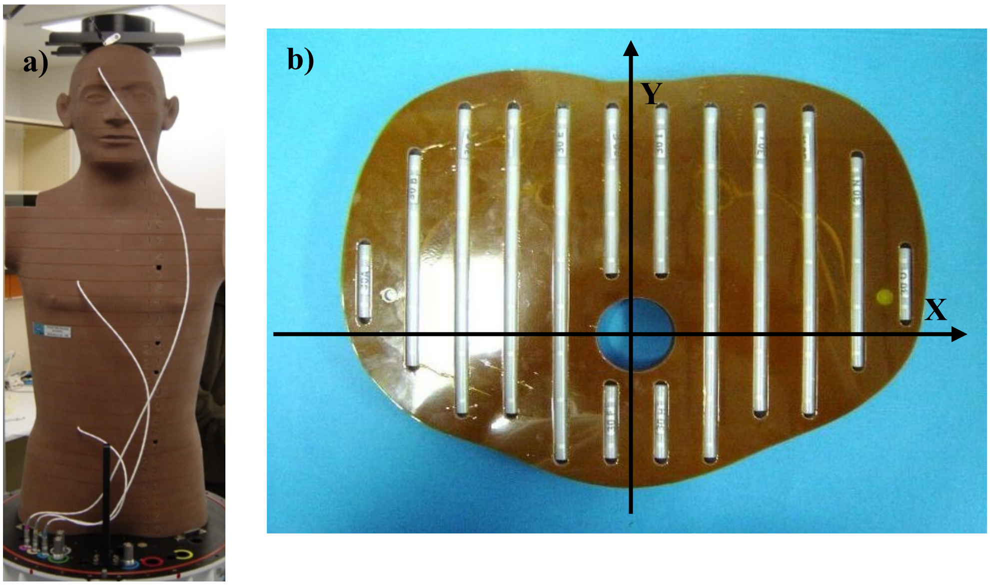

Figure 1. The RANDO phantom front view (a) and the top view of slice 30 equipped with the TL detectors (b).

A numerical voxel model of the RANDO® phantom, which was used in these simulations, has been recently developed at IFJ Krakow to be used in the MTR experiment calculations [4]. This voxel phantom, called NUNDO (Numerical RANDO), was constructed on base of the computed tomography (CT) scans of the RANDO® phantom. The voxel size of the NUNDO is 1x1x5 mm^3. Masses of each organs and tissues of NUNDO phantom were scaled to the masses of the ICRP reference man organs [3].

3. MATROSHKA Simulations

The measurements performed with TLDs in frame of the MTR experiment were compared to the results of simulations done using the 3-dimensional Monte Carlo code PHITS [5], which recently has been extensively benchmarked for space applications [6-11].

The simulations presented in this paper were based on the geometry of the NUNDO phantom with material composition as shown in table 1. Around the phantom a container, made of 0.85 g/cm^2 of carbon fiber composed by hydrogen (4.2%), carbon (42.2%), oxygen (4.2%), nitrogen (28.5), fluorine (8.4), silicon (11.7), chlorine (0.6) and sulfur (0.3), was located. The phantom, together with the container, was placed on the aluminum foundation of 1 g/cm^2 thickness. The inside of the foundation as well as the inside of the container were filled with air. The container together with the foundation, were located on the simplified ISS geometry chosen as an aluminum cylinder shape with a thickness of 15 g/cm^2.

Figure 2 shows the geometry of the simulations.

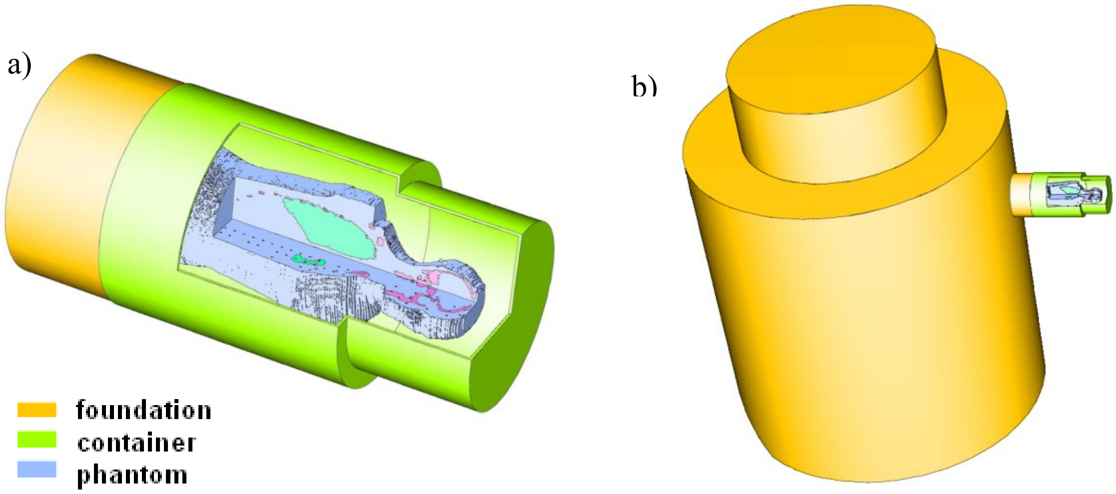

Figure 2. Simulated geometry of the phantom, container and foundation (a) and the simplify ISS geometry with MTR facility (b).

TLDs were simulated by material composed of Li-7 (0.2691 %), Li-6 (0.0001 %) and F-19 (0.7308 %) with the density of 2.7 g/cm^3. Size of the detector was taken as 5 x 5 x 3 mm^3 to represent the real stack of TLDs used in the experiment.

External space radiation environment for the average altitude of the ISS during the period MTR was outside the ISS (apogee 264 km, perigee 345 km, inclination 52 ^{o}) was performed by Cosmic Ray Effects on Micro-Electronics Code (CREME96) [12]. A spherical radiation source, with a diameter of 345 cm, was used in the simulations. The particles from the source were emitted inward, creating an isotropic environment inside the sphere. Simulations were done separately for Trapped Protons (TP) and Galactic Cosmic Radiation (GCR). In this paper only the results of TP are presented as the calculations of GCR are still running because such complicated particle spectrum, from protons up to nickel with energies from 1 MeV/u up to 100 GeV/u, needs many of cpu hours.

The simulations were done on a Linux based cluster at National Supercomputer Centre in Linkoping, Sweden. To reach reasonable statistics more than 5000 cpu hours for TP calculations were used.

4. Results

The results of the simulations were compared to the MTR experimental data [1]. Tubes 3, 4 and 5, in the head region, as well as 22 and 23, corresponding to the chest height in the phantom, were selected for the first comparisons. Figures 3, 4, 5, 6 and 7 show some results of the experimental data with simulations of the TP. In the simulations, the phantom, container, foundation and ISS were included. This figures show preliminary calculations of the dose distributions from the TP inside the MTR during Extra-Vehicular Activity. As can be seen, the shapes of the calculated dose distributions calculations are roughly the same as the measured ones. Once should also bear in mind that a very approximate geometry for the shielding from the ISS was sued in the simulations since the exact geometry of the ISS was not available.

Acknowledgement

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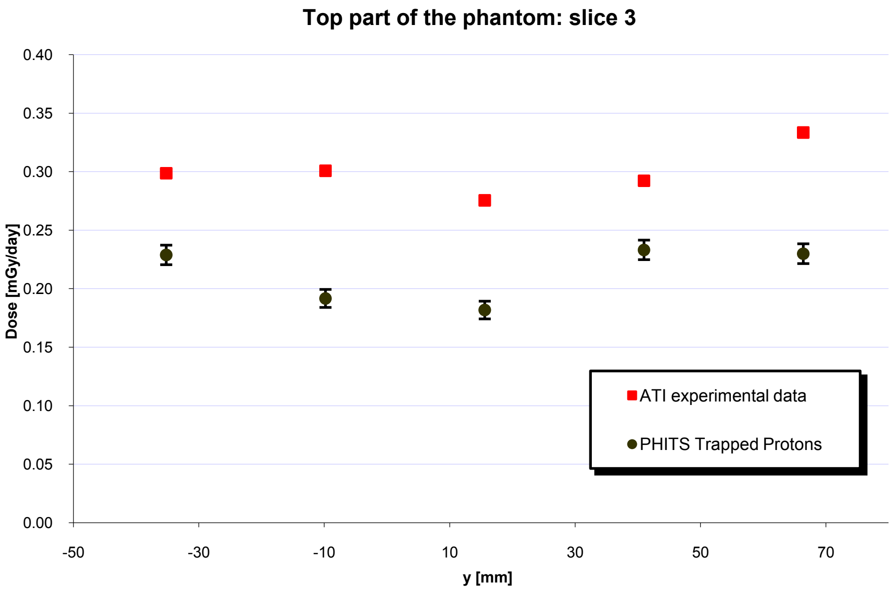

Figure 3. Simulations of MTR for slice 3 together with experimental data of ATI.

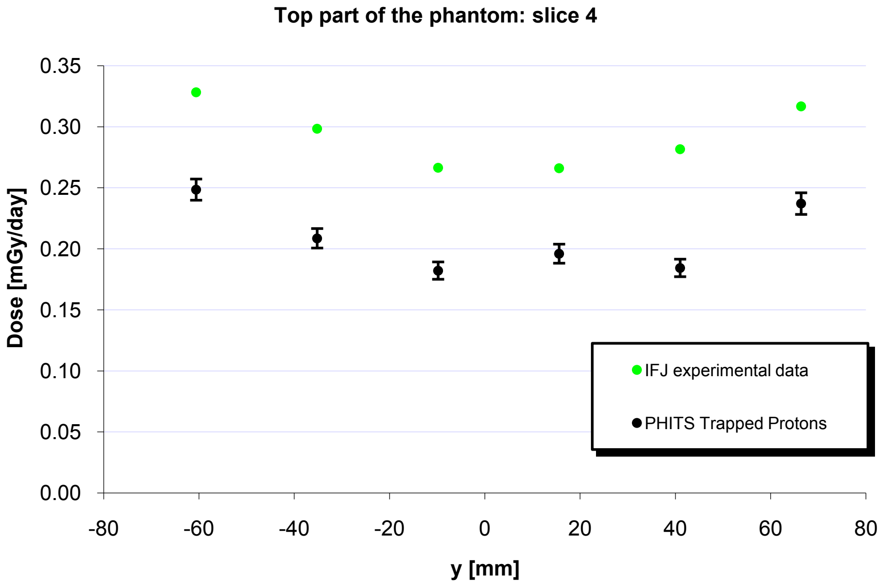

Figure 4. Simulations of MTR for slice 4 together with experimental data of IFJ.

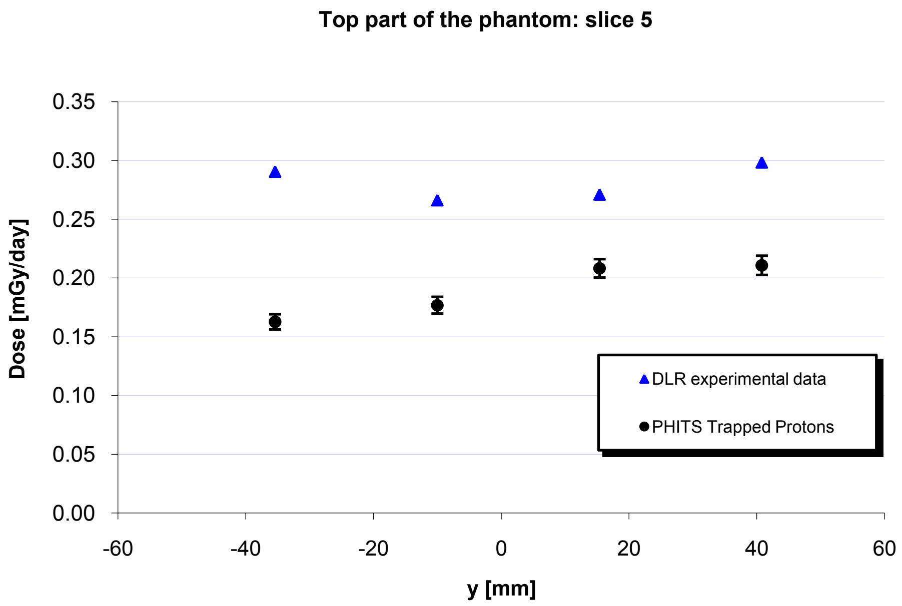

Figure 5. Simulations of MTR for slice 5 together with experimental data of DLR.

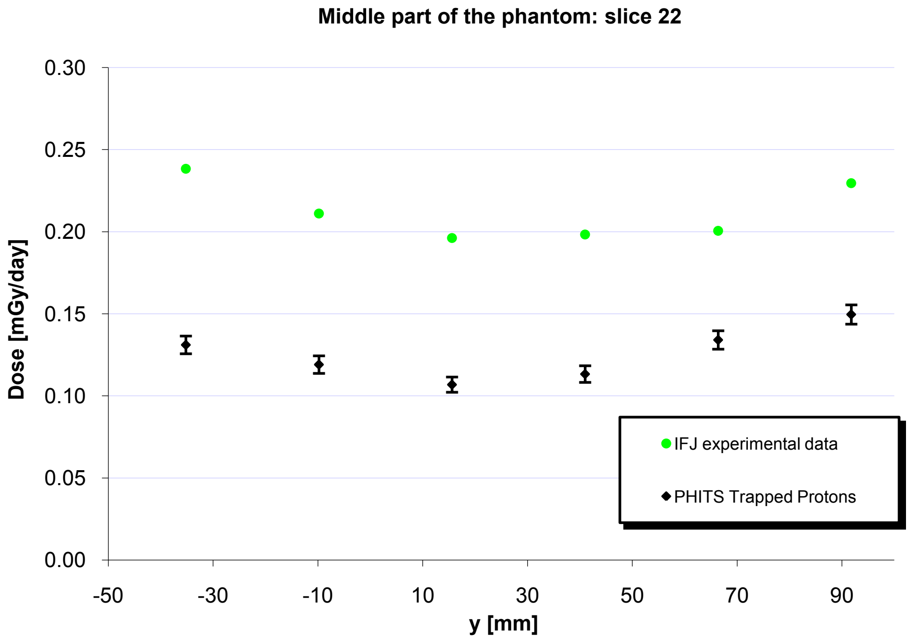

Figure 6. Simulations of MTR for slice 22 together with experimental data of IFJ.

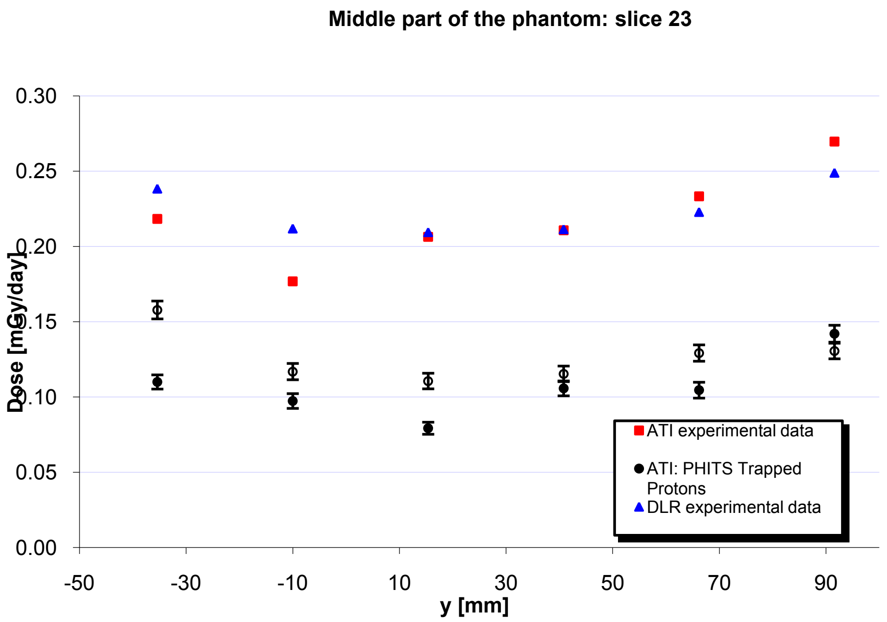

Figure 7. Simulations of MTR for slice 23 together with experimental data of ATI and DLR.

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