
23rd WRMISS 2018
Conference Program
4-6 September 2018
Reseach Institute of Nuclear Engineering
University of Fukui, Tsuruga, Japan

Co-organized by:

- Research Institute of Nuclear Engineering, University of Fukui
- National Institute of Radiological Sciences (NIRS) / QST

Supported by:

- Fukui Convention & Visitors Bureau
- Tsuruga City

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23rd WRMISS Conference Program: Tuesday 4th September 2018

09.00 – 09.15	Welcome (by G. Reitz, N. Yasuda and T. Fuchikami, Town Major)
09.15 – 09:55	Invited Talk I
09:55 – 10:35	Invited Talk II
10:35 – 11:15	Coffee/Tea Break
11.15 – 13:00	Scientific Session 1
13:00 – 15:00	Lunch and Kehi Shrine
15.00 – 16:15	Scientific Session 2
16:15 – 17:00	Coffee/Tea Break
17:00 – 18.15	Scientific Session 3

Guenther Reitz, Nakahiro Yasuda	Welcome and Organisational Issues
Takanobu Fuchikami, Major of Tsuruga	Welcome

Invited Talk I

Tatsuo Torii (given by Nakahiro Yasuda)	Radiation monitoring for decontamination and decommissioning after the Fukushima Daiichi Nuclear Power Station accident

Invited Talk II

Kunihiro Morishima	Muon Radiography in the Egyptian Pyramids

Scientific Session 1

Achid Machrafi	Response of Space Bubble Detectors to Heavy Charged Particles
Quazi M. R. Nizam (paper not given)	High accuracy scattering angle measurement and topological branching of carbon fragment using CR-39 on both sides imaging technique
Iva Ambrožová	Comparison of three different types of particle-track detectors
Marianthi Fragopoulou	A innovative neutron dosemeter

Scientific Session 2

Chen Baowei	Plan of Advanced technology research of cosmic radiation dose measurement based on altitude condition
Attila Hirn	Pille Measurements on ISS (April 2017 – February 2018)
Olga Gorokhova (given by **Attila Hirn**)	Pille-ISS modernized sensors for EVA and radiation measurements in ISS compartments

Scientific Session 3

Rositza Koleva	Unified web-based database with Liulin type instruments' cosmic radiation data
Livio Narici	ERFNet, a network for ground work in radiation mitigation to support deep space exploration.
Martina Giraudo	ERFNet, consultation of scientists and technologists for needs and requirements

The 23rd WRIMSS
Tsuruga, Japan

22nd WRMISS Conference Program: Wednesday 5th September 2018

08.30 - 09.10	Invited Talk III
09:10 - 10:30	Scientific Session 4
10.30 - 11.15	Coffee/Tea Break
11.15 - 13:00	Scientific Session 5
13:00 - 15:00	Lunch + City bus
15:00 - 16.30	Scientific Session 6
16:30 - 17.00	Coffee/Tea Break
17.00 - 18.30	Scientific Session 7
19.30 - 22.30	Conference Dinner

Invited Talk III

Harufumi Tsuchiya	Recent status of the GROWTH experiment – Gamma-ray observations at the coastal area of Japan Sea

Scientific Session 4

Raisa Tolochek	Radiation Protection Properties of additional Shielding containing Hydrogen Materials installed in Crew Cabin of Russian Segment of ISS
Eric Benton	Assessment of Radiation Shielding Properties of Novel and Baseline Materials External to ISS
Christopher Light	AMS Low Energy Cosmic Rays

Scientific Session 5

Martin Smith	Bubble-Detector Measurements for Matroshka-R and Radi-N2: ISS-51/52 and ISS-53/54
Ramona Gaza	Passive Radiation Dosimeters Transition to Active Radiation Instrumentation for ISS Operations
Thomas Berger	DOSIS & DOSIS 3D onboard the ISS – Status and Science Overview from 2009 - 2018

Scientific Session 6

Cary Zeitlin (given by **Ryan Rios**)	Results from ISS-RAD
Eric Benton	Active Tissue Equivalent Dosimeter (ATED): a tissue equivalent proportional counter currently operating aboard ISS
Ryan Rios	Timepix Utilization on ISS

Scientific Session 7

Aki Goto	Dose Calculation inside Kibo Using PHITS and ISS 3D-CAD Geometry
Soenke Burmeister	The DOSIS 3D Project on-board the International Space Station – Analysis of the Solar Particle Event in September 2017
Daniel Matthiä	The solar particle event on 10-13 September 2017 – Spectral reconstruction and calculation of the radiation exposure in aviation and space

22nd WRMISS Conference Program: Thursday 6th September 2018

08:30 – 10:30	Scientific Session 8
10:30 – 11:15	Coffee/Tea Break
11.15 – 12:45	Scientific Session 9
12.45 – 13.30	Lunch
13.30 – 15:15	Scientific Session 10
15:30 – 18.30	Excursion (Five Lakes)

Adjourn

Scientific Session 8

Tatsu Sato	Real-Time Estimation of Astronaut Doses During Large Solar Particle Events Based on WASAVIES
Satoshi Kodaira	Contribution to dose in healthy tissue from secondary target fragments in therapeutic proton, He and C beams measured with CR-39 plastic nuclear track detectors
Cary Zeitlin (given by **Don Hassler**)	Latest Updates from the MSL-RAD Experiment
Victor Benghin	Radiation measurements with Liulin-MO dosimeter of FREND instrument aboard ExoMars Trace Gas Orbiter during cruise to Mars and in Mars orbit

Scientific Session 9

Rositza Koleva	First results for the radiation environment on Mars orbit measured by Liulin-MO dosimeter aboard Trace Gas Orbiter
Krasimir Krastev	Quantitative estimates of the main dosimetric quantities based on the LIULIN - MO - ExoMars measurements
Livio Narici	LIDAL: status of the project
Larry Pinsky	Update on the Next Generation Timepix, The Timepix2

Scientific Session 10

Ulrich Straube	Future Experiments: ESA Active Dosimeter (EAD) on the NASA ORION EM-1 Mission
Razvan Gaza	MARE International Payload aboard Orion EM-1: Status Update for 23rd WRMISS
Stuart, George (given by **Kerry Lee**)	Update on The HERA System for Radiation Monitoring on Orion Exploration Missions and the International Space Station
	Summary , Discussion, next Location of WRMISS

EXCURSION (15:30 18:30)

ADJOURN

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Radiation monitoring for decontamination and decommissioning after the Fukushima Daiichi Nuclear Power Station accident

Tatsuo Torii

Division Head of the Remote System and Sensing Technology Division,
Collaborative Laboratories for Advanced Decommissioning Science (CLADS),
Japan Atomic Energy Agency (JAEA).

The Great East Japan Earthquake on March 11, 2011 generated a series of large tsunami waves that resulted serious damage to the Fukushima Daiichi Nuclear Power Station (FDNPS) and radioactive substances were discharged to the environment. To assess the scope of influence of radioactive substances diffused which spread in a wide area; we performed aerial monitoring using helicopters in the whole area of Japan. As a result, the deposition of radioactive cesium on the ground was obtained, and it was clarified that range of radioactive cesium spread had been almost limited from the southern part of Iwate Prefecture to Kanto areas of Japan. The variation distribution of dose rate in Japan was also revealed in this measurement. We have also developed a radiation measurement tool using unmanned aerial vehicles (UAVs) and measured detailed distribution of contamination level of soil and ambient dose-rate around the FDNPS. I introduce our study focusing on remote radiation measurement using aerial vehicles in this presentation.

Furthermore, development of radiation measurement methods is requested in high dose-rate environment to accelerate implementation of decommissioning of the FDNPP. We are now developing the technology which measures the 3-D distribution of the contamination level of radioactive substances at high dose-rate fields in the buildings of the FDNPP. It would also be introduced about a recent study about such radiation imaging technology.

Muon Radiography in the Egyptian Pyramids

Kunihiro Morishima

Nagoya University

Muon radiography is a non-destructive technique used for imaging of inner structure of large scale objects. Cosmic-rays include muons which is one of subatomic particles. Muons have high penetration power to materials. Thus, by detecting cosmic ray muons which passed through materials, we can take contrast image of large density length (more than 1km thick rock) in each muon's penetrating path. To detect muons, we are developing nuclear emulsion detector. Nuclear emulsion is high resolution three dimensional particle detector which is able to record minimum ionizing particle with micrometric accuracy. Since 2013, we have been applying nuclear emulsion for muon radiography to measure inner structure of Fukushima Daiichi Nuclear Power Plant No.2. Through this measurement, we revealed meltdown in the reactor. Since 2015, we have been applying this technique to investigation of pyramids in Egypt (ScanPyramids project). In this project, we discovered unknown structure inside the pyramid by observing over ten million muons. In this presentation, we will present the methodology and the latest status of these experiments.

Response of Space Bubble Detectors to Heavy Charged Particles

Rachid Machrafi[a], Alexander Miller[a], Eric Benton[b], Hisashi Kitamura[c], Satoshi Kodaira[c]

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To investigate the response of the space bubble detector to heavy charged particles, a series of experiments has been conducted with different heavy ion beams. A set of space bubble detectors with sensitivity similar to those in use aboard the International Space Station (ISS) has been exposed to 150 MeV/nucleon Helium, 280 MeV/nucleon Carbon, 400 MeV/nucleon Oxygen, 490 MeV/nucleon Silicon, 400MeV/nucleon Neon, and 500 MeV/nucleon Iron at the Heavy Ion Medical Accelerator in Chiba (HIMAC) at NIRS. The present paper outlines the results of a series of experiments with the space bubble detectors exposed to different heavy ion beams of known linear energy transfer LET. The paper presents the minimum LET_{min} required for each ion to form a bubble in the space bubble detector and discusses its dependence on the atomic number Z of the projectile ion.

High accuracy scattering angle measurement and topological branching of carbon fragment using CR-39 on both sides imaging technique

(Presentation not given)

Quazi Muhammad Rashed Nizam[a, b], Kanoko Yoshida[a], Tatsuki Sakamoto[a], Thibaut Charraire[a], Tomoki Nomura[a], Batgerel Turbat[a], Nakahiro Yasuda[a]

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Study of nucleus-nucleus interaction is very important for design of space radiation shielding as well as prediction of effects on human body. The dose received by the astronauts is determined by the transportation mechanism of energetic particles through spacecraft walls, equipment and human tissues. Interaction of heavy ion is followed by two main process, called the electromagnetic and nucleus-nucleus interactions while propagating through the material. The theory of electromagnetic interaction is well developed but no concreter theory for the nucleus-nucleus collision yet. Models for nucleus-nucleus interaction have been still under progress through new experimental data. We are trying to measure the projectile scattering angle and total charge changing cross section for ^{12}C ion on several shielding material such as Al (as typical shielding material) and CR-39 (as tissue equivalent material). These are useful to verify the models, to optimize shielding in space radiation circumstances and also to improve the treatment planning on therapy, as well.

We are investigating the Coulomb scattering angle of projectile for ^{12}C+Al interaction and the total charge changing cross section was measured for ^{12}C+CR-39 interaction. Target interleaved with CR-39 detector of 5 cm x 5 cm area was irradiated with ^{12}C ion at 55 MeV/n and 135 MeV/n at the Wakasa wan Energy Research Center (WERC) and HIMAC, respectively. Exposed detectors were etched in 7N NaOH solution at 70 ˚C to visualize the tracks produced by primary ion beam and its fragmentations. The FSP-1000 imaging microscope has been used to get images of etch pit on both side of the detector, and analyzed its locations and sizes the PitFit-1000 image analysis software. For measuring the scattering angle, we established the higher angular resolution of ~0.02 degree and for the total charge changing cross section, we demonstrate for the new detection method (both sides imaging technique) of multiple fragments from incident carbon to get the topological branching cross sections with emission angles.

Comparison of three different types of particle-track detectors

I. Ambrožová[1], M. Lužová[1,2], M. Sommer[1,2], V. Bradnová[3], P. Zarubin[3], S. Kodaira[4], O. Ploc[1]

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We will present first results from single track coincidence measurements using three different types of particle track detectors. Plastic nuclear track detectors, nuclear emulsions, and Timepix were exposed at HIMAC in various ion beams. For each detector and exposure, coordinates of detected tracks were determined and then compared for all three detectors on individual track basis. Properties of each method (such as duration of analysis process, detection efficiency, spatial resolution, spectroscopic properties) will be discussed. The purpose of this experiment is to observe and clearly list the advantages and disadvantages of individual types of particle-track detectors for their use in mixed radiation fields on-board spacecraft.

Plan of Advanced technology research of cosmic radiation dose measurement based on altitude condition

Chen Baowei[1], Xie Weimin[1,2], Gao Qi[2]

[1)] China Institute for Radiation Protection, [2)] Tibet University.

Plateau residents, aircraft crews and passengers, and astronauts in space all face significantly higher cosmic radiation dose rates. This type of radiation exposure have been received more and more attention in recent years. Some high mountain observatories or research stations started research on cosmic radiation dose measurement on ground, and some advanced methods developed by these researches have been used in civil aviation and manned space flight fields. So we put forward a scientific research project to study the advanced cosmic radiation dose measurement technology depending on Tibet plateau conditions. The qinghai-tibet plateau, known as the roof of the world, also known as the world's third pole, provides us with favorable conditions for this project. The experimental sites will be selected in Yang-Bajin (about 4300m a.s.l.) and Na-Qu districts (about 5000m a.s.l.), so the advantages of high-altitude can be used. Anthropomorphic dosimetry phantoms, TLDs, nuclear track detectors (CR-39), bubble neutron dosimeters, CZT detectors and plastic scintillator optical fiber detectors will be used to detect cosmic rays' dose distribution in the phantom. The organic and tissue equivalent dose and body's effective dose will be evaluated from measurement data. The personal dose monitoring technology based on CZT detectors have been used to astronauts in Shenzhou 7 - 11 (China) spacecraft and it is possible to use it in civil aviation field. The plastic scintillator optical fiber detectors also have the possibility of using in aeronautics and astronautics fields in the future.

This project has been funded by the National Natural Science Foundation of China (NSFC) from 2017.

Pille Measurements on ISS (April 2017 – February 2018)

A. Hirn[1], I. Apáthy[1], V. A. Bondarenko[2], S. Deme[1], O. Gorokhova[3], O. Ivanova[2], V. Mitrikas[2], I. V. Nikolaev[3], V. A. Shurshakov[2], A. Strádi[1], V.V. Tsetlin[2]

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[2]State Scientific Center, Institute for Biomedical Problems, Russian Academy of Sciences, Moscow, Russia
[3]Rocket and Space Corporation, Energia, Russia

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 15 years the dosimeter system was utilized for routine dose measurements inside the ISS, and as personal dosimeter system during Extra-vehicular Activities (EVAs).

The Pille system consists of a lightweight reader device and a number of TL dosimeters ($CaSO_4$:Dy). It 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.

In the present paper the measurement data (including several EVA measurements) obtained by the Pille system from the period between April 2017 – February 2018 are presented. The results are compared with previous measurement results. For a long time, a solar particle event (the September 2017 event) has been detected again with the Pille dosimeter used for automatic measurements.

Some preliminary information on the performance of the new Pille reader delivered to ISS in June 2018 will be also given.

Pille-ISS modernized sensors for EVA and radiation measurements in ISS compartments

Olga Gorokhova, Attila Hirn, Istvan Apáthy, Vyacheslav Shurshakov, Olga Ivanova, Ivan Kartsev, Gennady Shmatov, Igor Nikolaev.

The dosimeter system “Pille-ISS” was developed by MTA EK (Hungary) and it is regularly used on board the ISS for dose monitoring at different locations of the Russian Segment and for personal dosimetry during Extravehicular Activities (EVA) since 2003. The system is based on thermoluminescent (TL) technique and consists of a set of dosimeters and a reader. The dosimeters contain $CaSO_4$:Dy as TL material integrated with their individual heater and a memory chip. After exposure, the dosimeters are read out automatically by inserting them into the reader and turning them. The Pille-ISS dosimetry system is easy to use and has proved its stability and reliability during the last one and a half decade. The measurement results processed by MTA EK and IBMP RAS showed that due to the shielding of the case and the holder part of the dosimeter the dose values are underestimated. This is especially critical for dose measurements during EVAs. The Russian space radiation safety standards define dose limits for critical organs. During EVA eye lens and skin are the most vulnerable because of their relatively thin selfshielding. As the current dosimeter construction does not allow the measurement of eye lens and skin doses during EVA, at the moment experts of the radiation safety service of IBMP RAS use only estimations. The modernized Pille-ISS dosimeters significantly reduce the shielding of the TL material. This modernization allows to measure skin and eye lens doses during EVA. The shielding reduction will allow to take into account dose increases from electron fluxes of the Van Allen radiation belts.

Unified web-based database with Liulin type instruments' cosmic radiation data

T. Dachev[1], K. Lilovski[2], N. Bankov[1], B. Tomov[1], Y. Matviichuk[1], P. Dimitrov[1], J. Semkova[1], **R. Koleva[1]**, V. Shurshakov[3], V. Benghin[3], D.-P. Häder[4], G. Horneck[5], G. Reitz[5,6]

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A total of fourteen different space instruments were developed, qualified and used in numerous space missions between 1988 and 2018 by the scientist from the Solar-Terrestrial Physics Section, Space Research and Technology Institute, Bulgarian Academy of Sciences (SRTI-BAS). The first was used on MIR space station between 1988 and 1994. Six of them were flown on the International Space Station (ISS) in missions of more than one year duration. Another five were flown on satellites in short-term low-earth orbits. One experiment was for one year in a 100/200 km lunar orbit. The Liulin-MO instrument was launched toward Mars in 2016 and now is operating in a 400 km Mars orbit.

During the implementation of the Contract No. 4000117692/16/NL/NDe (http://esa-pro.space.bas.bg/) with ESA an unified web based database with Liulin-type instruments' cosmic radiation data" was developed between 2016 and 2018. The database contains data from ten space experiments performed between 1991 and 2018. Two separate options were foreseen in the database. First option downloads to the user computer original, zipped "DATA SOURCES" (http://esa-pro.space.bas.bg/datasources) in comma separated values (CSV) format, which is directly opened in an EXCEL program. The data sources contain the measured flux and absorbed dose rate with a resolution between 10 sec and 1 hour and the time at which the data were taken and the geographical and geomagnetic coordinates of the vehicle for each data point. The "DATABASE" allows (http://esa-pro.space.bas.bg/database) following functions: source selection; data export in CSV and TXT format; and several charts: visualization, synchronized zoom, tooltip and hairline; export to vector, JPEG and PDF format.

(The user manual of the database is available online at the following link: http://esa-pro.space.bas.bg/sites/default/files/Liulin_database_user_manual_July_2018.pdf
The manual describes the structure of the database and its operation.

ERFNet, a network for ground work in radiation mitigation to support deep space exploration.

Livio Narici *for the ERFNet collaboration*

The international research and technological efforts aimed at mitigating radiation risks during exploration class missions is broad and includes activities in many interdisciplinary areas. Several facilities in Europe devoted to space exploration research are supporting these works, by simulating, for example, radiation environment and / or space habitats. Increasingly larger efforts in several relevant scientific teams and panels have been put in the development and validation of risk models, to be able to quantify the radiation effects on the crew.

The researcher, technologist or R&D member of a space firm approaching these issues should navigate through the many related interdisciplinary areas to quantify the relevance of a possible new idea, and, whenever needed, to design the best strategy for its exploitation. This often relies on personal contacts, leading to non-optimal approaches and possibly lower efficacy.

To improve and support these endeavors and to provide upgrading strategies for the relevant facilities, ESA has financed the feasibility work for the European Radiation Facilities Network (ERFNet).

ERFNet goals are to provide an experimenter, who wants to exploit a specific idea in this field, with an easy access to the information, data, simulations and optimization needed to i) assess the feasibility, novelty and relevance of that idea; ii) optimizing the developmental strategy, using the final risk as endpoint; and iii) provide indications on how to optimally test the idea in the available facilities (irradiation facilities or habitat facilities – both hardware and virtual). ERFNet will also suggest, to ESA, or to other interested institutions and firms, the best upgrading strategies for the 'weakest' portions of the networked facilities. The network will be both easy to access and user friendly, to facilitate newcomers in the field, as well as accurate and complete, providing a valid knowledge-base and physical tools to the experienced researcher.

To achieve what described above, ERFNet will develop a structure to efficiently pair a radiation risk model to the optimization routines, while maintaining the highest degree of upgradability to be able to follow future model upgrades. The "smart core" of ERFNet will be the ERFNet Knowledge Base (EKB): a smart system able to connect information, optimization and user needs in order to provide the guided suggestions described above. A simple demonstrator of the EKB, responding to a simplified single user problem, will be developed in the course of the feasibility work.

In this talk ERFNet will be presented. The WRMISS will be asked to "join" the net, as a most qualified meeting to provide inputs and ideas, to use most of the outcome, to use the network itself.

ERFNet, consultation of scientists and technologists for needs and requirements

Martina Giraudo for the ERFNet collaboration

Following the presentation of the ERFNet concept, this talk will describe the questionnaire prepared by the ERFNet team, aimed to collect opinions and suggestions from the WRMISS community on possible ERFNet content options and/or variations to exploit the efficacy of the network.

As an example, among ERFNet goals is to provide the space user with easy access to information (such as data, simulation results, and so on..), so it is fundamental for the ERFNet team to propose the most useful options inside ERFNet system or, at least, to start addressing from the beginning the necessary interfaces.

The questionnaire will address both the typologies of possible user queries as well as the structure of the system output, and suggestions will be looked for about the inner structure of the (smart) system eventually leading to the outputs.

For this reason, the questionnaire will ask the WRMISS community to evaluate the foreseen contents in this preliminary phase and, at the same time, to provide the ERFNet team with useful suggestions on possible additional/improved options.

In ERFNet team opinion the collaboration with the WRMISS, starting with this questionnaire, will be a quite important asset for both communities.

Recent status of the GROWTH experiment – Gamma-ray observations at the coastal area of Japan Sea –

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Keywords: lightning, thunderclouds, particle acceleration, gamma rays, photonuclear reactions

Since 2006, the Gamma Ray Observation of Winter Thundercloud (GROWTH) experiment has been successfully operating at the coastal area of Japan sea. The GROWTH experiment aims at elucidating how particles in lightning and thunderclouds are accelerated to relativistic energies to produce gamma rays and occasionally neutrons. According to observations done by the GROWTH experiment, it is found that there are two types of radiation bursts associated with thunderstorm activities. One is long bursts lasting for a few tens of seconds to a few minutes, being not clearly related to lightning. The other is short bursts in association with lightning. In this presentation we explain general properties of the two sorts of bursts and then show two new findings recently observed. One, which is categorized into long bursts, clearly exhibits a relationship between a long burst and an intra/inter-cloud discharge (Wada et al., GRL 45, 2018). The other is a combination of short bursts and long ones, providing a new insight into the nature of short bursts, with simultaneous detections of prompt gamma rays and the annihilation ones (Enoto et al., Nature 511, 2017). These gamma-ray signals enabled us to confirm that photonuclear reactions certainly take place in lightning.

Radiation Protection Properties of additional Shieldin containing Hydrogene Materials installed in Crew Cabin of Russian Segments of ISS

Raisa Tolochek[1], Vyacheslav Shurshakov[1], Igor Nikolaev[2], Satoshi Kodaira[3], Hajime Kawashima[3], Yukio Uchihori[3], Iva Ambrozova[4],

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Space radiation is known to be key hazard of manned space mission. According to radiation monitoring crew cabins in the Russian segment of International Space Station (ISS) are known to be less protected against space radiation comparing to neighboring compartments. To decrease radiation exposure of crew member special additional shielding named "Protective curtain" was designed and delivered to ISS in 2010 year. Protective curtain is a tissue bag, where hygienic wipes and towels were stored in 4 layers. Protective curtain was installed along outer wall, the less protected location of crew cabin of RS ISS. The thickness of outer wall is estimated as 1.5 g/cm^2 and the thickness of protective curtain is about 6 g/cm^2 thus protective curtain is considered to have tangible effect against radiation.

Measurements of absorbed and equivalent dose were done with thermoluminescent (TLD) and plastic nuclear track (PNTD) detectors. 6 packages were located on the protective curtain surface, another 6 packages were installed in parallel on the other side or on the crew cabin aside. TLD and PNTD were exposed during 7 sessions in period of 2010 – 2017 years. Results of TLD and PNTD measurements shows that ratio between dose in protected locations and unprotected (Dprotected/Dunprotected) varies from 53 to 93 % for absorbed doses and 52 to 97 % for equivalent dose. Results are compared with calculations performed by IBMP group which are in good agreement with experimental data. Estimation of protective curtain properties is done in case when protective curtain is made from different materials.

It is shown that properly mounted local shielding can effectively mitigate the radiation dose in space station compartments.

Assessment of Radiation Shielding Properties of Novel and Baseline Materials External to ISS

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The E. V. Benton Radiation Physics Laboratory at Oklahoma State University (OSU) in collaboration with the OSU School of Materials Science and Engineering is developing carbon composite multifunctional materials for use in construction of future space craft and planetary habitats. The radiation shielding properties of one of the candidate materials, SC2020 containing Boron Nitride-loaded ultrahigh molecular weight polyethylene, together with those of baseline materials (polyethylene, aluminum, copper), will be exposed on the exterior of the ISS as part of the eleventh Materials on ISS Experiment (MISSE-11) scheduled for Spring 2019. Absorbed dose as a function of shielding depth will be measured using TLD, while the LET spectrum at several depths will be measured using CR-39 PNTD. Maximum sampel thickness will be 2.54 cm. Material properties of the samples will also be tested following recovery of the experiment. A preliminary experiment, using only a 0.7 cm sample of SC2020 and TLDs, is currently underway aboard ISS as part of the MISSE-9 experiment.

AMS Low Energy Cosmic Rays

Christopher Light

University of Hawaii at Manoa – Dr. Veronica Bindi's AMS Group

The Alpha Magnetic Spectrometer (AMS), on the International Space Station (ISS) since May 2011, has acquired the largest number of particles ever measured in space by a single experiment, performing the most precise measurement of galactic cosmic rays (GCR) to-date. The detailed time variation of multiple particle species fluxes measured in the first years of operations, during the ascending phase of solar cycle 24 and reversal of the Sun's magnetic field polarity (from negative A < 0 to positive A > 0). For all particles, the high energy spectrum remains stable versus time, while the low-energy range is strongly modulated by the solar activity. In addition, AMS measured several Forbush decreases (FD) and solar energetic particles (SEP) associated with the short term solar activity. AMS data allows us to study the time evolution of the rigidity dependence of these type of events for multiple particle species. Selected FD and SEP events observed by AMS, since the beginning of its mission, will be presented.

Bubble-Detector Measurements for Matroshka-R and Radi-N2: ISS-51/52 and ISS-53/54

M.B. Smith[1], S. Khulapko[2,3], H.R. Andrews[1], H. Ing[1], E.M. Johnston[1], M.R. Koslowsky[1], R. Machrafi[4], I. Nikolaev[3], V. Shurshakov[2], L. Tomi[5]

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Neutrons encountered in low-Earth orbit, for example on the ISS, are produced predominantly by 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. Since 2006, bubble detectors have been used to characterise neutron radiation on the ISS for the Matroshka-R, Radi-N, and Radi-N2 experiments. These ongoing measurements are conducted in both the Russian Orbital Segment (ROS) and the US Orbital Segment (USOS) of the ISS.

Matroshka-R and Radi-N2 continued to accumulate data during the recent ISS-51/52 and ISS-53/54 expeditions in 2017/18. The primary goal of Radi-N2 is to characterise the neutron dose equivalent and energy distribution in multiple USOS 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. Prior Radi-N2 measurements have been conducted in five modules of the USOS: Columbus, the Japanese Experiment Module, the US Laboratory, Node 2, and Node 3. During ISS-51/52 and ISS-53/54, surveys were conducted in Columbus, the US Laboratory, Node 2, and Node 3. The recent Radi-N2 results are compared with the earlier Radi-N and Radi-N2 data from the same ISS locations in order to assess potential influences on the neutron field.

During ISS-51/52 and ISS-53/54, Matroshka-R measurements in the ROS focussed on surveys in one of the Mini Research Modules, MRM2, and the first investigation of the Functional Cargo Block (FGB). The data collected are compared to earlier results from other modules, in order to assess variations in the neutron dose equivalent and energy distribution within the ROS.

Passive Radiation Dosimeters Transition to Active Radiation Instrumentation for ISS Operations

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Passive radiation detectors have been used for personal and ambient space radiation measurements since the Apollo program, and throughout the Space Shuttle and International Space Station programs. Even though passive detectors are well understood and capable of providing accurate cumulative dose measurements they do not provide the time-resolved data needed for long-term Exploration Missions (i.e., Mars). Thus, the Space Radiation Analysis Group at NASA Johnson Space Canter investigated several real-time or near-real time instruments for possible applications in personal and area space radiation dosimetry.

For ambient monitoring on board the ISS, the Timepix technology has been successfully used as part of the Radiation Environmental Monitor (REM) Technology Demonstration on ISS 2012-present. As a result, the REM transition to Operations - as a replacement for the passive Radiation Area Monitors (RAM) - started in 2016 and is expected to be finalized by Dec 2018.

Even more recently, the Crew Personal Active Dosimeter (CPAD) has been investigated as a potential replacement for the Crew Passive Dosimeter (CPD). The CPAD is based on direct ion storage technology and developed by Mirion Technologies specifically to meet NASA-designed requirements. Several ground calibration campaigns have been conducted, culminating with the CPAD ISS Technology Demonstration in Jul 2018.

This presentation will include status on REM transition to operations progress and CPAD ground and space measurement results, including comparison with other ISS instruments and dosimeters, such as the ISS Radiation Assessment Detector (ISS-RAD) and the CPDs.

DOSIS & DOSIS 3D onboard the ISS – Status and Science Overview from 2009 - 2018

Thomas Berger for the DOSIS & DOSIS 3D Team

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The radiation environment encountered in space differs in nature from that on Earth, consisting mostly of highly energetic ions from protons up to iron, resulting in radiation levels far exceeding the ones present on Earth for occupational radiation workers. Since the beginning of the space era the radiation exposure during space missions has been monitored with various passive and active radiation instruments. Also on-board the International Space Station (ISS) a number of area monitoring devices provide data related to the spatial and temporal variation of the radiation field in – and outside the ISS. The aim of the DOSIS (2009 – 2011) and DOSIS 3D (2012 - ongoing) experiment is the measurement of the radiation environment within the European Columbus Laboratory of the ISS. These measurements are, on the one hand, performed with passive radiation detectors mounted at eleven locations within Columbus for the determination of the spatial distribution of the radiation field parameters and, on the other hand, with two active radiation detectors (DOSTEL) mounted at a fixed position inside Columbus for the determination of the temporal variation of the radiation field parameters. The talk will give an overview of the current results of the data evaluation performed for the passive and active radiation detectors for DOSIS & DOSIS 3D in the years 2009 to 2018. Further on we will describe current ongoing work in terms of data comparison with the ALTEA, the DB-8, the ISS-RAD, the TRITEL and the R3DR2 instruments located at various positions in – and outside the ISS and provide current status of GEANT4 simulation results for the radiation environment inside the ISS.

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Results from ISS-RAD

Cary Zeitlin, Ryan Rios, Martin Leitgab, and Kevin Beard

We present the latest results from the ISS-RAD detector. ISS-RAD contains the Charged Particle Detector (CPD) and Fast Neutron Detector (FND) subsystems. It was deployed on Feb. 1, 2016, and has operated almost continuously since then, with an average up-time of 97%. ISS-RAD has been deployed in the USLab, JPM, Node3, and Columbus. In most locations, data have been acquired in at least 3 orientations, with the CPD telescope typically pointing in a given direction for a week. The September 2017 solar particle event was clearly seen by ISS-RAD in both the CPD and FND. Fluxes and dose and dose equivalent rates will be shown and compared to measurements made by other instruments on ISS, as well as to similar measurements made by MSL-RAD on Mars.

Active Tissue Equivalent Dosimeter (ATED): a tissue equivalent proportional counter currently operating aboard ISS

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A compact, portable tissue equivalent proportional counter (TEPC) called the Active Tissue Equivalent Dosimeter or ATED is currently operating aboard the ISS. ATED was developed at the E. V. Benton Radiation Physics Laboratory at Oklahoma State University with support from the NASA EPSCoR program as a low cost, portable, easy-to-use active dosimeter for use aboard spacecraft, aircraft and high altitude balloons. ATED was launched to ISS on the OA-9 on 21 May 2018 and installed in Node 3 on 13 July 2018. The TEPC is a 3” diameter acrylic sphere filled with tissue equivalent gas in order to simulate a 2 μm diameter volume of tissue. Beside the TEPC chamber, the unit consists largely of COTS parts, including HVPS, preamplifier, amplifier spectrometer and power supplies. Data is processed by a Raspberry Pi 3 Model B computer and stored on an SDRAM card. Data is transmitted to the ground once per month. Preliminary analysis of data measured by ATED indicates that the instrument is functioning as designed, measuring dose rates within the SAA of up to 10 times that during the rest of the orbit. In this talk we will present preliminary dose rate measurements as a function of time and lineal energy spectra measure by ATED.

Timepix Utilization on ISS

R. Rios

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NASA utilizes Timepix pixel detector read-out chips for particle imaging and detection in various configurations for low Earth orbit and exploration class missions. Two configurations - Radiation Environment Monitor (REM) and Minituarized Particle Telescope (MPT) - are deployed and operating on the International Space Station (ISS), with more configurations and instruments deploying before the end of 2018. General status on operations and data analysis/utilization will be shown for the REMs and MPT. Short-term comparisons with ISS-RAD (Radiation Assessment Detector) while located in the Columbus laboratory and multi-year comparisons with other instruments will also be shown.

Dose Calculation inside Kibo Using PHITS and ISS 3D-CAD Geometry

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The International Space Exploration Coordination Group (ISECG) is planning future human space missions following the International Space Station (ISS) mission, such as the lunar orbital station mission (called “Deep Space Gateway”) and exploration on the Moon and Mars. One of the problems to solve for realizing such missions is space radiation effects on human health. In space, high liner-energy-transfer (LET) radiation that causes significant biological damage flows from outside the solar system and the sun. Especially, outside the geomagnetic field where the future missions will be undertaken, the radiation flows at high dose rates. Establishment of radiation protection technology is required for conducting the future missions while ensuring astronauts safety. The radiation protection technology includes accurate estimation of exposure dose and optimization of shielding design. We expect computer simulation using a radiation transport code as a method to estimate exposure dose for the future missions. In order to perform the simulation for actual missions, it is needed to evaluate the accuracy of a transport code and radiation environment models, and the appropriate setting of calculation geometry.

This time, we created the International Space Station (ISS) partial 3D-CAD model, which includes Japan Experiment Module (JEM called “Kibo”) and some modules close to JEM, and JEM 3D-CAD model, and calculated the doses inside JEM using PHITS (Particle and Heavy Ion Transport Code System) code. And, the calculated doses were compared with the measured doses obtained in the Area PADLES (Passive Dosimeter for Lifescience Experiments in Space) experiments.

The ISS partial 3D-CAD model (ISS model) includes JEM, the other modules (e.g. Columbus, U.S. Lab, and Node 1-3), and the truss structure. The JEM 3D-CAD model (JEM model) includes Pressurized Module (PM), Experiment Logistics Module Pressurized Section (ELM-PS), Exposed Facility (EF), and Node 2. Especially, PM and ELM-PS models reproduce the approximate geometry of the outer shell structure, the debris bumpers, the racks, and so on. The ISS and JEM model were converted to PHITS input format by SuperMC (Super Monte Carlo simulation program for nuclear and radiation process) software. Each part of ISS and JEM models was composed of Al alloy or Al. Matthiä et al. model and AP8 model were used as existing radiation environment models. Absorbed dose (D) and dose equivalent (DE) in the virtual dosimeters placed inside JEM were calculated by PHITS Monte Carlo simulations.

In this presentation, we show the calculation results, and discuss the method to estimate doses based on the comparison between the calculated data and the experimental data.

The DOSIS 3D Project on-board the International Space Station – Analysis of the Solar particle Event in September 2017

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The nominal radiation environment in Low Earth Orbit (LEO), especially for the International Space Station (ISS), is dominated by two sources. The first is galactic cosmic radiation (GCR) which is modulated by the interplanetary and the Earth's magnetic fields and the second is trapped radiation in the form of the Van Allen Belts. The trapped radiation inside the ISS is mostly due to protons of the inner radiation belt. In addition to these sources sporadic Solar Particle Events (SPEs) can produce high doses inside and outside the ISS, depending on the intensity and energy spectrum of the event. Before 2017, the last SPE observed inside the ISS with relevant radiation detectors occurred in May 2012. Even though we are currently approaching the next solar minimum, an SPE was observed in September 2017, which was a) a Ground Level Enhancement (GLE 72); b) measured with various radiation detector systems on-board the ISS and c) observed on the surface of Mars. This presentation gives an overview of the 10 September 2017 SPE measured with the DOSIS 3D-DOSTEL and the ISS-RAD (Radiation Assessment Detector) instruments, both located at this time in close proximity to each other in the Columbus Laboratory of the ISS. The additional dose received during the SPE, was 146.2 µGy in Si as measured by ISS-RAD and 67.8 µGy in Si as measured by the DOSIS 3D-DOSTEL instruments. In addition we will show first results of GEANT4 simulations for the 10 September 2017 event and also provide comparison with events observed with DOSTEL like instruments on space station MIR (1997) and on the ISS (2001).

The CAU contributions to DOSIS and DOSIS 3D are financially supported by BMWi under Grants 50WB0826, 50WB1026, 50WB1232 and 50WB1533. At DLR, Cologne, DOSIS 3D was supported by the DLR grant FuE-Projekt ''ISS LIFE'' (Programm RF-FuW, Teilprogramm 475).

The solar particle event on 10-13 September 2017 – Spectral reconstruction and calculation of the radiation exposure in aviation and space

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The solar energetic particle event on 10 September 2017 and on the following days was the strongest event in recent years. It was recorded as Ground Level Enhancement 72 by Neutron Monitors Stations on the Earth and measured by a number of instruments in space. One aspect of such a space weather event is the potentially increased radiation exposure in aviation and space. Numerical simulations can help estimate the elevated dose rates during the event; a critical aspect in these simulations is the description of the primary particle spectrum. In this work, we present 1 hour averaged proton spectra during the event derived from GOES measurements and described by two different analytic functions. The derived proton spectra are used to calculate the radiation exposure in aviation and different space scenarios: low-Earth orbit, interplanetary space, and Mars surface and the results are discussed in the context of available experimental data. While the results indicate that in most of these scenarios in aviation and space the event was of little relevance compared to the total exposure from galactic cosmic radiation, the skin dose in a lightly shielded environment in interplanetary space may have reached about 30% to 60% of the NASA 30-day dose limit.

Real-Time Estimation of Astronaut Doses During Large Solar Particle Events Based on WASAVIES

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Real-time estimation of astronaut doses during solar particle events (SPE) is one of the most challenging tasks in cosmic-ray dosimetry. We therefore develop a new computational method that can nowcast the solar energetic particle (SEP) as well as galactic cosmic-ray (GCR) fluxes on any Earth orbit during a large SPE associating with ground level enhancement. It is an extended version of WArning System for AVIation Exposure to Solar Energetic Particle, WASAVIES, which can nowcast the radiation doses in the atmosphere using the real-time data of the count rates of several neutron monitors at ground level and high-energy proton fluxes observed by the GOES satellite. The most important feature of WASAVIES is that it is fully based on physics models of SEP transport from the Sun to the ground level of the Earth, and this feature enables to easily extend the system applicable to the Earth orbit.

The extended system is named WASAVIES-EO, where EO represents Earth Orbit. The shielding effect of the spacecraft can be considered in WASAVIES-EO by introducing the response functions for a virtual International Space Station (ISS) developed using PHITS. The astronaut doses in any locations in ISS during a large SPE are then derived from the calculated GCR and SEP fluxes multiplied with the fluence-to-dose conversion coefficients. The count rates of radiation detectors such as LIULIN can be also estimated by providing their response functions to the system. The detailed calculation procedures of WASAVIES-EO will be presented at the meeting, together with the results of its validation based on the experimental data measured in ISS during GLE60, 71 and 72.

Contribution to dose in healthy tissue from secondary target fragments in therapeutic proton, He and C beams measured with CR-39 plastic nuclear track detectors

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The LET spectrum, absorbed dose and dose equivalent from secondary particles of LET_H2O ≥15 keV/µm deposited within the plateau of the Bragg curve in primary particle-induced nuclear target fragmentation reactions in tissue during proton and heavy ion radiotherapy were measured using CR-39 plastic nuclear track detectors and analyzed by means of atomic force microscopy. It was found that secondary target fragments contributed 20% to dose equivalent for primary protons (157 MeV), 13% for primary helium ions (145 MeV/n) and 4% for primary carbon ions (383 MeV/n), respectively. While this additional dose is currently not considered in any standard treatment planning software, such contributions to dose to healthy tissue are significant from the point of view of patient radiation safety. The smaller contribution measured for energetic carbon ion beams compared to proton beams can be considered an advantage of carbon ion radiotherapy over proton radiotherapy. This type of measurement is not only relevant to radiation protection in cancer therapy, but also in space radiation dosimetry and protection, since 99% of the space radiation environment consists of energetic protons and helium nuclei. Some verification of secondary particles with CR-39 were reported by measuring stopping particles in the detector. The type of ground-based experiment reported here are useful for investigating the dose contribution of secondary target fragmentation produced by space radiation to the absorbed dose and dose equivalent received by space crews.

Latest Results from the MSL-RAD Experiment

Cary Zeitlin on behalf of the MSL-RAD Science Team

The RAD instrument aboard the Curiosity rover has been operating on Mars for nearly 6 years. The instrument continues to return dosimetric and spectral data to characterize the energetic particle environment in Gale Crater. The continuing weakening of solar modulation as cycle 24 heads towards minimum is clearly visible in the rising dose rates seen on the Martian surface. RAD observed elevated dose rates during the large Solar Particle Event of September 2017, as well as clear evidence of the arrival of the ICME at Mars; dosimetric results from the event, and from the subsequent strong Forbush decrease, will be presented. New analysis of LET spectra has also been performed, and correlations of <Q> with atmospheric column depth generally show the expected trends, although changes in heliospheric conditions are also found to affect <Q>. Work to verify the normalization of neutral particle spectra is in progress and preliminary results will be presented.

Radiation measurements with Liulin-MO dosimeter of FREND instrument aboard ExoMars Trace Gas Orbiter during cruise to Mars and in Mars orbit

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The Trace Gas Orbiter (TGO) was launched on 14 March 2016 according with a joint ESA - Rosscosmos program ExoMars for investigating Mars. The dosimetric telescope Liulin-MO for measuring the radiation environment onboard the ExoMars 2016 TGO is a module of the Fine Resolution Epithermal Neutron Detector (FREND) onboard TGO.

Results will be presented from measurements of the charged particle fluxes, dose rates, and estimation of dose equivalent rate in the interplanetary space during the cruise of TGO to Mars and on high elliptic orbit around it in 2016 – 2017 years and measurement results of 2018 on 400 km circular scientific orbit.

There was made a comparison of flux and dose rate measurements with calculation based on galactic cosmic ray models and Mars "shadow effect" estimations. There are marked surplus of measured flux and dose rate on calculated.

First results for the radiation environment on Mars orbit measured by Liulin-MO dosimeter aboard Trace Gas Orbiter

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We present recent results from measurements of the charged particle fluxes, dose rates, linear energy transfer spectra and estimation of dose equivalent rates in ExoMars TGO science orbit and comparison with the data obtained during the cruise and in high elliptic Mars's orbit, provided by Liulin-MO dosimeter aboard TGO.

TGO transit to Mars took place from March to September 2016. TGO was inserted into Mars high elliptic orbit on 19.10.2016. From 22.04.2016 (when Liulin-MO was turned on) to 07.03.2017 – start of the aerobraking phase there were no SPE events and Liulin-MO measured the flux and doses of GCR. During these 10.5 months the flux of CGR increased with ~ 5 %, the dose rate in Si – with ~10 % and the dose equivalent rate with ~15 %. The increase of the charged particles dose rate and flux correspond to the increase of GCR intensity during the declining phase of the solar activity. The obtained data show that during a cruise to Mars and back (6 months in each direction), taken during the declining of solar activity, the crewmembers of future manned flights to Mars will accumulate at least 60% of the total dose limit for the cosmonauts/ astronauts career in case their shielding conditions are close to the average shielding of Liulin-MO detectors - about 10 g cm^{-2} .

In March 2018 TGO reached its science orbit – circular orbit with 400 km altitude, 73^{o} inclination and 2 hours period. On 16.04.2018 Liulin-MO was turned on for a nominal work. In April-July 2018 in TGO Mars science orbit the flux is ~ 90%, dose rate is ~ 84%, dose equivalent rate is ~70% of that in February-March 2017. A strong dependence of the measured fluxes on the part of the FOV shadowed by Mars is observed.

Quantitative estimates of the main dosimetric quantities based on the LIULIN - MO - ExoMars measurements

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Nowadays the study of the radiation environment in the interplanetary space is becoming increasingly important. Comparing measurements obtained from different instruments at different points of space and different phases of the solar cycle helps for better understanding the mechanisms of cosmic ray propagation and modulation. For accurate data comparison, it is necessary to abstain from planetary influences on the galactic cosmic rays flux.

This paper presents the results of estimation of galactic cosmic rays flux and dose at 1.5 au from the Sun. Estimates of galactic cosmic rays flux in the interplanetary space are based on data obtained from the LIULIN - MO instrument aboard ExoMars TGO. TGO was inserted into Mars high elliptic orbit on 19.10.2016. In March 2018, the Trace Gas Orbiter entered the science orbit around Mars of about 400 km height and 73^{o} inclination.

LIDAL: status of the project

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LIDAL (Light Ion Detector for ALTEA) is a detector based on scintillators for fast time applications. It is designed to work paired with three ALTEA Silicon Detector Units (SDUs). Its major features are the capability of performing Time of Flight (ToF) measurements for passing through particles and to provide a low Linear Energy Transfer (LET) trigger to the LIDAL-ALTEA system. This last feature allows extending the ALTEA detection capability up to relativistic protons and helium ions.

Moreover, by merging particle velocity measured by the ToF with the deposited energy measured by the ALTEA SDUs, Particle Identification capability will result significantly enhanced. The LIDAL-ALTEA system will therefore provide an unprecedented detector able to measure, track and discriminate all ions in the International Space Station (ISS).

This presentation will provide an overview of the new LIDAL detector, focusing on the timing performances required for the ToF. Simulation results, and the chosen on-the-edge available electronics and technology will show how it is possible to fulfill timing requirements.

A ToF prototype has been developed at University of Tor Vergata and tested at the proton beam line in TIFPA (Trento, Italy), confirming the results of the simulations, and showing a ToF uncertainty (sigma) less than 90 ps for protons with E=0.2 GeV. The results are presented and discussed. LIDAL will have two identical models: an engineering model (EM) and a flight model (FM). The EM should be ready for testing in TIFPA by the end of October 2018, and the FM by the following February, ready for the mission of the Italian astronaut Luca Parmitano in the summer.

At the moment we are defining collaboration with NASA for combined measurements with a MEDIPIX device for a detailed cross calibration. A similar collaboration is foreseen also with DLR to use DOSTEL as a further cross calibration.

Update on the Next Generation Timepix, The Timepix2

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After 12 years since the ubiquitous Timepix chip was designed the CERN-based Medipix2 Collaboration has produced the Timepix2, the next generation of the Timepix technology. Preserving the 55 um square pixel size, the TImepix2 had been designed using the TSMC 130 nm technology, increasing by a factor of ~4 the number of discrete components per pixel. The success of the TImepix has been enhanced with simultaneous Time Over Threshold, TOT (ADC) and Time of Arrival, TOA (TDC) capability in a fungible 28-bit output register. Many other improvements offer the venerable Timepix have been incorporated such as “ghost track” suppression, and provisions to allow completion of ongoing TOT measurement after the frame time has terminated. Perhaps the biggest improvement for space radiation measurements is the change to hole collection bias, which translates to a new front end amplifier that has a linear dynamic range of 3-4 times that of the venerable Timepix, along with a suppression of the so-called “volcano effect.” Timepix2 assemblies and their companion interfaces are expected to be operational by Late 2018.

Future Experiments: ESA Active Dosimeter (EAD) on the NASA ORION EM-1 Mission

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Over the last decade human presence in space has increased significantly. Extended missions lasting half a year or more became “standard” scenarios. Challenges to human health and wellbeing are though still significant, increasing with mission length and workload. For future exploration missions as the planned ORION mission to the Moon and the subsequent Lunar Orbital Platform radiation surveillance of the astronauts has to be performed with active personal radiation detectors. Within the EAD project small active personal dosimeters (MU = Mobile Units) have been developed and successfully applied for measurements onboard the ISS. These measurements were done on one hand during the “Iriss” mission in 2015 enabling for the first time a full overview from mission start (Soyuz launch on 2 September 2015) to landing (Soyuz return on 12 September 2015) and later onboard the ISS in the frame of the EAD Project (2016 – 2017). For the upcoming NASA ORION-EM-1 mission upgraded versions of the EAD MU will be provided. The talk will give an overview of lessons learned with the Mobile Units in orbit and expand on the planned future mission for the ORION EM-1 flight.

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MARE International Payload aboard Orion EM-1: Status Update for 23rd WRMISS

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The natural ionizing radiation environment present in space poses risks to human exploration that require mitigation.Spacecraft designed for Exploration beyond Earth orbit (BEO) do not benefit from the Earth's magnetosphere protection and are subject to stricter radiation design requirements than their low Earth orbit (LEO) counterparts. Orion is NASA's nextgeneration crewed spacecraft, developed specifically for Exploration missions. Orion's first test flight Exploration Flight Test 1 (EFT-1) was successfully completed in December 2014. The upcoming Orion mission Exploration Mission 1 (EM-1) is scheduled for 2019. The EM-1 trajectory will reach cis-lunar space for a total mission duration of 21-42 days. The Van Allen proton exposure during EM-1 is expected to be lower than EFT-1 primarily due to faster transit through the belts, but significantly higher than experienced by the International Space Station (ISS) during South Atlantic Anomaly (SAA) passes. Lockheed Martin is the NASA prime contractor responsible for the Orion vehicle. Radiation protection has been incorporated in the Orion spacecraft as a design driving requirement and consistent with the ALARA principle. Feedback invited by Lockheed Martin as part of ongoing efforts to optimize radiation protection of the Orion crew attracted interest in an incremental improvement of previous MATROSHKA experiments. In coordination with Lockheed Martin Advanced Programs, an ionizing radiation science payload referred to as MARE (Matroshka AstroRad Radiation Experiment) was proposed by the German Aerospace Center DLR and the Israel Space Agency ISA. In May 2017, MARE was approved by NASA and manifested aboard the Orion EM-1 flight. MARE consists of two CIRS ATOM® 702 Adult Female radiotherapy phantoms flown inside the Orion cabin at seat positions 3 and 4. The

phantoms are fitted with ionizing radiation detectors placed both internal for organ point-, and external for skin exposure measurements. In an improvement over the ISS MATROSHKA, the science objectives are expanded to include characterization of a novel personal protection equipment item deployed on one of the phantoms, the AstroRad individual radiation protection shield. AstroRad is the product of an international collaboration between StemRad Ltd., Israel and Lockheed Martin. AstroRad provides customizable radiation protection for astronauts, focused on radiation-sensitive stem-cell rich organs and tissues. The MARE suite of radiation detectors includes over 5,000 passive detectors for dose depth profile and organ point measurements, consisting of Thermoluminescence- and Optically Stimulated Luminescence dosimeters, and Plastic Nuclear Track Detectors. For purposes of dosimetry intercomparison and detector cross-characterization assemblies of dosimeters provided by the international research community will be included in MARE with heritage participation in the DOSIS-3D experiment. MARE also features active detectors - the DLR M-42, the NASA CPAD (Crew Personal Active Dosimeter) and the ESA Active Dosimeter Monitor Unit – Orion (EAD MU-O). Time-resolved measurements provided by the active detectors will allow separate characterization of mission-phase-specific environments. This presentation will include background on the Orion vehicle, and focus on the current MARE status including active radiation detector development, testing and characterization.

In conjunction with other radiation detectors aboard the vehicle, the Matroshka AstroRad Radiation Experiment is designed to provide a comprehensive picture of the radiation environment beyond Earth orbit specific to the Orion vehicle and internal to human body analogs. This data set will inform about expected exposures, enable better planning by validating the operational toolsets used to predict crew radiation exposure risk on future Orion missions, and evaluate a potential countermeasure. MARE epitomizes the spirit of international collaboration toward human space exploration. The experiment is co-managed by DLR and ISA, with NASA participation as a co-PI. StemRad and Lockheed Martin contribute to the development of AstroRad science objectives. Numerous research groups on three continents participate as co-Is, including ESA. Lockheed Martin personnel facilitate payload integration in the spacecraft. As one of the first science payloads to fly aboard Orion, MARE demonstrates the research opportunities aboard NASA’s next generation space exploration vehicle.

Update on The HERA System for Radiation Monitoring on Orion Exploration Missions and the International Space Station

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HERA is an autonomous radiation monitor designed to protect crew health on Orion MCPV and on the International Space Station. It consists of three silicon Timepix hybrid pixel detectors coupled to a central processing unit for online data processing and analysis. This talk provides an overview of the HERA system and an update on the progress of HERA since the last WRMISS. Since then the EM-1 version of HERA has been integrated into the MCPV capsule and prepared for deployment on ISS. Significant progress has also been made with updates to particle recognition algorithms for Orion EM-2 forward. These updates allow HERA to provide a 20 bin proton spectrum from 5 MeV to 1.5 GeV as well as other information about particle fluxes including those of photons, heavy ions and electrons. Finally we will discuss future updates to the HERA system for use in a deep space habitat.

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