WRMISS 2015 Abstracts:

1- A Directional Trapped Proton Model for the International Space Station Orbit

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The completion of the international space station (ISS) in 2011 has provided the space research community an ideal proving ground for future long duration human activities in space. Ionizing radiation measurements onboard ISS form the ideal tool for the validation of radiation environmental models, space radiation transport codes and nuclear reaction cross sections. At low Earth orbit (LEO), a vehicle encounters exposure from trapped particles and attenuated galactic cosmic rays (GCR). Within the trapped field, a challenge arises from properly estimating the amount of exposure acquired. There exist a number of models to define the intensities of the trapped particles during the solar quiet and active times. During active times, solar energetic particles (SEP) generated by solar flare or coronal mass ejection (CME) also contribute to the exposure at high northern and southern latitudes. Among the more established trapped models are the historic and popular AE8/AP8 dating back to the 1980s, the historic and less popular CRRES electron/proton dating back to 1990s and the recently released AE9/AP9/SPM. The AE9/AP9/SPM model is a major improvement over the older AE8/AP8 and CRRES models. This model is derived from numerous measurements acquired over four solar cycles dating back to the 1970s, roughly representing 40 years of data collection. In contrast, the older AE8/AP8 and CRRES models were limited to only a few months of measurements taken during the prior solar minima and maxima. In this presentation, at LEO, the isotropic (omnidirectional) spectra of trapped proton models from AP8 and AP9 are re-casted into anisotropic (directional) spectra by modulating them with a measurement derived angular formalism. Since at LEO, electrons contribute minimally to exposure, the presentation ignores the AE8 and AE9 component of the models and presents the angular simulation of AP8 and AP9 in the vicinity of the south Atlantic anomaly (SAA) where protons exhibit east-west (EW) anisotropy and have a relatively narrow pitch angle distribution. Within the SAA, the EW anisotropy results in different level of exposure to each side of a target point within ISS. While the magnitude of the EW effect at LEO depends on a multitude of factors such as trapped proton energy, orientation of the spacecraft along the velocity vector and altitude of the spacecraft, the presentation draws quantitative conclusions on the combined effect of proton pitch angle and EW anomaly.

2- Preliminary attempt of implementing a full-scale geometrical input file of the International Space Station (ISS) and BION-M #1 (ENERGIA RSC) Biosatellite in MCNPX using AutoCAD solid modelling

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A reduced model of MCNPX has been developed and applied to the International Space Station (ISS) as well as the recoverable Russian biosatellite BION-M1. This work outlines a full-scale simplified AutoCAD model. It focuses on the modeling and conversion of the geometric input file from AutoCAD into MCNPX. The model can be used to simulate different particles and locations. It has been successfully implemented in MCNPX and the simulation time was around two days. In this work, a description of the model will be presented.

3- Exposure Risk Analysis for Human Exploration of Deep Space

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Space radiation protection methods are derived largely from ground-based methods recommended by the National Council on Radiation Protection and Measurements (NCRP, 1993) or International Commission on Radiological Protections (ICRP, 1990). Radiation protection is built on the principles of risk justification, limitation, and ALARA (as low as reasonably achievable). However, because of the large uncertainties in high charge and energy (HZE) particle radiobiology and the small population of space crews, distinct methods are used at NASA to implement a radiation protection program. The approach derived from recommendations by the NCRP (1989, 2000, 2014) has been undergone external review by the National Research Council (NRC, 2008, 2012), NCRP (2014), and through peer-review publications (Cucinotta et al., 2001, 2006, 2012, 2013a, 2013b; Cucinotta, 2014, 2015) in developing the NASA Space Cancer Risk (NSCR) model. For the understanding of the architectures and strategies of human exploration missions, various-class mission types are designed for Mars reference missions, and for asteroid and lunar missions. The fatal cancer risks, which have been considered the dominant risk for galactic cosmic radiation (GCR), are estimated for the exposure risk analysis by implementing the NSCR model with GCR environmental models, particle transport codes describing the GCR modification by atomic and nuclear interactions in spacecraft and tissue shielding, and NASA defined quality factors for solid cancer and leukemia risk estimates for HZE particles. The analysis will ultimately contribute to the optimization of radiation safety and well-being of space crew members participating in long-term space missions.

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4- On the Use of Superheated Bubble Detectors on Space Missions

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Superheated bubble detectors (SBD) have been used aboard spacecraft for over two decades, including aboard the Russian Mir Space Station, the International Space Station, and on Russian BioSatellites. Interpretation of bubble detector readings made in space has been problematic due to the fact the space radiation environment is dominated by charged particles and especially protons, while the characterization of SBD has largely been confined to neutrons. By means of experiments carried out using heavy ion and proton beams of known LET at particle accelerators, we demonstrate that SBDs are high-LET threshold detectors. Heavy charged particles with LET greater than a certain LET threshold will produce bubbles through direct ionization (i.e. electromagnetic rather than nuclear processes). High energy (relativistic) protons, α-particles and light ions of LET below the LET threshold can only produce bubbles via nuclear target fragmentation reactions that yield secondary charged particles of LET above the threshold within the sensitive volume of the detector. Neutrons are detected by SBD by undergoing nuclear interactions and producing secondary charged particles of LET above the threshold within the sensitive volume of the detector. For the SBD specifically designed for use aboard spacecraft, we determined the threshold for bubble formation to be $\mathrm{LET}_{\infty}\mathrm{H_2O}$ ³ 110 ± 10 keV/μm. We plan to determine a conversion coefficient to convert bubble detector readings, in different space missions, to an operational dosimetric quantity.

5- Estimation of dose contribution of secondary target fragment particles for space radiation dosimetry

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High energy protons, the main component of the cosmic rays, dominate the radiation risk for astronauts in space. In addition to energy loss by ionization processes, energetic protons can undergo nuclear interactions with target nuclei of Z >1, resulting in the production of short range (<10 μm), high-LET target fragment particles. According to the results of space radiation dosimetry experiments using CR-39 plastic nuclear track detectors (PNTD), the proton-induced secondary particles significantly contribute to the total absorbed dose and dose equivalent received by the astronauts during space missions. One of the few methods to detect these short-range particles is by using of CR-39 PNTDs analysed with an atomic force microscope (AFM). For the dose evaluation of these short-range and high LET target fragments, CR-39 (BARYOTRAK) PNTDs were irradiated with 30 - 230 MeV protons at HIMAC and cyclotron facilities in NIRS. CR-39 PNTDs are insensitive to primary protons of these energies due to the LET detection threshold of CR-39. In this presentation, the dose contribution and LET spectra of secondary particles for primary protons will be presented.

6- Calculations of the relative efficiency of LiF thermoluminescent detectors to cosmic radiation spectrum at the Earth's orbit

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Lithium fluoride thermoluminescent detectors (TLD) were used for cosmic radiation dosimetry already in early 1960s. Since that time they have been constantly applied in numerous space missions for personal dosimetry, area monitoring (e.g. DOSIS project), phantom measurements (MATROSHKA project) and dosimetry for biological experiments (e.g. EXPOSE-E). The relative efficiency of TLDs, defined as the ratio of their response to a given radiation and to a reference radiation, is not constant, but depends on ionization density. This raises a question about the relative efficiency of TLDs exposed to the complex cosmic radiation spectrum encountered at the Earth's orbit, which consists of variety of particles, including heavy ions, the spectrum of which covers an extremely broad energy range. The present work is an attempt to find an answer to this question.

The particle energy spectra were calculated for realistic flight conditions of the International Space Station (ISS). The calculation of the GCR component was based on the input spectra generated with the DLR model for solar minimum (2009) and solar maximum (2013) conditions. Contributions of trapped protons were estimated based on the AP8 model for solar minimum and maximum taking into account the altitude variations of the ISS. The interactions of the primary particles with the ISS were simulated with GEANT4 using a shielding geometry derived from the mass distribution of the Columbus Laboratory of the ISS.

The calculated spectra were convoluted with the experimental data on the relative TL efficiency measured for ions ranging from H to Xe at various particle accelerators]. The preliminary results will be presented for two main types of TLDs: LiF:Mg,Ti and LiF:Mg,Cu,P.

Acknowledgments: This work was supported by the National Science Centre (No DEC-2012/06/M/ST9/00423)

7- Neutron Measurements using Bubble Detectors: ISS-39/40 and ISS-41/42

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Radiation protection associated with human spaceflight is an important issue that becomes more vital as both the length of the mission and the distance from Earth increase. Neutrons encountered in low-Earth orbit (LEO), for example on the ISS, are produced predominantly by nuclear interactions of galactic cosmic rays (GCRs) and trapped protons with various elements in the walls and interior components of the spacecraft, and by neutron albedo from GCRs incident on the Earth's atmosphere. Previous investigations, using bubble detectors and other instruments, have shown that neutrons contribute significantly to the total radiation dose received by astronauts in LEO.

For almost a decade, bubble detectors have been used to characterise neutron radiation on the ISS for the Matroshka-R, Radi-N, and Radi-N2 experiments. During the ISS-13 (2006) to ISS-38 (2013/14) missions, a series of measurements was performed in both the Russian Orbital Segment (ROS) and the US Orbital Segment (USOS) of the ISS. The Matroshka-R and Radi-N2 experiments continued to collect data during the recent ISS-39/40 and ISS-41/42 expeditions. The Radi-N2 measurements continued in four modules of the USOS: Columbus, the Japanese Experiment Module, the US Laboratory, and Node 2. The goal of Radi-N2 is to characterise the neutron field in these four locations over a prolonged period of time, enabling an assessment of potential influence quantities such as location within the ISS, solar activity, and ISS altitude on the neutron contribution. Meanwhile, measurements in the ROS included investigation of the neutron dose and energy spectrum in the Mini Research Modules, MRM1 and MRM2. The experiments in MRM1 were performed using the Matroshka-R spherical phantom.

The recent Radi-N2 dose and spectral measurements are not significantly different from the earlier Radi-N and Radi-N2 results in the same ISS locations, despite the large variations in solar activity since the Radi-N experiment was conducted in 2009. The neutron dose measured in MRM2 is slightly lower than in other ISS locations, which may be due to the smaller mass of this module. The measurements with the phantom in MRM1 suggest that the dose inside the phantom is approximately 70% of the dose at its surface, confirming the results of earlier investigations. The results from ISS-39/40 and ISS-41/42, which reinforce the importance of neutrons on the ISS, will be presented and discussed.

8- Ground Testing of Bubble Detectors used in Space Radiation Dosimetry: Response to High Energy Neutrons

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Bubble detectors used for space dosimetry are initially calibrated against an AmBe neutron source. In order to assess the validity of the calibration factor used to adjust their sensitivity when used in high neutron energy field, a series of experiments have been conducted in ground-based high energy neutron environment similar to that encountered in space. The experiments have been conducted at the Los Alamos Neutron Science Center (LANSCE) at the Los Alamos National Laboratory, New Mexico USA. A set of bubble detectors of the same type used in space were exposed to a neutron spectrum from 0.6 to 800 MeV using the 30L beam line used for single event upset testing of semiconductor devices. The shape of the neutron spectra of the beam line is similar to the one encountered inside spacecraft during spaceflight. From the readings of the bubble detectors, the dose value has been determined and a calibration factor has been extracted to adjust the sensitivity of the bubble detector.

9- Recent Radiation Environment Studies aboard Biological Satellites

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Living organisms in space flight are continuously exposed to ionizing radiation with doses many times greater than the natural level on the ground. The actual doses vary as a function of flight duration, orbit, solar activity cycles, and space weather that depends on the geomagnetic situation and solar energetic charged particles that may hit the spacecraft. They space radiation doses also can be modified by the spacecraft shielding. The goal of radiation investigations, performed during the Bion-M1 30-day flight (April 19 – May 19, 2013) and Foton-M4 45-day flight (July 19 – September 1, 2014) within the framework of the ‘Bioradiation’ and ‘Bioradiation-F’ experiments, was to measure radiation effects to which biological specimens were exposed inside and outside the recovery module. The accumulated data helped identify the radiation dose distribution within the spacecraft and dose gradient on its exterior surface, taking into consideration shielding thickness. They were also used to determine the contribution of neutrons into the total dose was also obtained in the experiments. Techniques and procedures that can be used in dosimetric measurements on biological satellites will be demonstrated. The studies aboard Biological satellites demonstrate that radiation monitoring of biological specimens in space has to be performed using specific methods and procedures to assess biologically significant parameters of the radiation field. It is also required to account for radiation composition and anisotropy as well as noticeable dose gradients inside and outside the recovery module.

10- The DOSIS and DOSIS 3D project on-board the International Space Station – Current Status and Science Overview

Thomas Berger for the DOSIS and DOSIS 3D Science Team

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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, resulting in radiation levels far exceeding the ones present 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 experiment “Dose Distribution Inside the ISS” (DOSIS), under the project and science lead of DLR, was launched on July 15th 2009 with STS-127 to the ISS. The DOSIS experiment consists of a combination of “Passive Detector Packages” (PDP) distributed at eleven locations inside Columbus for the measurement of the spatial variation of the radiation field and two active DOSTELs with a Data and Power Unit (DDPU) in a dedicated nomex pouch mounted at a fixed location beneath the EPM rack for the measurement of the temporal variation of the radiation field parameters. The DOSIS experiment suite measured during the lowest solar minimum conditions in the space age from July 2009 to June 2011. In July 2011 the active hardware was transferred to ground for refurbishment and preparation for the follow up DOSIS 3D experiment. The hardware for DOSIS 3D was launched with Soyuz 30S to the ISS on May 15th 2012. The PDPs are replaced with each even number Soyuz flight starting with Soyuz 30S. Data from the active detectors is transferred to ground via the EPM rack which is activated once a month for this action. The presentation will give an overview of the DOSIS and DOSIS 3D experiment and focus on the results from the passive radiation detectors from the DOSIS 3D experiment (2012 – 2015) in comparison to the data of the DOSIS experiment (2009 – 2011).

The Polish contribution was supported by the National Science Centre (No DEC-2012/06/M/ST9/00423). The CAU contributions to DOSIS and DOSIS 3D are financially supported by BMWi under Grants 50WB0826, 50WB1026 and 50WB1232.

11- Overview of TLD and OSL measurements at SCK•CEN in the framework of the DOSIS and DOSIS 3D and the most recent biological experiments

Olivier Van Hoey

SCK•CEN

The radiation field in space is much higher than on earth. Therefore, it is important to monitor the radiation doses received by astronauts. Also radiation doses absorbed by biological samples in space must be quantified to be able to determine the relationship between the observed biological effects and the radiation dose. This requires compact passive radiation detectors. Due to the complexity of the radiation field in space, one has to combine different detectors like OSL, TL and track etch detectors in order to cover the complete LET spectrum.

For many years SCK•CEN has been participating in different experiments in low earth orbit. We usually send both TLD (LiF:Mg,Ti and LiF:Mg,Cu,P) and OSL (Luxel) detectors. Firstly, our methodology will be explained. Next, an overview will be given of our results from DOSIS and DOSIS 3D from 2009 up to the most recent experiments (DOSIS 1 and 2 and DOSIS 3D parts 1 to 6). Our data will be compared with that of the other laboratories. Also the observed trends over the years will be discussed. Further, the measured doses will be compared with that of the most recent biological experiment sent with the FOTON-M4 spacecraft in collaboration with our microbiology department. Finally, the radiation doses measured recently by LiF:Mg,Cu,P detectors and EPD-N2 dosimeters sent for a short flight with a weather balloon up to 30 km above the earth's surface will be compared with doses predicted by the CARI-6M software.

12- 3D Dose Distribution Measurements by Passive Detectors in the Columbus Module

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The DOSIS-3D project is a follow up experiment of the DOSIS measurement (2009-2011) in the Columbus module of the International Space Station (ISS), with the aim of obtaining 3 dimensional dose distribution information at different locations and shielding conditions using active and passive detector systems. Since 2012 six successful phases were completed. This long timeline makes it possible to study the effects of the Sun's activity (solar cycle) and the variation of the ISS altitude on the radiation environment inside the module.
The combined stacks of the MTA EK (Centre for Energy Research, Hungarian Academy of Sciences) consist of solid state nuclear track detectors (SSNTDs) and thermoluminescent dosimeters (TLDs). They are integrated in the passive dosimetry packages (PDPs) and are installed at 11 locations. One of the packages contains a central box and 1-1 boxes on four sides (Triple PDP). Mounting of the stacks in different orientations inside the package allows measuring the directional distribution of the cosmic rays. The evaluations of the data from the first five phases are completed and will be presented.
The dosimetric results of the experiment constitute essential information for the application of radiation protection standards for manned spaceflight and for any radiation susceptible experiment in space.

13- Monitoring onboard of ISS with passive detectors – long-term data

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This contribution deals with the measurements using passive detectors onboard of the International Space Station during last several years. The detectors were exposed every year since 2007 at various locations inside the station; typical duration of each session was about half a year. Spectra of linear energy transfer, total absorbed doses, dose equivalents, and quality factors were determined by combination of thermoluminescent and plastic nuclear track detectors. Variation of dosimetric quantities with different parameters such as the phase of solar cycle, orbit parameters of ISS, detectors' positions etc. will be discussed.

14- Pille Measurements on ISS (May 2014 – March 2015)

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The Pille system was developed 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 nine years the dosimeter system was utilized for routine dose measurements inside the ISS, and as personal dosimeter system during Extra-vehicular Activities (EVAs).
With the system consisting of a lightweight reader device and a number of TL dosimeters, more than 47000 read-outs were carried out until now. The Pille system provides monthly dose data from locations of the space station while two dosimeters are dedicated to EVA measurements, and one is read out in every 90 minutes automatically to provide high time resolution data.
Results to be presented: In the present paper the measurement data (including several EVA measurements) from the latest expeditions (Expeditions 40/41 and 42/43, May 2014 – March 2015) obtained by the Pille system is presented. The results are compared with previous measurement results.

15- The DOSIS and DOSIS 3D experiments on-board the International Space Station – Current Status and Latest Data from the DOSTELs as Active Instruments

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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 experiment DOSIS (Dose Distribution Inside the ISS) under the lead of DLR has been 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 of a combination of passive detector packages (PDP) distributed at 11 locations inside the European Columbus Laboratory and two active radiation detectors (Dosimetry Telescopes = 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 rack (EPM) inside COLUMBUS.

The active components of the DOSIS experiment were operational from July 18th 2009 to June 16th 2011. After refurbishment the hardware has been reactivated on May 15th 2012 as active part of the DOSIS 3D experiment and provides continuous data since this activation.

The presentation will focus on the latest results from the two DOSTEL instruments as absorbed dose, dose equivalent and the related LET spectra gathered within the DOSIS (2009 - 2011) and DOSIS 3D (since 2012) experiment.

The CAU contributions to DOSIS and DOSIS 3D are financially supported by BMWi under Grants 50WB0826, 50WB1026, 50WB1232 and 50WB1533.

16- Comparing Active Detectors: ALTEA and DosTel

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A complete space environment radiation model will describe the radiation environment in a deep space habitat, and will be used for mission planning and for the related steps in risk forecasting. This model shall feature the needed amount of details to perform a meaningful risk assessment, even in very complex situations such as those eventually building up in space habitats. This model will have to undergo a validation with measured radiation fields of similar complexity.

The International Space Station (ISS) is a real space habitat and features an inside radiation environment which is not much different to what will be found in habitats in deep space, when limiting to data at high latitude passages (where the effects of the Earth magnetic field is minimal, and there is no contribution from the SAA). This similarity extends also to the complexity due to the inside mass distribution.

Active detectors are the only ones to provide time information (needed to focus at high latitude data), as well as dose and energy transfer (LET). Some of them may measure or calculate input energy, the values of ions charge and the incoming radiation direction. These are the ones best fulfilling the details required for this kind of validation in complex habitats.

The exploitation of the radiation measurements performed in the ISS by all the instruments is therefore mandatory to provide the largest possible database to the scientific community, to be merged with detailed CAD models, in the quest for a full model validation.

While some effort in comparing results from multiple active detectors have been attempted, a throughout study of the procedure to follow to merge data in a single data-matrix so to provide the best validation set for radiation environment models has never been attempted.

This comparison process may include the use of models, either to complete the datasets or to insert data from different detectors in a common data set architecture, and therefore it is also a tool to study models applicability.

Aim of this talk is to describe such a procedure, applying it to two of the most performing active detectors in the ISS (ALTEA and DosTel), showing the use of simulations and models in the process.

General agreement between the two datasets is shown to be remarkable. Attention is also focused on several issues where results from the two measurements sets appear to slightly differ.

17 - TRITEL Measurements in the Russian Service Module (April – July 2013)

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An experiment developed in the Centre for Energy Research, Hungarian Academy of Sciences in cooperation with BL-Electronics Ltd and consisting of a three dimensional silicon detector telescope system (TRITEL) and a 3D passive detector package containing thermoluminescent detectors and CR-39 track etch detectors was delivered to the ISS at the end of March 2013 in the frame of the Matroshka-R space experiment in cooperation with the State Scientific Center, Institute for Biomedical Problems, Russian Academy of Sciences (IBMP), Moscow.
Our presentation addresses the scientific objectives as well as a short description of the experiment. Results of the first three months of TRITEL operation on board the Russian Service Module will be presented as well.

18- November 2013 analysis of high energy electrons on the Japan Experimental Module (JEM: Kibo)

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Albedo (precipitating/splash) electrons, created by galactic cosmic rays (GCR) interaction with the upper atmosphere move upwards away from the surface of the earth. In the past validation work these particles were often considered to have negligible contribution to astronaut radiation exposure on the International Space Station (ISS). Estimates of astronaut exposure based on the available Computer Aided Design (CAD) models of ISS consistently underestimated measurements onboard ISS when the contribution of albedo particles to exposure is neglected. Recent measurements of high energy electrons outside ISS Japan Experimental Module (JEM) using Exposed Facility (EF), Space Environment Data Acquisition Equipment - Attached Payload (SEDA-AP) and Standard DOse Monitor (SDOM), indicates the presence of high energy electrons at ISS altitude. In this presentation the status of these energetic electrons is reviewed and mechanism for the creation of these particles inside/outside South Atlantic Anomaly (SAA) region explained. In addition, limited dosimetric evaluation of these electrons at 600 MeV and 10 GeV is presented.

19- Variation of long term space radiation monitoring and the PHITS simulation during the solar minimum to maximum of the 24th solar cycle inside/outside of the ISS 'KIBO'

Aiko Nagamatsu (JAXA), **Tatsuhiko Sato** (JAEA), **Keiichi Kitajo** (AES**), Ken Shimada** (AES)**, Sayuri Sakane** (AES), **Kazuo Takeda** (RIST**), Koji Niita** (RIST), **Nakahiro Yasuda** (RINE)

Continuous space-radiation dosimetry for the radiation health management of Japanese astronauts throughout their careers is a key JAXA mission, while from a scientific perspective, environmental monitoring inside/outside the ISS 'KIBO' is essential for human space activities. Accumulated data and knowledge are also beneficial when designing new radiation monitors, supporting radiation risk assessments, and shielding the design of future space vehicles toward future interplanetary missions.

Since 2008, we have performing continuous space radiation dosimetry using a passive and integrating dosimeters, PADLES (Passive Dosimeter for Life-Science Experiments in Space) to obtain doses and the dynamic range of broad LET distributions.

Shielding effect of each ISS module has not been looked at so far. Series Free-Space PADLES[1] experiment for radiation environment outside the 'KIBO' has also started. The shielding case with varying thickness between approximately 0 to 4 mm^t in aluminum. This work will be expected to evaluate shielding effect of ISS hull wall due to direct comparative and simultaneous study with inside and outside measurement results.

As consequences, several hundreds of PALDES detectors have been used for various types of experiments[1,2] onboard the 'KIBO' under different shielding distributions, in an altitude between 337 to 418 km, during the solar minimum to maximum of the 24th solar cycle. The obtained results shows anisotropy of radiation environment and dose rate changes due to the ISS attitudes and the difference of shielding conditions. This tendency was also verified by Monte Carlo simulation using Particle and Heavy Ion Transport code System (PHITS) code[3], which is incorporated well developed 'KIBO' geometry and the shielding construction.

Based on the both actual measurements and the benchmark study with PHITS code, new development of techniques is starting for manned space flight operation beyond LEO. On this occasion, new personal alarm meter 'D-Space' which is very small, light, and also consumes very little electricity, and optimization study of shielding material for interplanetary spaceship and moon/Martian base will be presented with the discussions.

1. Nagamatsu, A., 2015. Space Radiation Dosimetry in the ISS, spearheading the following steps on the pathway to human space exploration beyond low-Earth orbit. In: ICRR2015 in Kyoto, Japan.
2. Nagamatsu., A. et.al., 2015. Space radiation dosimetry to evaluate the effect of polyethylene shielding in the Russian segment of the International Space Station, Physics Procedia, to be submitted.
3. Sato, T.,et.al., 2013. Particle and Heavy Ion Transport Code System PHITS, Version 2.52, J. Nucl. Sci. Technol. 50, 9, 913-923.

20- The Results of 5 Sessions of Experimental Study of Local Water Shielding Efficiency to Space Radiation with the Protective Curtain in ISS Crew Cabin

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Crew cabins in the ISS Service Module are known to be less shielded from space radiation comparing with the neighboring compartments. 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 inside protective curtain in 4 layers thus creating an additional shielding thickness. The protective curtain was installed along the outer wall of the starboard crew cabin. The thickness of outer wall is estimated as 1,5 g/cm^2 (H_2O), and the thickness of protective curtain is ~6 g/cm^2(H_2O) thus protective curtain is considered to have tangible effect against radiation. To study the radiation shielding effect 12 passive detector packages with thermoluminescent detectors (TLDs) and plastic nuclear track detectors (PNTDs) 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 5 sessions in period of 2010-2014 years. Results of both TLD and SSTD are presented. The radiation shielding effect varies from 11% to 48% for absorbed dose and from 5% to 47% for equivalent dose. The results are in good agreement with performed calculations. It is shown that properly mounted local shielding can effectively mitigate the radiation dose in space station compartments.

21- Global dose distributions of Lunar neutrons and gamma-rays obtained by the Kaguya gamma-ray spectrometer

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[3] National Institute of Radiological Sciences, Chiba, Japan;
[4] University of Coimbra, Coimbra, Portugal

The Kaguya Gamma-Ray Spectrometer (KGRS) onboard the Japanese lunar polar orbiter "Kaguya" has measured the gamma rays emitted from the global lunar surface during the period Feb. 10 to May 28, 2009. The gamma-rays and neutrons are generated by nuclear interaction of Galactic Cosmic Rays (GCRs) with the Moon surface materials. Using these gamma-ray and neutron data measured by the KGRS, the global maps of ambient dose equivalents due to lunar neutrons and gamma-rays were obtained. The mean doses from neutrons and gamma-rays on the lunar surface were 70 mSv/yr and 3mSv/yr, respectively. The dose equivalents are found to be high in mare regions, especially western Mare, which is attributed to the correlation with the enhancement of Fe and Ti and depletion of Ca and Al. The doses are also enhanced in the Eastern mare region. The doses in highlands are much lower than 70 mSv/yr because the elements are depleted in Fe and Ti and enhanced in Ca and Al. Especially, the neutron dose, occupying about 10 % of the total ambient dose equivalent due to primary GCR particles, is considerable contribution for radiation safety and protection in up-coming manned mission on the Moon.

22- Overview and Future Plans of NASA Dosimetry for Manned Spaceflight Operations

Eddie Semones

SRAG, NASA JSC, Houston

To continue supporting long term presence of crews on ISS and future exploration class missions to cis-lunar space or Mars, NASA is supporting several dosimetry and radiation measurement projects. The projects range from repairing backup hardware and development of new operational hardware designs to supporting scientific investigations on ISS and at Mars. Status and plans of each of these projects will be presented.

23- Dose Calibration of the ISS-RAD Fast Neutron Detector (C. Zeitlin on behalf of the ISS-RAD Science Team)

Cary Zeitlin

Lockheed Martin Information Systems & Global Solutions

The ISS-RAD instrument has been fabricated by Southwest Research Institute and delivered to NASA for flight to the ISS in late 2015 or early 2016. ISS-RAD is essentially two instruments that share a common interface to ISS. The two instruments are the Charged Particle Detector (CPD), which is very similar to the MSL-RAD detector on Mars, and the Fast Neutron Detector (FND), which is a boron-loaded plastic scintillator with readout optimized for the 0.5 to 10 MeV energy range. As the FND is completely new, it has been necessary to develop methodology to allow it to be used to measure the neutron dose and dose equivalent. This talk will focus on the methods developed and their implantation using calibration data obtained in quasi-monoenergetic (QMN) neutron fields at the PTB facility in Braunschweig, Germany. The QMN data allow us to determine an approximate response function, from which we estimate dose and dose equivalent contributions per detected neutron as a function of the pulse height. We refer to these as the “pSv per count” curves for dose equivalent and the “pGy per count” curves for dose. The FND is required to provide a dose equivalent measurement with an accuracy of □10% of the known value in a calibrated AmBe field. Four variants of the analysis method were developed, corresponding to two different approximations of the pSv per count curve, and two different implementations, one for real-time analysis onboard ISS and one for ground analysis. We will show that the preferred method, when applied in either real-time or ground analysis, yields good accuracy for the AmBe field. We find that the real-time algorithm is more susceptible to change-coincidence background than is the algorithm used in ground analysis, so that the best estimates will come from the latter.

24- Capabilities, Calibration, and Impact of the ISS-RAD Fast Neutron Detector

Martin Leitgab

SRAG, NASA JSC, Houston

In the current NASA crew radiation health risk assessment framework, estimates for the neutron contributions to crew radiation exposure largely rely on simulated data with sizeable uncertainties due to the lack of experimental measurements inside the ISS. Integrated in the ISS-RAD instrument, the ISS-RAD Fast Neutron Detector (FND) will deploy to the ISS on one of the next cargo supply missions. Together with the ISS-RAD Charged Particle Detector, the FND will perform, for the first time, routine and precise direct neutron measurements inside the ISS between 0.5 and 80 MeV. The measurements will close the NASA Medical Operations Requirement to monitor neutrons inside the ISS and impact crew radiation health risk assessments by reducing uncertainties on the neutron contribution to crew exposure, enabling more efficient mission planning. The presentation will focus on the FND detection mechanism, calibration results and expectations about the FND's interaction with the mixed radiation field inside the ISS.

25- Signal processing of the ISS-RAD Fast Neutron Detector (FND) electronics

Michael Vincent

Southwest Research Institute, Boulder

The Rad Detector for the international Space Station uses a Boron loaded plastic scintillator. This allows for detection of fast neutrons by looking for the characteristic pulse pair. A fast neutron will produce a prompt recoil proton pulse. Neutrons that are sufficiently thermalized within the scintillator are likely to undergo the 10B (n, d) capture. A capture pulse, in delayed coincidence with the prompt pulse, is used to identify neutron events.

The Field Programmable Gate Array (FPGA) responsible for the neutron discrimination has to process the digitized pulses produced from a photomultiplier tube in such a way as to (1) be computationally efficient for power and design size constraints in the FPGA (2) produce a result that is accurate as to the magnitude of the scintillation light (3) contain the logic to correctly identify neutron pulse pairs.

Aspects of the design will be presented including details of the following:

- DC baseline estimation
- Pulse-size dependant infinite impulse response AC baseline estimation

Lessons learned regarding pulse pair discrimination that led to the requirement to store pulse triplets in order to correctly identify neutron pulse pairs.

26- Status of ISS RAD

R. Rios[1] , C. Zeitlin[2], K. B. Beard[2], M. Leitgab[1], E. Semones [1]

[1]SRAG, NASA JSC, Houston; [2] Lockheed Marin

The International Space Station (ISS) Radiation Assessment Detector (RAD) is an intra-vehicular energetic particle detector designed to measure a broad spectrum of charged particle and neutron radiation unique to the ISS radiation environment. RAD consists of two main detectors – the RAD Sensor Head (RSH) – also referred to as the Charged Particle Detector (CPD) – and the Fast Neutron Detector (FND). The RSH consists of four detectors used in measuring the spectroscopy of charged particles – A, B, C, and D; high-energy neutral particles and charged particles are measured in E; and the last detector – F – is an anti-coincidence detector. A, B, and C are made from Si; D is made from BGO; E and F are made from EJ260XL plastic scintillator. The FND consists of a Boron loaded plastic scintillator (EJ254XL); flashes in the scintillator are detected by a photomultiplier tube (PMT).

A summary of the calibration campaigns for the RSH, status of ISS RAD as well as operational plans for ISS will be presented.

27- RAG Measurements performed during the Orion EFT-1 Mission

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The Exploration Flight Test 1 (EFT-1) was the first flight of the Orion Multi-Purpose Crew Vehicle (MPCV). The flight was launched on December 5, 2014, by a Delta IV Heavy rocket and lasted 4.5 hours. The EFT-1 trajectory involved one low altitude orbit and one high altitude orbit with an apogee of almost 6000 km. As a result of this particular flight profile, the Orion MPCV passed through intense regions of trapped protons and electron belts.

In support of the radiation measurements aboard the EFT-1, the Space Radiation Analysis Group (SRAG) provided a Battery-operated Independent Radiation Detector (BIRD) based on Timepix radiation monitoring technology similar to that employed by the ISS Radiation Environmental Monitors (REM). In addition, SRAG provided a suite of optically and thermally stimulated luminescence detectors, with 2 Radiation Area Monitor (RAM) units collocated with the BIRD instrument for comparison purposes, and 6 RAM units distributed at different shielding configurations within the Orion MPCV.

A summary of the EFT-1 Radiation Area Monitors (RAM) mission dose results obtained from measurements performed in the Space Radiation Dosimetry Laboratory at the NASA Johnson Space Center will be presented. Each RAM included LiF:Mg,Ti (TLD-100), ^{6}LiF:Mg,Ti (TLD-600), ^{7}LiF:Mg,Ti (TLD-700), Al_2O_3:C (Luxel^{TM}), and CaF_2:Tm (TLD-300). The RAM mission dose values will be compared with the BIRD instrument total mission dose.

In addition, a similar comparison will be shown for the ISS environment by comparing the ISS RAM data with data from the six Timepix-based REM units deployed on ISS as part of the NASA REM Technology Demonstration.

28- PCV NASA Space Exploration Active Measurements and Future Operations

Kerry Lee

SRAG, NASA JSC, Houston

The NASA Multi-Purpose Crew Vehicle (MPCV) Exploration Program is the future of manned exploration. The MPCV had a test flight (EFT-1) in December of 2014 and there were several radiation detectors onboard. One was an active instrument called BIRD (Battery-operated Independent Radiation Detector) which consisted of two sensors that were derived from the Medipix technology. The other detectors were the RAM passive radiation detectors identical to those flown on the ISS. This presentation will focus on the active measurements made on the EFT-1 flight and will go into the plans for how NASA plans to operate the MPCV when it leaves the Low-Earth Orbit environment. These operations will include plans on dealing with large SPE should one occur during a mission when the vehicle and crew are not protected by the Earth's magnetic field.

29- Updates from the MSL-RAD Experiment on the Mars Curiosity Rover (C. Zeitlin on behalf of the MSL-RAD Science Team)

Cary Zeitlin

Lockheed Martin Information Systems & Global Solutions

The MSL-RAD instrument continues to operate flawlessly on Mars. As of this writing, some 1040 sols (Martian days) of data have been successfully acquired. Several improvements have been made to the instrument's configuration, particularly aimed at enabling the analysis of neutral-particle data. The dose rate since MSL's landing in August 2012 has remained remarkably stable, reflecting the unusual and very weak solar maximum of Cycle 24. Only a few small SEP events have been observed by RAD, which is shielded by the Martian atmosphere. Gale Crater, where Curiosity landed, is 4.4 km below the mean surface of Mars, and the column depth of atmosphere above is approximately 20 g cm-2, which provides significant attenuation of GCR heavy ions and SEPs. Recent analysis results will be presented, including updated estimates of the neutron contributions to dose and dose equivalent in cruise and on the surface of Mars.

30- Modeling the dose rate variations of MSL/RAD measurement during its cruise to Mars

Jingnan Guo

University of Kiel

The instrument Radiation Assessment Detector (RAD), onboard Mars Science Laboratory's (MSL) rover Curiosity, measures a broad spectrum of energetic particles along with the radiation dose rate during the 253-day cruise phase as well as on the surface of Mars. With these first ever measurements inside a spacecraft from Earth to Mars, RAD observed the impulsive enhancement of dose rate during solar particle events as well as a gradual evolution of the galactic cosmic ray (GCR) induced radiation dose rate due to the modulation of the primary GCR flux by the solar magnetic field, which correlates with long-term solar activities and heliospheric rotation.

In oder to predict the cruise radiation environment related to future human missions to Mars, the correlation between solar modulation potential and the dose rate measured by RAD has been analyzed and empirical models have been employed to quantify this correlation. We analyzed the dependence of the dose rate measured by RAD on solar modulation potentials and estimated the dose rate and dose equivalent under different solar modulation conditions.

These estimations help us to have approximate predictions of the cruise radiation environment, such as the accumulated dose equivalent associated with future human missions to Mars. The predicted dose equivalent rate during solar maximum conditions could be as low as one-fourth of the current RAD cruise measurement. However, future measurements during solar maximum and minimum periods are essential to validate our estimations.

31- MSL RAD Measurements of the Neutron Spectrum in Transit to Mars and on the Martian surface

Jan Köhler

University Kiel

The Radiation Assessment Detector (RAD) onboard Mars Science Laboratory's rover Curiosity has measured the energetic charged- and neutral-particle spectra and the radiation dose rate during most of the 253-day 560-million-kilometer cruise to Mars and is now measuring on the Martian surface.

An important factor for determining the biological impact of the Martian surface radiation is the specific contribution of neutrons, which possess a high biological effectiveness. In contrast to charged particles, neutrons and gamma rays are generally only measured indirectly, requiring the transfer of kinetic energy from neutral to one or more charged particles. Therefore, the measurement is the result of a complex convolution of the incident particle spectrum with the measurement process. We apply an inversion method to calculate the gamma/neutron spectra from RAD neutral particle measurements. Here we show first measurements of the gamma/neutron spectra during transit and on Mars and compare them to theoretical predictions.

The MSL RAD inversion method will also be applied to future ISS RAD gamma/neutron measurements.

32- Particle spectra on the Martian surface – A comparison of models and MSL-RAD measurements

Daniel Matthiä[1], Bent Ehresmann[2], Henning Lohf[3], Jan Köhler[3], Cary Zeitlin[4] Jan Appel[3], Tatsuhiko Sato[5], Tony Slaba[6], Cesar Martin[3], Thomas Berger[1], Eckart Boehm[3], Stephan Boettcher[3], David E. Brinza[7], Soenke Burmeister[3], Jingnan Guo[3], Donald M. Hassler[2], Arik Posner[8], Scot C. R. Rafkin[2], Günther Reitz[1], John W. Wilson[9], and Robert F. Wimmer-Schweingruber[3]

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Since the landing of the curiosity rover on Mars on August 6th 2012 the MSL-RAD instrument has measured the radiation environment on the surface. MSL-RAD has been the first instrument that has provided detailed information about charged and neutral particle spectra and dose rates on the Martian surface. In this work, several numerical radiation transport models are used to predict the radiation environment caused by galactic cosmic rays on Mars in order to validate them with the experimental results. The goal is to identify models suitable for providing information about the radiation environment complementing the measurements of particle spectra and the radiation exposure on the Martian surface. Such models can be used to predict dose rates for future manned missions to Mars or other celestial bodies as well as for performing shield optimization studies.

With proper choices of input parameters and physical models, in many cases a good agreement was found for GEANT4, PHITS and HZETRN/OLTARIS simulations with the MSL-RAD results. This indicates an applicability of these models to more detailed studies on how the radiation environment is influenced by the solar modulation, the Martian atmosphere and soil, and changes due to the Martian seasonal pressure cycle. By extending the range of the calculated particle spectra with respect to the experimental data additional information about the radiation environment is gained, and the contribution of different particle species to the dose is estimated

33- Current and Future Developments of the Medicpix Technology for Space Radiation Monitoring

Larry Pinsky

University of Houston

The Timepix detector technology from the Medipix2 Collaboration is in current developmental use by NASA onboard the ISS and has been flown successfully in the BIRD (Battery-powered Independent Radiation Detector) instrument on the recent EFT-1 test flight of the new Orion capsule. The development of hardware for use on the next 2 Orion text flights, that is also based on the current version of the Timepix detector is well underway as part of the HERA (Hybrid Energetic Radiation Assessor) project at NASA/JSC. A different approach in the design of the Timepix chip has been used by the follow-on Medipix3 Collaboration to produce the Timepix3, which is currently under evaluation, and the Medipix2 Collaboration is itself in the midst of a re-design of the Timepix to be called theTimepix2. In addition, a Medipix4 Collaboration is in the process of forming to push the envelope in what is currently possible by making use of the latest semi-conductor fabrication technology. A summary of these advances and prospects will be laid out in the talk.

34- Neutron Spectrometry Using a 7-Li Enriched CLYC Scintillation Detector

Alexander Miller

University of Ontario Institute of Technology, Canada

A recently developed 7Li-enriched version of the CLYC scintillator has been investigated for possible use as a dual detector for neutron and gamma spectrometry. The 35Cl(n,p)35S nuclear reaction provides a possibility for fast neutron detection. The sensor has been mounted on a photomultiplier tube controlled with a miniature electronics board and irradiated in different gamma and neutron radiation fields. A series of experiments has been carried out with different gamma energies as well as well with mono-energetic neutrons from a KN Van de Graff accelerator, and the pulse height spectra have been measured. To clarify different features observed on the response functions of the detector, a Monte Carlo model of the scintillator has been built using MCNP6 and emitted charged particles have been tracked. The simulation data along with the experiments are analyzed, compared and reported.

35- Development of Active Space Radiation Detector, A-DREAMS-2 at NIRS

Y. Uchihori, S. Kodaira, H. Kitamura

National Institute of Radiological Sciences, Chiba, Japan

For real time radiation monitoring in space environment, active radiation dosimeters, A-DREAMS have been developed in NIRS. They have silicon semi-conductor detectors and electric circuits to obtain LET distribution of space radiation from protons to iron ions in space radiation. The 1st version of the active dosimeter is named A-DREAMS-1 and has one silicon semi-conductor detector. The A-DREAMS-1 has been operated in some experiments in ground-based accelerators, HIMAC and a cyclotron facilities in NIRS and irradiated to high energy protons and heavy ions. The obtained results show good linearity for deposit energies in the silicon detector.

The advanced version of the active detector will have two silicon semi-conductor detectors and be designed to observe space radiation with limited solid angle and limited pass length. The latest version is called A-DREAMS-2 and it is now constructing. The concept and design will be shown and it is planned to be used for the MATROSHKA-III experiment.

36- Development of new cosmic radiation detectors at NPI

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We'll introduce three attempts to develop a new/improved cosmic radiation detectors: First, we've modified the Liulin detector for a simple calibration of energy deposition spectra using the alpha radionuclide source. We will show the calibration method and the results obtained onboard aircraft. Second, we are developing a new detector with the silicon diode. The advantages of our concept is low noise and low battery consumption. First measurements onboard aircraft and at ELBE (Electron Linac for beams with high Brilliance and low Emittance). Third, we'll present our proposal for measurement of terrestrial gamma-ray flashes on ground, onboard aircraft and spacecraft and using the Flying Dosimetry Unit (FDU).

37- Future experiments onboard the ISS and beyond

Thomas Berger

DLR German Aerospace Center, Institute of Aerospace Medicine, Cologne, Germany

For a better understanding of the radiation environment in space and especially onboard the International Space Station various joint international experiments working either on updating investigations concerning phantom measurements or personal dosimetry are currently in the planning and/or final stage of hardware building. This talk will give an overview of the status of these experiments in terms of planning, hardware development and flight schedule.