PHITS calculation of radiation field in HIMAC BIO

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The Heavy Ion Medical Accelerator in Chiba (HIMAC), at the National Institute of Radiological Sciences, is not only an excellent cancer-treatment facility but also a facility to perform experiments related to both radiation therapy and space radiation protection. HIMAC BIO is an irradiation room used for experiments related to biology and physics, frequently for calibration of detectors used onboard the International Space Station. To be able to evaluate these experiments, it is essential to know the experimental setup, as well as the beam characteristics, in details. Both narrow and broad parallel heavy ion beams (up to ϕ 10 cm), with flat circular profile at the isocenter, can be provided in HIMAC BIO. Such beams are obtained by using beam-line components, similar to those used during radiation therapy. However, these components decrease the energies of the primary beams and are sources of secondary particles. To be able to draw correct conclusions from the experimental results, and to be able to compare the measurements with simulations, it is crucial to know the real energy of the primary ions and the beam composition at the location of the biological samples and the physical detectors. The energies of the primary ions are calculated from Bragg curve measurement with a Markus chamber before each experiment. However, the exact beam composition including the fluence and energies of the secondary fragments and neutrons are usually unknown. The purpose of this paper is to provide detailed information about all the components in the beam line at the HIMAC BIO room to be able to perform particle and heavy ion transport simulations of the beam characteristics. The main sources of secondary particles have been investigated, and the beam composition was calculated by the Monte Carlo code PHITS (Particle and Heavy Ion Transport code System) and compared with measurements using a silicon detector (Liulin) exposed to various monoenergetic and Spread Out Bragg Peak (SOBP) heavy ion beams. We propose a new method of silicon detector calibration using only one heavy ion beam.

Assessment of Galactic Cosmic Ray flux models

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The precise estimation of the radiation exposure of astronauts is a moral and legal obligation for the space faring nations. Relevant radiation field parameters such as absorbed dose and dose equivalent are commonly determined by measurements with various active and passive radiation detector techniques. In addition computer-based dose calculations have been used extensively in the last years to provide estimates for various mission scenarios which have not been previously accessible to measurements. For the latter approach, a valid description of the Galactic Cosmic Ray (GCR) spectra is a crucial prerequisite for any accurate estimation of the radiation exposure. The aim of this work is to investigate models describing the Galactic Cosmic Ray spectra and to test these models for their applicability for the dose assessment of astronauts by comparison with measurements.

In this talk we will present an evaluation of the most commonly used GCR models. We examined the updated Badhwar/O'Neill model published in the year 2010, CREME 2009 which uses the International Standard model for GCR and CREME96. The accuracy of these models was evaluated by comparing the model-generated GCR spectra for various particles over several decades with measurements on high-altitude balloon experiments and on board the Advanced Composition Explorer (ACE) spacecraft. Furthermore, we have estimated the radiation exposure in near-Earth interplanetary space resulting from the GCR environment as described by the various models allowing us to quantify the differences arising from the different models in terms of absorbed dose and dose equivalent. We found that for the description of the near-Earth GCR environment, the Badhawar-O'Neill 2010 model is the most accurate. Secondly, the CREME96 model should not be applied after the year 1997 and lastly, the average difference arising in the dose quantities when using these three models over the last 10 years is ~20%.

An update on the development of a model for ISS radiation mission planning

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A NASA operated tissue equivalent proportional counter (TEPC) has been measuring the ambient dose equivalent rate aboard the International Space Station (ISS) since late 2000. It is proposed that these data can be used as the basis of a model to predict space crew exposure during planned missions aboard the ISS.

A preliminary model correlating the ambient dose equivalent rate measured by the TEPC to the cutoff rigidity magnetic shielding parameter demonstrated an ability to predict the total ambient dose equivalent experienced aboard the ISS to within 20% of measured values. The preliminary assessment was based on limited data collected from July 7-13, 2001 and December 10-16, 2008 and presented at the 15th WRMISS conference. Recent access to the entire TEPC data set from late 2000 to early 2010 has allowed for an updated and more complete model.

An improved correlation for galactic cosmic radiation (GCR) exposures is developed and includes the identification of localized shielding effects on the observed dose equivalent rate. Furthermore, a new technique to model exposures resulting from trapped radiation sources within the South Atlantic Anomaly (SAA) is proposed. The trapped radiation dose rate distribution can be modeled as a function of latitude and longitude. The most recent distribution can be used in a prognostic manner to estimate the doses in the upcoming year because of the small drift of the SAA. This proposed model approximates the extent of the two-dimensional trapped radiation dose rate distribution within the SAA and minimizes the uncertainty associated with estimating the drift-rate of the SAA with time.

Numerical estimation of the radiation exposure during the solar energetic particle event on 13th of December 2006

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The solar energetic particle event (SPE) on 13th of December 2006 was characterized by a hard energy spectrum leading to a Ground Level Enhancement (GLE) of Neutron Monitors which lasted over several hours. The solar energetic proton fluence measured by the Geostationary Operational Environmental Satellite (GOES) was increased for over 24 hours.

In this work the radiation exposure at ISS orbit during this event was estimated by calculating organ doses and the effective dose with the GEANT4 Monte-Carlo toolkit. Different approaches to determine the effective dose are presented. Results using the ICRP and the Numerical RANDO Model (NUNDO) human phantom voxel models are compared to calculations based on organ shielding distribution functions, and the influence of different shielding thicknesses as well as different shielding materials on the expected radiation exposure are investigated. The protecting effect of the Earth's magnetosphere is estimated by additionally calculating the effective dose for near Earth interplanetary space mission scenarios.

The primary proton spectrum was derived from Neutron Monitor count rate increases for energies above 500 MeV and GOES measurements otherwise. The contribution of solar particles in the different energy regimes to the effective dose is quantified.

Preliminary Results of 2nd and 3rd Proton ICCHIBAN Experiments

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The ICCHIBAN working group (ICWG) carried out 3rd Proton ICCHIBAN experiments to make comparisons the responses of luminescence detectors on January and February 2011. We exposed the proton beams with energy 30 MeV (~2 keV/µm in water) at the NIRS-Cyclotron and 235 MeV (~0.4 keV/µm in water) at the National Cancer Center Hospital East (NCCHE) Cyclotron which is placed at Kashiwa in Japan and used for cancer treatment.

In this presentation, we will show the preliminary results of 4 different energy proton beams adding 40 and 70 MeV beams exposed at the NIRS-Cyclotron on 2010 as 2nd Proton Experiments and introduce the characteristic of the radiation field at NCCHE Cyclotron which we used first time for the ICCHIBAN experiments.

ISS and Space Shuttle Radiation Measurements at Solar Minimum

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A summary of 2008-2011 ISS and Space Shuttle radiation dosimetry results for inside-vehicle radiation monitoring in low Earth orbit will be presented. Results include new data from radiation area monitors on ISS Expedition 22-25/20A and passive radiation dosimeters on Shuttle missions STS127-STS133. Radiation measurement locations on ISS 20A included three Node 2 crew quarters locations at NOD2S5_CQ, NOD2P5_CQ, and CQ-3 (Deck), as well as locations in ESA Columbus and JAXA Kibo modules. The ISS 20A and STS127-STS133 missions were flown at 51.6° inclination with an altitude range of 330-350 km. The passive radiation results will be presented in terms of measured daily dose obtained using luminescence detectors (Al_2O_3:C, LiF:Mg, Ti, and CaF_2:Tm).

In addition, preliminary results from the DOSIS 2 Project, in which Space Radiation Analysis Group (SRAG) collaborated with the German Space Agency (DLR), will be presented. SRAG's participation in the DOSIS 2 exposure on ISS (11/16/2009-05/26/2010) involved passive radiation measurements at 10 different shielding locations inside the ESA Columbus Module.

The DOSIS experiment onboard the Columbus Laboratory of the ISS: Detector evaluation status and the status of the upcoming DOSIS 3D experiment

T. Berger and G. Reitz for the DOSIS and DOSIS 3D science team

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The aim of the DOSIS (Dose Distribution inside the ISS) experiment, under the project and science lead by the DLR, was the spatial and temporal determination of the radiation field parameters inside the European Columbus laboratory onboard the International Space Station. This goal was achieved by applying a combination of passive (Thermo- and Optical luminescence – TLD and OSL - and Nuclear track etch), as well as, active (silicon telescope) radiation detectors. The passive radiation detectors – so called passive detector packages (PDP) were mounted at eleven positions within the Columbus laboratory – aiming at the spatial dose distribution measurement of the linear energy transfer spectra, absorbed dose, and the dose equivalent with an nominal exposure time of six months. Two active silicon telescopes – so called- Dosimetry Telescopes (DOSTEL 1 and DOSTEL 2) together with a Data and Power Unit (DDPU) were mounted within the DOSIS Main Box at a fixed location beneath the European Physiology Module (EPM) rack. The DOSTEL 1 and DOSTEL 2 detectors were positioned at a 90° angle to each other for the precise measurement of the temporal and spatial variation of the radiation field, especially during crossing the South Atlantic Anomaly (SAA).

The DOSIS-1 hardware was launched with the Space Shuttle Endeavour to the International Space Station on 15 July. The first PDP set was downloaded after an exposure time of 136 days in November, 2009 and a second PDP set was installed in November, 2009 and downloaded in May, 2010 after an exposure time of 191 days. The active, silicon detector system worked continuously from July 2009 to June 2011.

The presentation will give an overview of the current status of data evaluation of the DOSIS experiment – both for the active and passive radiation detectors. Further on the current status of the follow up experiment DOSIS 3D – to be launched for a three year exposure period onboard the Columbus Laboratory – in March 2011 will be presented and discussed.

The Austrian activities within the DOSIS experiment were supported by the Austrian Space Applications Programme (ASAP) of the Federal Ministry for Transport, Innovation and Technology under contract no. 819643. The Polish contribution to the DOSIS experiment was supported by the Ministry of Science and Higher Education, grants No. DWM/N118/ESA/2008 and N N505 261 535.. The Hungarian contribution was supported by the ESA PECS grant No. C98066. The contributions of CAU were supported by DLR under grants 50WB0826 and 50WB1026.

Recent results of TLD and OSL measurements from SCK•CEN

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The effects of the complex radiation field in space, consisting of protons, neutrons, electrons and high-energy heavy charged particles, on biological samples are of high interest in the fields of radiobiology and exobiology. Radiation doses absorbed by biological samples must be quantified to be able to determine the relationship between observed biological effects and the radiation dose. The quantities of interest are the absorbed dose and the equivalent doses to the samples.

Due to the complex irradiation field in space, space dosimetry is not as straightforward as routine gamma dosimetry. A combination of several techniques, being OSL, TL and track etch technology can be used to cover the complete LET-spectrum. SCK•CEN, in collaboration with other institutes, has been participating in several experiments conducted in low earth orbit for the development of a standard dosimetric method (as a combination of different techniques) to measure accurately the absorbed doses and equivalent doses in biological samples.

The methodology and results from our latest dosimetric measurements, containing DOSIS-II and CFSA short term experiments will be presented. For both experiments TLD (LiF:Mg,Ti and LiF:Mg,Cu,P) and OSL(Al2O3:C (Luxel)) detectors were used.

Next to these experiments, SCK•CEN also participated in the ICCHIBAN-3 experiment. This experiment is intended to characterize the high LET behavior of detectors. The results of these experiments were compared to the results achieved in previous similar experiments in order to obtain an efficiency curve, used to correct the space dosimetry results. The results on this characterization will be presented as well.

Radiation Monitoring using PADLES on board the ISS Japanese Experiment Module, Kibo

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We have utilized a PADLES dosimeter consisting of CR-39 PNTDs and TLD-MSOs (Mg_2SiO_4:Tb) for space radiation dosimetry. Area PADLES is a series program to perform area radiation monitoring in ISS Japanese Experiment Module（JEM）, Kibo. The continuous radiation area monitoring has conducted at 17 fixed-points inside the Kibo. First area monitoring started at the same time as the installation of a Kibo's pressurized module on June 1, 2008 during a space shuttle mission STS-124/1J; second on Mar. 16, 2009 during STS-119/15A; third on Aug. 29, 2009 during STS-119/17A; fourth on April 5, 2010 during STS-131/19A, fifth on March 2011 during STS-133/ULF5, and sixth on May 2011 during 25S (TMA-20). The fourth and fifth PADLES dosimeters recovered in 2011 are now under analysis at Tsukuba Space Center.

Along with the third Area PADLES experiment, an Exp PADLES experiment was conducted to study directional dependence of radiation dose inside JEM. An Exp PADLES package consists of 6 modified Area PADLES dosimeters, which was installed to TVC bracket on the zenith of ELM-PS, which is a part of JEM and . Doses above 10 keV/ μm obtained from CR-39 PNTDs faced to the Earth were smaller than those from CR-39 PNTDs installed perpendicularly to the Earth.

Radiation dosimetry for bio-specimens (Bio PADLES) is in progress for various life science experiments. At the present, we provided Bio PADLES dosimeters for 13 life science experiments. We also report the results of the Bio PADLES dosimeters, in addition to past results of area radiation monitoring on the Kibo.

Dose Measurements Onboard the ISS with the Pille TLD System

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The Pille system was developed by the KFKI Atomic Energy Research Institute as the first and to date the only TLD system containing an on-board reader designed specifically for use by cosmonauts and astronauts while traveling in space. Since the first time it was launched in 1980, the Pille system worked on board each space station. It has been continuously used on board the International Space Station since October 2003 under the supervision of the Institute for Biomedical Problems (IBMP) as the service dosimeter system of the Russian Zvezda module. In the past seven years the dosimeter system was utilized for routine dose measurements inside the ISS, and as personal dosimeter system during EVAs. With the system consisting of a lightweight reader device and a number of TL dosimeters, more than 30 000 read-outs were carried out until now. The Pille system provides monthly dose data from locations of the space station including Matroshka while two dosimeters are dedicated to EVA measurements, and one is read out in every 90 minutes automatically to provide high time resolution data.

The measurement data (including several EVA measurements) from the latest expeditions (Expeditions 23-24 and 25-26, April 2010 – April 2011) obtained by the Pille system will be presented. The results will be compared with previous measurement results.

Preliminary results of the SPD Box experiments onboard ISS

J. Szabó, J.K. Pálfalvi, V.A. Shurshakov, R. Tolochek

The Radiation and Environmental Physics Department of the Atomic Energy Research Institute (Hungarian Academy of Sciences) participated in the SPD Box experiment in 2010 with 6 passive detector stacks containing thermoluminescence and solid state nuclear track detectors. The stacks were placed in 6 different locations on the ISS for ~211 days.

The track detectors were etched in 2 steps and evaluated by the VIRGINIA image analyzer system (semi-automatic measurements). Beside these investigations, manual HZE track analysis was also performed. The results obtained by the two different detector types were then convolved. LET spectra, absorbed dose, dose equivalent and average quality factor values will be presented.

Dose distribution in SPD box and CR-39 PNTD results: Comparison between NPI and NIRS

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We have carried out several experiments onboard the International Space Station using CR-39 plastic nuclear track detectors and luminescence detectors. Issues regarding differences in the results from luminescence detectors, especially from particles below 10 keV/μm, are being addressed by the Proton ICCHIBAN campaign. We are currently focusing on differences in dose and dose equivalent results ≥10 keV/μm measured in CR-39 PNTD.

We mapped the dosimetric distribution inside an SPD box which is commonly used in the Russian module of the ISS using CR-39 PNTD and luminescence glass detector in order to determine whether the variation in dose throughout the box may be responsible for the variations seen in detectors from different laboratories. We also compared the CR-39 PNTD results from NPI and NIRS using the same data set with common analysis software (PitFit). We show those results and suggest some ways of verifying CR-39 PNTD results for onboard space experiments.

On the uncertainty of linear energy transfer spectra measured with track-etched detectors in the space

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Linear energy transfer (LET) spectra of cosmic radiation particles can be used for the calculation of dosimetric quantities like the absorbed dose or dose equivalent. On board spacecraft, LET spectrometry is often performed with track-etched detectors (TED). The processing, readout and calibration of TED is a multistage process, where each stage affects the accuracy of the measured LET spectrum. The aim of our work is to analyze the accuracy of a typical LET spectrum measurement with TEDs by estimating related uncertainties. So far, such in-depth analysis has not been published.

The study was performed with LET spectra measured with polyallyldiglycol carbonate-based TEDs (known as CR-39) manufactured as TD1 by Japan Fukuvi Chemical Industry Co on board of ISS. The calibration was performed with several heavy ion species (He, C, Ne, Si, Ar, Fe, Kr) of different energies at the HIMAC-BIO facility. The detectors were processed with methods described elsewhere. Uncertainties of both the calibration curve and the resulting LET spectra were determined using methods described in the Guide to the expression of uncertainty in measurement [1].

A method for the evaluation of the uncertainty of LET spectra measured with track-etched detectors was developed and will be presented, including the calibration curve of TD1, measured LET spectra, and all uncertainties.

[1] JCGM 100: 2008. Evaluation of measurement data – Guide to the expression of uncertainty in measurement

Review of Bubble Detector Measurements on board the International Space Station

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The bubble-detector personal neutron dosimeter and bubble-detector spectrometer have been used as part of the international Matroshka-R and Radi-N experiments, on board the ISS, to characterize the neutron dose and the energy spectrum of neutrons. Experiments using bubble dosimeters inside a tissue-equivalent phantom were performed during the ISS-13, ISS-14, ISS-15, ISS-16, ISS-18, and ISS-19 expeditions. During the ISS-20 and ISS-21 missions, the bubble dosimeters were supplemented by a bubble-detector spectrometer, a set of six detectors which was used to determine the neutron energy spectrum at various locations inside the ISS. The temperature compensated spectrometer set used is the first to be developed specifically for space applications.

Results of the dose measurements indicate that the dose received at two different depths inside the phantom are not significantly different, suggesting that bubble detectors worn by a person provide an accurate reading of the dose received inside the body. The energy spectra measured using the spectrometer are in good agreement with previous measurements and do not show a strong dependence on the precise location inside the station.

This paper provides an overview of the experiments that have been performed on board the ISS using both bubble personal dosimeters and the bubble spectrometer in different expeditions.

Results from the DOSIS Experiment

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Besides the effects of the microgravity environment, and the psychological and psychosocial problems encountered in confined spaces, radiation is the main health detriment for long duration human space missions. The radiation environment encountered in space differs in nature from that on earth, consisting mostly of high energetic ions from protons up to iron, resulting in radiation levels far exceeding the ones encountered on earth for occupational radiation workers. Accurate knowledge of the physical characteristics of the space radiation field in dependence on the solar activity, the orbital parameters and the different shielding configurations of the International Space Station ISS is therefore needed.

For the investigation of the spatial and temporal distribution of the radiation field inside the European COLUMBUS module the DLR experiment DOSIS (Dose Distribution Inside the ISS) was launched on July 15th 2009 with STS-127 to the ISS. The experimental package was transferred from the Space Shuttle into COLUMBUS on July 18th. It consists in a first part of a combination of passive detector packages (PDP) distributed at 11 locations inside the European Columbus Laboratory. The second part is two active radiation detectors (DOSTELs) with a DDPU (DOSTEL Data and Power Unit) in a nomex pouch (DOSIS MAIN BOX) mounted at a fixed location beneath the European Physiology Module (EPM) inside COLUMBUS. After the successful installation the active part has been activated on the 18th July 2009. Each of the DOSTEL units consists of two 6.93 cm^2 PIPS silicon detectors forming a telescope with an opening angle of 120°. The two DOSTELs are mounted with their telescope axis perpendicular to each other to investigate anisotropies of the radiation field inside the COLUMBUS module especially during the passes through the South Atlantic Anomaly (SAA) and during Solar Particle Events (SPEs).

The data from the DOSTEL units are transferred to ground via the EPM rack which is activated approximately every four weeks for this action. Results from the DOSTEL measurements such as count rate profiles, dose rates and LET spectra will be presented in comparison to the data obtained by other experiments.

The contributions of the Kiel University were supported by DLR under grants 50WB0826 and 50WB1026.

Overview of Recent ISS Measurements and Future Human Spaceflight Operational Planning

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The Space Radiation Analysis Group (SRAG) monitors radiation levels for all manned spaceflight missions and is involved in developing requirements and concepts of operation for future exploration missions. Recent measurements made by active instrumentation aboard the ISS will be presented, particularly observations of the recent Solar activity. In addition, the future developments of active instrumentation and operational planning needed for exploration missions, while using the ISS as a test-bed for such missions, will be discussed.

Iron flux inside the International Space Station is measured to be lower then predicted

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Iron abundance in cosmic rays impinging humans in space habitats is of paramount importance when calculating the radiation risk for human space exploration. The concurrent relative abundance of iron in Galactic Cosmic Rays (GCR) and iron ability to produce damages at cellular and molecular levels, together with recent radiobiology results suggests iron as a major candidate to be studied in order to produce accurate radiation risk assessments. Iron may be in fact responsible for a large percentage of cancer risk during a long interplanetary voyage, and therefore deserves a specific attention. In this work we show a 50% to 75% overestimation of simulated iron abundances when compared to available measurements inside the International Space Station (ISS). This will be evidenced using published and new data acquired with the ALTEA detector in the ISS, as well as a novel simple model. We suggest that sources for iron, possibly not yet accurate enough in Low Earth Orbit, maybe responsible for part of this discrepancy and that new concurrent measurements (inside – outside the ISS) should be performed to help resolving this issue.

Analysis of the EVA Doses Observed by Liulin-Type instruments on ISS

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Data for this paper are collected by the Radiation Risk Radiometer-Dosimeter R3DE during the flight of the instrument at the European Technology Exposure Facility (EuTEF) on the Columbus External Payload Adaptor at the ISS inside of the ESA EXPOSE-E facility in the period February 2008–August 2009 and during the flight of the R3DR instrument inside of the ESA EXPOSE-R facility on the external pallet of the Russian Zvezda module during the period March 2009-August 2010. The construction of the R3DE/R instruments shows that the total external and internal shielding before the Si detector (0.3 mm thick, 2 cm^2 area) is 0.41 g cm^{-2}. The calculated stopping energy of normally incident particles to the detector is 0.78 MeV for electrons and 15.8 MeV for protons. The developed previously data analysis procedures allow on the base of the dose to flux ratio to be separated predominant different particles depositing the doses. Different EVA paths are selected and analyzed to understand the dose rate and accumulated dose depositions dynamics by different radiation sources: GCR, protons in inner radiation belt (SAA) and electrons from outer radiation belt. The R3DE/R data were compared with the TEPC data [1] (Zapp, 2011) and Pille data presented by (Apathy et al., 2010) during the 15th WRMISS workshop [2]. Main conclusion from the study is that the EVA dose dynamic is too complicated to be predicted by instruments situated inside of the station. Passive measurements with Pille type instruments are very useful but don't give opportunity to be developed EVA strategy which will minimize the doses. Only small active personal dosimeters, which are able to distinguish between different kinds of radiation sources can, measure the real astronauts/cosmonauts doses during EVA.

[1] http://cdaweb.gsfc.nasa.gov/

[2] http://wrmiss.org/workshops/fifteenth/Szanto.pdf

Influence of flight parameters on the dosimetric characteristics measured with Liulin semiconductor detector on board ISS during solar maximum and minimum

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Cosmic radiation measurements at low Earth orbit are essential for evaluation of spacecraft crew exposure. The total absorbed dose and dose equivalent of members of a given mission depend on many details of the mission itself; one can state the orbit parameters of the spacecraft, solar cycle phase, thickness and material of the shielding as examples. Our research was aimed on the influence of flight parameters such as altitude, position against the South Atlantic anomaly (SAA), and solar cycle phase. Preliminary calculations show influence of the altitude on absorbed dose inside the ISS, 10 km change in altitude causes about 10% change. This effect is more important inside of SAA.

The work deals with evaluation and comparison of data measured with Liulin-type semiconductor spectrometers on-board the International Space Station. We will present the energy deposition spectra and dose equivalent rates measured with two types of Liulins: R3DE and E094. The R3DE device was placed on-board EuTEF platform during the period from 22nd of February 2008 to 2nd September 2009 (solar minimum). The Liuin-E094 system was placed on US Laboratory module between May and August 2001 (solar maximum). In particular, attention is paid on examination of changes of energy deposition spectra with respect to perigee and apogee and altitude changes inside and outside of the SAA. Further the work deals with comparisons of measured data at low Earth's orbit during the solar minimum and maximum.

Study of Local Water Shielding Efficiency to Space Radiation with the Protective Curtain in ISS Crew Cabin

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The ISS Service Module crew cabins are known to be less shielded from space radiation as compared with the neighboring compartments. The outer wall of the cabin is only 1.5 g/cm^2 aluminum shielding. To increase the crew cabin shielding a special protective curtain was designed and then delivered to ISS in 2010. The hygienic wipes and towels containing water are stored in the protective curtain in 4 layers thus producing an additional shielding thickness of about 8 g/cm^2 water-equivalent matter. Total mass of the curtain with wipes and towels is 65 kg. The protective curtain was installed along the outer wall of the starboard crew cabin. To study the radiation shielding effect 12 passive detector packages with thermoluminescent detectors (TLD) and solid state track detectors (SSTD) are used. 6 packages are installed on the protective curtain surface and the other 6 packages are installed directly on the crew cabin wall behind or aside the curtain. The passive detector packages were exposed in the Service Module starboard crew cabin during 2 sessions: 149 days from July 4 to November 29, 2010 and from December 17, 2010 to May 5, 2011. During the exposure period additional measurement sessions with Pille-ISS thermoluminescent dosimeter and Bubble dosimeter were also carried out. The radiation shielding effect of the protective curtain is from 20 to 60 % for absorbed dose. In this experiment, water shielding proved to be more effective than aluminum. It was demonstrated that local shielding if properly mounted can effectively mitigate the radiation dose in space station compartments.

Space experiment BTN-Neutron on Russian segment of International Space Station

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The science goals, description of equipments and results for last four years for space experiment "BTN-Neutron" onboard "Zvezda" module of Russian segment of the International Space Station are presented. The goals of experiment are the registration of fast and epithermal neutrons, X-rays, and gamma rays in near-earth space. The goals, equipment and first steps in development for future second stage of experiment "BTN-Neutron" are presented too.

Study of Dose Distribution in a Human Body in ISS Compartments with the Spherical Tissue-Equivalent Phantom

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In the space experiment MATROSHKA-R, the spherical tissue equivalent phantom (30 kg mass, 35 cm diameter and 10 cm central spherical cave) made in Russia was originally installed in the star board crew cabin of the ISS Service Module in 2004 and then successfully used in other ISS compartments. Due to the specially chosen phantom shape and size, the chord length distributions of the detector locations are attributed to self-shielding properties of the critical organs in a real human body. If compared with the anthropomorphic phantom Rando used inside and outside the ISS, the spherical phantom has lower mass, smaller size, and requires less crew time for the detector installation/retrieval; its tissue-equivalent properties are closer to the standard human body tissue than the Rando-phantom material. In the first phase of the experiment with the spherical phantom the dose measurements were realized with only passive detectors (thermoluminescent and solid state track detectors). The experimental sessions with the spherical phantom were carried out in the ISS crew cabin, from Aug. 11, 2004 to Oct. 10, 2005, then in ISS Piers-1 Module from May 12, 2007 to Feb. 10, 2008 and from May 14, 2008 to Dec. 1, 2008, and from May 7, 2009 to Oct. 11, 2009, and then in MIM-2 Module from Apr. 30, 2010 to Nov. 29, 2010. The detectors are placed inside the phantom along the axes of 20 containers and on the phantom outer surface in 32 pockets of the phantom jacket. The results obtained with the passive detectors returned to the ground after each session show the dose difference on the phantom surface as much as a factor of 2, the highest dose being observed close to the outer wall of the compartment, and the lowest dose being in the opposite location along the phantom diameter. Maximum dose rate measured in the phantom is obviously due to the galactic cosmic ray (GCR) and Earth' radiation belt contribution on the ISS trajectory. Minimum dose rate is caused mainly by the strongly penetrating GCR particles and is observed behind more than 5 g/cm^2 tissue shielding. Critical organ doses, mean-tissue and effective doses of a crew member in the ISS compartments are also estimated with the spherical phantom. The estimated effective dose rate is found to be from 10 to 15 per cent lower than the averaged dose on the phantom surface as dependent on the body attitude.

Simulations of MATROSHKA-R experiment 2006 at the ISS using PHITS

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It is well known that space radiation represents a major hazard to crew members on long-duration manned space missions both, at the International Space Station (ISS) and on the planned interplanetary missions to Mars. The absorbed dose on board of space vehicles can either be measured or calculated using particle and heavy-ion transport codes. In some cases it may be very difficult or even impossible to directly measure the dose for all possible systems and therefore reliable and accurate particle and heavy-ion transport codes are needed.

This contribution presents simulations of long-term dose measurements at the surface and inside the tissue equivalent spherical phantom MATROSHKA-R placed in the ISS Service Zvezda Module from December 2005 to September 2006. The simulations were performed with the three-dimensional Monte Carlo Particle and Heavy-Ion Transport code System (PHITS). The simulated absorbed doses in 8 pockets on the surface of the phantom and inside the phantom in 4 equatorial containers were compared with passive detectors (packages of thermoluminescent and plastic nuclear track detectors) measurements. Furthermore, the contribution of trapped protons, galactic cosmic rays and some of its ions to the total absorbed dose as a function of a depth in the phantom was calculated.

The data calculated using the PHITS code assuming an ISS shielding of 3 g/cm^2 and 5 g/cm^2 aluminum mass thickness are in good agreement with the measurements. Using a simplified geometrical model of the ISS, the influence of variations in altitude and wall mass thickness of the ISS on the simulated absorbed dose was estimated. It was found that a difference in altitude of $\pm$ 10 km can cause $\pm$ 15 % difference in the absorbed dose in the phantom. A $\pm$ 1g/cm^2 difference in the wall mass thickness of the aluminum shielding results in a $\pm$ 7 % difference in the simulated absorbed dose. The uncertainties of the calculated data are also discussed; the relative expanded uncertainty of absorbed dose was estimated to be 44 % at a 95 % confidence level.

Neutron Production in a Spherical Phantom aboard the International Space Station

R. Machrafi, A. Tasbaz, V. Kovaltchouk, V. Shurshakov, N. Khoshooniy

In an attempt to estimate the relationship between the internal and external neutron dose in a shielded space environment, a spherical phantom has been modeled using Monte Carlo Calculation code. The code has been used to simulate the neutron production in different layer after exposing the phantom to external neutron spectra and to different mono energetic protons. The resulted neutron flux spectra have been calculated in different cell of the phantom and the internal to external ratio has been analyzed.

HAMLET: Ground Based Experiments for the harmonization of thermoluminescence data gathered in frame of the MATROSHKA experiment

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The FP7 HAMLET project is devoted to in-depth analysis of the MATROSHKA experiment performed onboard the International Space Station in the years 2004 – 2011. Besides compilation of data measured in the three phases of the experiment, an important part of the project is the study of the detector properties and the harmonization of data gathered with various detector systems applied within the MATROSHKA experiment. The first aim of these studies is the intercomparison of the relative efficiency of thermoluminescence detectors (TLD) to a simulated heavy ion space radiation environment by the joint irradiations of TLDs from DLR, Cologne, Germany, ATI, Vienna, Austria and IFJ, Krakow, Poland. These experiments were realized at the NIRS, Chiba and at GSI, Darmstadt, Germany, using helium, carbon, silicon, neon, argon, iron and nickel beams.

Further on the study was devoted to the investigation of long term stability of the performance of thermoluminescence detectors – taking into account the very long duration of the various MATROSHKA phases. This study was accomplished at IFJ and consisted of the over one-year storage of TLDs, with irradiations realized at different times during the storage period. Two storage temperatures (room temperature and -18°C) and two radiation modalities (gamma-rays and thermal neutrons) were used.

For a precise comparison of measured data it is necessary to prove, that also the calibration performed by the various research groups is consistent. For this an intercomparison experiment was realized, in which TLDs from DLR, ATI and IFJ were exposed to gamma calibration doses in each of the three participating laboratories.

The talk will give overview of the performed experiments and will present a summary of the most important results.

This work was realized in the frame of the HAMLET project, funded by the European Commission under the EU´s Seventh Framework Programme (FP7) under Project Nr: 218817 and coordinated by the German Aerospace Center (DLR) http://www-fp7-hamlet.eu. Irradiations at NIRS were realized within the HIMAC research project 20P-240. Irradiations at GSI were realized within the ESA-IBER research project AO-08-IBER-12.

HAMLET: Final Results from the MTR-1 / -2A and -2B experiment – Thermoluminescence Detectors

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The MATROSHKA (MTR) experiment, carried out under the science and project lead of DLR, is dedicated to determine the radiation load on astronauts when staying within or outside the International Space Station (ISS). The MTR mimics a human head and torso; it is an anthropomorphic phantom containing over 6000 radiation detectors to determine the depth dose and organ dose distribution in the body. It is the largest international research initiative ever performed in the field of space dosimetry and combines the expertise of leading research institutions around the world, thereby generating a huge pool of data of potentially immense value for research. The ESA facility MATROSHKA was launched in January, 2004 to the International Space Station ISS. Up to March 2011 four exposure phases have been performed. While during the MTR-1 experiment phase (2004 – 2005) the facility was located outside the Russian Service Module Zvezda, the MTR-2A experiment phase was carried out in the year 2006 inside the Russian PIRS module. The third phase (MTR-2B) was conducted in the years 2007 – 2009 inside the Service Module followed by a fourth experimental phase inside the Japanese Experimental Module (JEM) in 2010 – 2011 (MTR-2 KIBO).

Aiming at optimal scientific exploitation, the FP7 project HAMLET (Human Model MATROSHKA for Radiation Exposure Determination of Astronauts) intends to process and compile the data acquired individually by the participating laboratories of the MATROSHKA experiment. A concise overview will be given of data generated using thermoluminescence detectors focusing on the results from DLR, Cologne, Germany; ATI, Vienna, Austria and IFJ, Krakow, Poland for the three different MTR experiment phases -1 / -2A and -2B. This will include an into depth comparison of the differences of the various measured data, as organ dose, skin dose and depth dose distribution in relation to the locations and times of the exposure phases followed by an intercomparison with data generated within the MATROSHKA-R experiment.

Further on preliminary first data of the fourth MTR (MTR-2 KIBO) experiment phase in the Japanese KIBO module will be presented.

The HAMLET project is funded by the European Commission under the EU´s Seventh Framework Programme (FP7) under Project Nr: 218817 and coordinated by the German Aerospace Center (DLR) http://www-fp7-hamlet.eu

HAMLET: Results for the Nuclear Track Etch Detectors Evaluation for the MATROSHKA-1, -2A und -2B experiment phases

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The radiation environment encountered in space differs in nature from that on Earth, consisting mostly of high energetic ions from protons up to iron and heavier particles, resulting in radiation levels far exceeding the ones encountered on Earth by occupational radiation workers. The accurate knowledge of the physical characteristics of the space radiation field in dependence on the solar activity, the orbital parameters and the different shielding configurations of the International Space Station (ISS) is, therefore, needed to ensure reliable radiation protection for the crew. The combination of passive thermoluminescence detectors (TLD) and nuclear track etch detectors (PNTD) for the determination of the LET spectra, absorbed dose and dose equivalent has been used onboard the ISS, both for area monitoring and as part of the personal dosemeters of the astronauts in the last years. Especially within the MATROSHKA experiment the combination of TLD and PNTD was applied for the measurements at the surface of the MATROSHKA phantom (so called Poncho Detector Boxes) and at the places of dedicated organs (so called Organ Detector Boxes). PNTD from various research groups have been used for all the four MATROSHKA experiment phases in the years 2004 – 2011. Aiming at optimal scientific exploitation, the FP7 project HAMLET (Human Model MATROSHKA for Radiation Exposure Determination of Astronauts) intends to process and compile these data acquired individually by the participating laboratories of the MATROSHKA experiment. One part of this data processing was focused on the evaluation of track etch detectors provided by the Oklahoma State University (OSU). The already etched detectors were evaluated with the manual track detection and measurement systems developed at DLR, Cologne, Germany. The laboratory at DLR has currently two identical measurement systems running which enabled the detector evaluation by two operators at once. Data generated within this work will be presented for all the MATROSHKA experiment phases -1 / -2A and -2B and compared with Nuclear Track Etch Detector data from the other MATROSHKA investigator groups.

The HAMLET project is funded by the European Commission under the EU´s Seventh Framework Programme (FP7) under Project Nr: 218817 and coordinated by the German Aerospace Center (DLR) http://www-fp7-hamlet.eu

HAMLET: Neutron dose assessments for MATROSHKA using the HPA neutron PADC dosemeter

L. Hager, J. Eakins and R. Tanner for the HAMLET consortium

The UK Health Protection Agency's (HPA) PADC dosemeters have been used to measure neutron doses as part of the European Space Agency MATROSHKA project. Recent involvement within the EC-funded project HAMLET has provided more data and improved the methods used in their analyses.

The dosemeter was designed initially for use within terrestrial workplace fields, though its scope was later extended to measure neutrons encountered at commercial aircraft altitudes. The reference neutron fields used to calibrate the dosemeter were therefore chosen accordingly, such that the response of the device is quite well characterized up to 200 MeV. But, the response to higher energy neutrons is less well understood, as is its response to ion sources, which could produce tracks in the PADC that are indistinguishable from those created by secondary charged particles from neutron interactions. The use of the device in space dosimetry consequently poses significant challenges due to the prevalence of mixed-particle, high-energy fields. In particular, any doses quoted for neutrons will be excessive if the unwanted contributions from these primary ions are not accounted for correctly. Doses from other particle types are estimated by other members of the HAMLET consortium.

A number of methods were used to discriminate these components. Specifically, it was found that ions for which $Z \geq 3$ could be identified by performing an additional chemical etch during the dosemeters' processing. With $Z = 1$ and $Z = 2$ ions direct identification is not possible, so to account for them novel techniques had to be developed: these combined analytical approaches, Monte Carlo calculations, and measurements from irradiations at HIMAC. A description and discussion of these various methods is the focus of the present work, which concludes by providing the estimates of the neutron doses that subsequently were found.

Part of the research leading to these results has been performed within the HAMLET project (http://www.fp7-hamlet.eu/), which has received funding from the European Community's Seventh Framework Programme (FP7) under Project No. 218817, and is coordinated by the German Aerospace Center (DLR).

Irradiations at NIRS were performed in the framework of HIMAC Research Project 20P-240 "Space Radiation Dosimetry-Ground Based Verification of the MATROSHKA Facility".

Proton irradiations at HIMAC were performed by Yukio Uchihori and colleagues from the National Institute of Radiological Sciences, Chiba, JAPAN, in collaboration with the HPA, UK.

HAMLET: Final Results from the MTR-1 / -2B experiment phase – Active Instruments

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MATROSHKA (MTR) is an ESA experiment under leadership of DLR Cologne. The radiation exposure inside a human phantom is measured by active and passive detectors. One part of MTR is the DOSimetry TELescope (DOSTEL), which was built at CAU Kiel. This particle telescope consisting of two Si-semiconductor detectors measures count rates as well as energy deposition spectra.

MTR was onboard ISS from January 2004 to August 2011. The active instruments were operating during the first mission phase (MTR-1) where the phantom was mounted outside the ISS from February 2004 to August 2005. In 2008 the active instruments were operating again in another mission phase (MTR-2B) inside the Service Module of the ISS.

Within the framework of the FP7 project HAMLET (leadership DLR Cologne), the complete data sets of MTR-1 and MTR-2B DOSTEL measurements were analyzed and compared to the results of the passive detectors as well as other measurements of the corresponding time periods.

In this work the absorbed dose and dose equivalent values for galactic and trapped particles will be presented for both mission phases.

The work was carried out in the frame of the HAMLET project. HAMLET p is funded by the European Commission under the EU´s Seventh Framework Programme (FP7) under Project Nr: 218817 http://www-fp7-hamlet.eu

HAMLET: Simulations of MATROSHKA experiments at ISS using PHITS

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The health risks associated with exposure to the various components of space radiation is of great concern when planning manned long term interplanetary missions, such as the planned future missions to the Moon and to Mars. Since it is not possible to measure the radiation environment inside human organs in deep space, simulations based on radiation transport/interaction codes coupled with phantoms of tissue equivalent materials are needed. However, the calculated results depend on the models used in the codes, and it is therefore necessary to verify their validity by comparing with measurements. In this presentation a comparison of measured and calculated organ doses during a long term extravehicular activity will be shown. The influence of the different solar activities and altitude conditions on the simulated dose and the dose equivalents will also be presented. The measurements were performed with the MATROSHKA-1 experiment, which took place outside the Zvezda module from February 2004 to October 2005, and the MATROSHKA-2B experiment which was performed inside the Zvezda module from October 2007 to March 2009. The calculations were performed with the three-dimensional Monte Carlo Particle and Heavy Ion Transport code System (PHITS) together with the voxel-based numerical human model NUNDO (Numerical RANDO). The calculations were done using a very schematic and simplified geometry of the ISS.

The work was carried out in the frame of the HAMLET project. HAMLET p is funded by the European Commission under the EU´s Seventh Framework Programme (FP7) under Project Nr: 218817 http://www-fp7-hamlet.eu

HAMLET – Verification of voxel phantoms using the Monte Carlo codes GEANT4 and FLUKA

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In the years 2008 to 2011, five irradiation campaigns have been performed within the framework of the HAMLET project at the Heavy Ion Medical Accelerator (HIMAC) of the National Institute of Radiological Science (NIRS), Japan. In these campaigns, the head of the ground-based MATROSHKA phantom was equipped with thermoluminescence detectors (TLDs) provided by different groups of the HAMLET Consortium and exposed to beams of several different ion species. Besides the intercomparison of TLD results from the inside of the phantom head, the measurements aimed at comparing the experimental results with simulations using numerical voxel-based models and the Monte Carlo codes GEANT4 and FLUKA. For the calculations, two different voxel models have been used: the NUNDO (Numerical Rando) and the MATSIM (MATROSHKA Simulation) model. NUNDO is based on a computer tomography (CT) scan of the MATROSHKA torso, combined with organ sizes and locations defined in the Zubal phantom. MATSIM is a voxel model developed at the AIT Austrian Institute of Technology, which is based on the same CT scan and imported in the Monte Carlo code FLUKA. Monte Carlo calculations of absorbed doses have been performed applying both models with the objective of investigating the interactions of high-energy particles in the phantom models and validating the implementation of the models against ground-based measurements. Absorbed doses were calculated inside the phantom head for a number of projectiles and energies used during the irradiation campaigns and compared to the corresponding experimental results at the TLD locations. An overview will be given of the experiments conducted at the HIMAC using the MATROSHKA phantom head. GEANT4 and FLUKA simulations will be compared using the voxel phantoms and experimental results from selected ion beams, respectively.

The HAMLET project is funded by the European Commission under the 7th Framework Programme (FP7), contract no. 218817, and coordinated by the German Aerospace Center; http://www-fp7-hamlet.eu.

Irradiations at NIRS have been realized within the HIMAC Research Project no. 20P-240.

The MATSIM project has been conducted within the Austrian Space Applications Programme (ASAP) as a co-investigation of the MATROSHKA experiment in collaboration between the AIT Austrian Institute of Technology, the Vienna University of Technology and the German Aerospace Center.

IV-TEPC – Status of the Intravehicular - Tissue Equivalent Proportional Counter (IV-TEPC) development for ISS

E. Semones on behalf of the Advanced Radiation Instrumentation Project at NASA Johnson Space Center

NASA Johnson Space Center, Houston, Texas USA

The next generation of tissue equivalent proportional counters for use on the ISS has been developed at NASA Johnson Space Center. The IV-TEPC is a single, portable unit comprised of two tissue equivalent proportional counters, a control and data processor, readout and display electronics, electronic non-volatile memory, 1553 data bus hardware, Ethernet adaptor, and power supply. The system also includes the necessary cabling to interface with the ISS 1553 data system and power via a UOP or SUP connector, and cabling to interface with an SSC laptop. The system is to be launched on ATV-3 and will begin operations in 2012. An overview of the hardware development and performance characteristics will be given.

Comparison of Boron-loaded Plastic Scintillators for ISS-RAD

C. Zeitlin, K. Neal, M. Vincent, C. Kofoed, D. Hassler

The ISS-RAD instrument will contain a sensor head similar to that used in MSL-RAD for detection of charged and neutral particles. The neutron detector in the sensor head is sensitive to neutrons with energies above about 5 MeV and its sensitivity cannot be significantly improved without a major re-design of the sensor head. Because ISS-RAD must measure neutrons with energies as low as 0.5 MeV, a separate "Fast Neutron Detector" (FND) will also be built and integrated with the sensor head into a new and larger unit with a shared electronic interface to the ISS. The FND will consist of a boron-loaded plastic scintillator attached to a photomultiplier tube. With a boron-loaded plastic, incident neutrons may, with an energy-dependent probability, lose their energy to recoil protons so that they are thermalized. The thermal neutrons then may be captured by a ^{10}B nucleus, resulting in a reaction that liberates about 2.3 MeV of energy. The capture reaction and the resulting second light flash follow an exponential distribution in time. For a scintillator that is 5% natural boron by weight, the second pulse occurs on average about 2 μs after the initial pulse. The characteristic time and amplitude of the second pulse allows for identification of neutrons (and rejection of charged particles and γ-rays), and the amplitude of the first pulse is related to the energy of the incident neutron.

Four plastic scintillators – three of them containing boron – were recently placed in low-energy neutron beams at the RARAF facility in order to test their responses in the 0.5 to 6 MeV energy range. Results will be presented showing the excellent performance of the scintillators and readout system.

Calibration of depleted type p-MOSFET dosemeter to high energy protons

M. Fragopoulou, S. Stoulos, M. Zamani, E. Benton, Y. Uchihori, Denis O'Sullivan, S. Siskos, T. Laopoulos, V. Konstantakos and G. Sarrabayrouse

Depleted p-MOSFETs manufactured at LAAS-CNRS Laboratory, Toulouse, France are promising devices for their use in space radiation dosimetry. Calibration to high energy protons was performed at HIMAC accelerator through the frame of ICCHIBAN collaboration. The response of the depleted dosemeters as a function of dose present a sub-linear behavior for low energies while at higher energies is almost linear. MOSFETs response is increased with decreasing proton energy. The response of these dosemeters is additionally about one order of magnitude higher than the response of the MOSFETs dosemeters presented in literature, which are enhancement type MOSFETs. The depleted p-MOSFET dosemeters present higher response than that of the enhancement p-MOSFET irradiated at the previous ICCHIBAN experiment. This response can be increased even more, about one order of magnitude, if a stack of 2 identical depleted p-MOSFETS dosemeters is used.

A Sort-of Tissue Equivalent Proportional Counter for Space Radiation Dosimetry Applications

E. Benton and T. Collums

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We describe a modular, low-cost Sort-of Tissue Equivalent Proportional Counter (STEPC) for use in space radiation and atmospheric radiation dosimetry applications being developed by our laboratory. The detector consists of a 2" diameter spherical ionization cavity and a preamplifier circuit mounted inside a pressurized, resealable canister. We present data from accelerator exposures to characterize the instrument carried out using energetic heavy ion beams at HIMAC and energetic proton beams at the ProCure proton cancer treatment center in Oklahoma City. We also describe a self contained version of the STEPC that incorporates a spectrometer, power supply, and data logger for use on high altitude balloon flights and satellites.

Status of Medipix-Based Radiation Environment Monitor (REM) Station Development Test Objective (SDTO)

N. Stoffle, L. Pinsky, K. Lee, E. Semones, N. Zapp, C. Amberboy, A. Bahadori, J. Hauss, S. Pospisil, J. Jakubek, Z. Vykydal, D. Turecek, A. Burian

Since WRMISS 15, a Station Development Test Objective (SDTO) project to deploy a number of Medipix-based Radiation Environment Monitor (REM) devices on the ISS has been initiated. Each REM unit is approximately the size of a typical USB flash drive and will be operated by being plugged into one of the existing laptops onboard the ISS. The software required to control these units and transfer data to the ground for evaluation will be uploaded to the ISS and control files containing operational parameters may be accessed and modified from the ground to vary the performance of the units as required during data-taking periods. A simple crew interface is provided that will display both current dose rates and cumulative doses employing the current NCRP Dose-Equivalent definitions based on actual track-by-track LET measurements. Ground-based validations and Monte Carlo simulation results of the detectors performance will be presented along with a live demonstration of the operation of the flight hardware during the presentation of the talk.

Passive cooling of s.c. magnetic systems for the protection from ionizing radiation of habitats in space.

Piero Spillantini

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Suitable configurations of the system and suitable attitudes can enhance the role of passive cooling of the huge s.c. magnetic systems required for protecting from ionizing radiation manned habitats in deep space. Passive methods are very important for the cooling of s.c. magnetic systems based on medium temperature and high temperature s.c. materials, opening in perspective the possibility of their fully passive cooling without having recourse to other thermo-dynamical or mechanical refrigeration systems. General parameterizations are given, simple schemes are treated and discussed and specific examples are evaluated.