WRMISS in Boulder 2024

Conference Program (final)

Workshop on Radiation Monitoring on International Space Station *

27th WRMISS

3 - 5 September 2024

27th WRMISS Conference Program: Tuesday 3th September 2024

08:00 – 09:00	Registration
09:00 – 09:15	Welcome, organizational Issues
09:15 - 09:30	SwRI- Our hosts profile
09:30– 10:30	Scientific Session 1
10.30 – 11:15	Coffee/Tea Break
11.15 – 12:15	Scientific Session 2
12:15 – 13:45	Lunch
13:45 – 15:15	Scientific Session 3
15:15 – 16:00	Coffee/Tea Break
16:00 – 17:30	Scientific Session 4

Guenther Reitz, Don Hassler, Bent Ehresmann, Diane Miller	Welcome, Organizational Issues
Joel Parker (SwRI)	Company Profile

Scientific Session 1

Xiaojing Xu	A Dynamic Near Earth Trapped Proton Model for Mission Analysis
James J. Connell	Enhanced Data Products from the Energetic Heavy Ion Seniors (EHIS) on GOES-16, -17, -18 and –19

Scientific Session 2

Karel Marsalek	Over 2000 days in space – the RAMIS radiation detector on the DLR Eu:CROPIS mission
Stuart George	Interplanetary Radiation Measurements in 2023 and 2024 from LETS Detectors on Astrobotic Peregrine and Biosentinel

Scientific Session 3

Attila Hirn	Pille Measurements on ISS (September 2022 – March 2024) and the latest upgrade of the Pille System
Eric Benton+	Space Tissue Equivalent Dosimeter (SpaceTED) and Atmospheric ionizing radiation Tissue Equivalent Dosimeter (AirTED)
Thomas Berger	DOSIS 3D 2009 – 2024 (Active and Passive + May 2024 SPE)

Scientific Session 4

Martin Losekamm	Update on the RadMap Telescope
Stuart George	Comparison of SRAG radiation monitor measurements in solar cycle 25
Luke Stegemann	This talk will discuss the radiation instruments aboard the ISS and how their measurements feed into RAE’s radiation dose and risk calculations

27th WRMISS Conference Program: Wednesday 4th September 2024

09:00 - 10:30	Scientific Session 5
10.30 - 11.15	Coffee/Tea Break
11.15 – 12:15	Scientific Session 6
12.15 - 13:45	Lunch
13:45 – 15:15	Scientific Session 7
15:15 – 16:00	Coffee/Tea Break
16:00 – 17:30	Scientific session 8
18:30– 22.00	**Conference Dinner**

Scientific Session 5

Stuart George	Dosimetric impacts of the May and June 2024 Space Weather and Solar Particle events at the International Space Station and Biosentinel
Thomas Berger	Status of the Mare Experiment
Marianthi Fragkopoulou	Characterizing the Radiation Environment on Artemis I
Kent Tobisca	Radiation Field Outside the ISS Observed by ARMAS Flight Module 9 March - December 2022

Scientific Session 6

Moritz Kasemann	Update on DLR M-42 Development + the Astrobotic Peregrine I Mission in January 2024 (almost to the Moon and back
Cary Zeitlin	Radiation Environments Beyond LEO

Scientific Session 7

Tony Slaba	Models and Measurements from Earth to Mars during Artemis-I
Martin Kroupa	60 years of radiation monitoring in space
Bent Ehresmann	The LEIA Mini-FND Fast Neutron Detector
James J. Connell	A synthetic diamond as Cerenkov detector (late insertion, no abstract)

Scientific Session 8

Kirill Grigorev	RadLab: A Comprehensive Database and Graphical and Programming Interfaces for Space Radiation Data
Livio Narici	Doreli 2024
Livio Narici	Modeling Aided Measurements (MAM): a new vision for evaluation of the radiation environment in a space habitat

27th WRMISS Conference Program: Thursday 5h September 2024

09:00 - 10:00	Scientific Session 9
10.00 – 10:45	Coffee/Tea Break
10:45 – 12:00	Scientific Session 10
12:00 – 13:00	Lunch
13:00 – 14:30	Scientific Session 11 (includes coffee)

Scientific Session 9

Bent Ehresmann	MSL/RAD Radiation Measurements on the Surface of Mars on the way to Solar Maximum- new Findings and updates.
Don Hassler	The May 2024 Solar Storms as seen at Mars by MSL/RAD
Bent Ehresmann	Regolith Shielding as Observed by MSL/RAD on the Surface of Mars

Scientific Session 10

Prem Saganti	Variations in the Radiation Environment and Observed Biological Consequences on the Long-Term Stored Embryonic Stem Cells in the Kibo Module of the ISS
Jack Miller	SpinSat, a platform for in situ studies of the effects of variable gravity and space radiation

Scientific Session 11

Kirill, Miller, Narici	RadLab Round Table
Guenther Reitz	Wrap up and adjourn

Participant List WRMISS 2024

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Abstracts:

A Dynamic Near Earth Trapped Proton Model for Mission Analysis

Xiaojing Xu
NASA

In mission analysis for exposure estimation, time dependence in the trapped proton environment can be critical, especially for Low Earth Orbit where the interaction with the atmosphere makes the time dependence particularly strong. To meet the needs of mission analysis, a dynamic near-Earth trapped proton model is developed. In this model, the secular geomagnetic field is simulated by the International Geophysical Reference Field (IGRF) model, and semi-theoretical functions are used to describe the geomagnetic field confinement of the particles and the impact of particles' collisional loss to the atmosphere. Solar cycle modulation to the environment is implemented through air density changes and included in the collisional loss function. The functions are obtained by fitting to the observations from Relative Proton Spectrometer (RPS-b) onboard one of the Van Allen Probes in 2013 and the Polar-orbiting Operational Environmental Satellite (POES) during 1998-2013. The model is verified by its capability of reproducing trapped proton environment recorded in AP8 model. It is concluded that the dynamic model performs well over time span of at least several decades.

Enhanced Data Products from the Energetic Heavy Ion Seniors (EHIS) on GOES-16, -17, -18 and –19

James J. Connell, University New Hampshire

There are now four Geostationary Operational Environmental Satellites, GOES-16, -17, -18 and –19, on orbit carrying modern space weather instruments, including Energetic Heavy Ion Seniors. Each EHIS measures protons from 10-200 MeV and heavy ions through Ni at energies with comparable penetration in Si. Employing the Angle Detecting Inclined Sensors (ADIS) system, EHIS achieves single element resolution with a sigma ~0.25 e at Fe. NOAA analysis of EHIS data for space weather purposes provides data with a five-minute integration period. Because of the requirement to measure protons, EHIS is a relatively small telescope (geometrical factor of ~1.5 to 0.5 cm2-ster) and a five-minute integration period yields only upper limits except under high-flux conditions. This limits the value of these data for both space dosimetry and scientific research. A new project funded by NASA under the Research-to-Operations-to-Research (R2O2R) program will address these limitations and also produce archival data with several integration times. The planned online version will allow users to choose integration periods suitable to their research or operational needs. An obvious example for this workshop would be the start and end times of an EVA. The software will also calculate Linear Energy Transfer (LET). Given the high energy depositions and biological effectiveness of heavy ions, we believe this work should be of interest and value for Human space dosimetry not only on the ISS, but also for future missions beyond low Earth orbit such as Artemis.

Over 2000 days in space – the RAMIS radiation detector on the DLR Eu:CROPIS mission

Karel Marsalek[1,*], Thomas Berger[1], Bartos Przyblya[1], Daniel Matthiä[1], Joachim Aeckerlein[1], Moritz Kasemann[1], Maximilian Radenhäuser[1], Aleksandra Rutczynska[1], Markus Rohde[1], Michael Wirtz[1], Stephan Sous[2], Hans-Herbert Fischer[2], Sven Jansen[2]

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RAMIS (size: 140x140x35mm^3, mass: 608 gram, power consumption 1.8 Watt) is a radiation detector developed for the DLR Eu:CROPIS satellite mission. *RAMIS* uses an arrangement of two silicon detectors in telescope geometry and maps the radiation environment in the course of the mission providing baseline data as count rate in the silicon detectors, but also dosimetric quantities as absorbed dose and dose equivalent rate. Eu:CROPIS was launched on December 03rd 2018 into a polar orbit circling around Earth at an average altitude of around 600 km. *RAMIS* is located on the outside of the satellite and was activated on 5 December 2018 and has continuously provided data during the course of the mission. Due to the polar orbit of the satellite *RAMIS* can measure: a) the variation of galactic cosmic radiation (GCR) in dependence on the Eu:CROPIS orbit showing the influence of the shielding of the Earth magnetic field; b) the contributions of protons in the inner Earth radiation (Van Allen) belts within the region of the South Atlantic Anomaly (SAA); c) variations of the trapped electron intensity during crossings of the outer radiation belt at high geomagnetic latitudes and finally (d) the changes in the radiation environment due to the changes in the solar cycle. *RAMIS* started its measurements near solar minimum conditions and currently we are approaching the next solar maximum. Therefore, it was also possible to measure a high number (n~20) of Solar Particle Events (SPEs) from late 2021 onwards and compare this data with instruments in lunar orbit (CRaTER) on the lunar surface of the Moon (LND) and on the Martian surface (MSL-RAD). The talk will give an overview of some highlighted results from the instrument, which will have been in space for over 2100 days in September 2024.

Interplanetary Radiation Measurements in 2023 and 2024 from LETS Detectors on Astrobotic Peregrine and Biosentinel

S.P. George, N. Stoffle, A. Schram, L. Stegmann, M. Kroupa, E. Semones, S. Santa-Maria

We report two sets of radiation measurements of the interplanetary radiation environment approaching and in solar maximum. Radiation measurements outside of the Earth's magnetic field are rare, and these both add considerably to that corpus. The measurements were both acquired from identical Linear Energy Transfer Spectrometer detectors on the Biosentinel free flying satellite (Nov 2022 – present) in Heliocentric Orbit and the Astrobotic Peregrine in very high Earth Orbit (Jan 2024). In both cases the measuring instruments consisted of Timepix hybrid pixel detectors, instruments of the of the same type standardized across a variety of NASA radiation measurement payloads including REM2 on ISS, HERA for Orion and ISS and ARES for HLS and Gateway.

In the case of the Peregrine we report a 7 day measurement of the free space GCR field with an average shielding depth of approximately 3g/cm^2 close to/at solar maximum. We measured an ICRP quality factor of 5.2 and a dose rate of 0.2 mGy/day.

We also report Biosentinel results from November 2022 to the time of writing in a more shielded environment than Peregrine with a median depth of about 8g/cm^2 which is similar to lightly shielded spacecraft. In this time period the GCR dose rate has almost halved from 0.36 mGy/day to 0.2 mGy/day with a mean quality factor of approximately 4 which was unchanged during this period. We also report on the impacts of at least 12 SPE in this time period the most significant of which delivered peak dose rates of 35 µGy/min. LETS also observed several X class solar x-ray flares in this time period the (minor) dosimetric impact of which is discussed.

Pille Measurements on ISS (September 2022 – March 2024) and the latest upgrade of the Pille System

A. Hirn[1], I. Apáthy[1], A. Csoke[1], S. Deme[1+], P. Pinczés[1], A. E. Lishnevskii[2], V. G. Mitrikas[2], V. A. Bondarenko[2], S. G. Drobyshev[2], O. V. Babueva[2], O. Gorokhova[3], O. Ivanova[2], I. V. Nikolaev[3], R. V. Tolochek[2], V. A. Shurshakov[2], V.V. Tsetlin[2]

B.

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Pille was developed as the first and to date the only thermoluminescent dosimeter system containing on-board reader designed specifically for spacefaring humans. Since its very first launch in 1980, the Pille system has been providing space radiation measurements from aboard almost every space station (Salyut-6, -7, Mir, International Space Station (ISS)). It has been continuously used on board ISS since October 2003 under the supervision of the Institute for Biomedical Problems (IBMP) as an essential part of the service dosimeter system of the Russian Zvezda module. In the past 21 years the dosimeter system was utilized for routine dose measurements inside the ISS and 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 obtained in different locations of the Russian module. Three dosimeters are dedicated to EVA measurements (two for the astronaut pairs, one inside the ISS for reference), and one is read out in every 90 minutes automatically to provide high time resolution data. In June 2022, a modified Pille-ISS dosimeter was introduced on board the ISS for EVA measurements and cross-calibrated with the standard Pille-ISS dosimeters. In the case the modified dosimeters, the technical modifications allowed reducing the excessive local shielding of the TL crystals, making it possible to be sensitive to electrons and protons with lower energies.

In our presentation the latest results (including several EVAs) and the assessment of the results of the new type of Pille-ISS dosimeters and the on-board cross-calibrations will be detailed, together with comparisons of data from different missions

Space Tissue Equivalent Dosimeter (SpaceTED) and

Atmospheric ionizing radiation Tissue Equivalent Dosimeter (AirTED)

Eric Benton, Tristen Lee, Conner Heffernan, Martin Yang, Garrett Thornton and Buddy Gersey

Physics Dept., Oklahoma State University, Stillwater, Oklahoma USA

The Space Tissue Equivalent Dosimeter (SpaceTED) has been successfully operating in JEM aboard the ISS since November 2023. Originally scheduled for return in May, the experiment has been extended until October 2024. SpaceTED possesses two detectors: 1) a spherical tissue equivalent proportional counter (TEPC) is used to measure the lineal energy spectrum of particles with LET ≥1 keV/μm, including secondary particles produced in neutron interactions with the tissue equivalent plastic of the ionization cavity; 2) particles with LET <1 keV/μm are detected by a COTS Si PIN photodiode. Two Red Pitaya STEMlab 125-14 dual input, digital signal processing boards are used as spectrometers and spectral data is collected once every 60 seconds. All data is stored locally on a Raspberry-Pi computer and data from the two detectors are combined to yield total absorbed dose and dose equivalent rates as functions of time. In this presentation, we will present preliminary data obtained by SpaceTED during operation on ISS.

A less expensive version of SpaceTED called AirTED is being developed for use aboard aircraft, UAVs and high altitude balloons. The designs of AirTED and a Si PIN only version, AirSiD (no TEPC yet), emphasize low-cost, low- or battery power, portability and ease of use. Our objective is to develop cost effective instrumentation sensitive to all the major types and energies of ionizing radiation of concern in the atmosphere and in space that can be deployed aboard multiple airborne and spaceborne platforms. AirTED has already benefited from lessons-learned from SpaceTED, making use of a single, four input version of the Red Pitaya STEMlab 125-14 board, eliminating the second STEMlab 125-14 board and the Raspberry-Pi, and making use of 3-D printing to fabricate the TEPC's ionization cavity from electrically conductive plastic filament. We will also show data collected on a 9 hour, 69,000 ft balloon mission over central Oklahoma carried out in July 2024 using an AirSiD detector.

DOSIS and DOSIS 3D – active and passive radiation measurements in Columbus from 2009 - 2024

Thomas Berger for the DOSIS 3D Team

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 in the years 2009 – 2024 and further focus on new data gathered for the solar particle event in May 2024.

Update on the RadMap Telescope

Martin Losekamm

The RadMap Telescope is a technology-demonstration experiment for assessing the performance of a scintillating fiber-based tracking calorimeter in the radiation environment inside the International Space Station. Its primary objective is to show that the instrument can provide charge- and energy-resolved flux measurements of particles and nuclei up to iron.

In this contribution, I present first results from a roughly nine-month operational period starting in May 2023. During this time, we collected about 2.7 billion events with the tracking calorimeter and recorded dose measurements with a version of the flight-proven M-42 dosimeter. A comparison of the data gathered by the two sensors, the results of which I will discuss, shows that the new calorimeter appears to work largely as expected. I also show first results of our track reconstruction and discuss the next steps of our analysis.

Comparison of SRAG radiation monitor measurements in solar cycle 25

Steve Johnson, Leidos given by Stuart George

Measurements from SRAG radiation monitors for Solar Cycle 25 are presented to reflect trends in measurements between Radiation Assessment Detector (RAD), Radiation Environment Monitor-2 (REM2s), Crew Active Dosimeters (CAD) and Artemis HERA on Space Station (AHOSS). GCR and trapped trends will be highlighted. Attitude influences are presented to discuss effects on measurements.

This talk will discuss the radiation instruments aboard the ISS and how their measurements feed into RAE's radiation dose and risk calculations

Luke Stegemann, Leidos

NASA's Space Radiation Analysis Group (SRAG) is responsible for tracking and reporting occupational radiation exposures for all NASA astronauts. The Risk Analysis Environment (RAE)—developed by Oak Ridge Center for Risk Analysis (ORRISK) in a collaboration with SRAG—is a web-based computational tool designed to conduct personalized astronaut radiation dose and risk assessment using the NASA Space Cancer Risk (NSCR) Model, store astronaut- and mission-specific data related to occupational radiation exposure, and generate astronaut radiation exposure history reports for 1) informed consent, 2) mission projection, and 3) medical liability purposes. For current radiation risk reporting procedures for astronauts on ISS missions, the radiation doses measured by Crew Active Dosimeters (CADs), Radiation Environment Monitors (REMs), the Radiation Assessment Detector (ISS-RAD), and the Artemis Hybrid Electronic Radiation Assessor (HERA) on Space Station (AHoSS) are all utilized by RAE for dose normalization purposes. That is, fluence distributions initially estimated from transport codes are eventually normalized such that fluence-derived absorbed doses are consistent with measured dose values prior to their use in calculating quantities related to past-and-current NASA-imposed radiation exposure limits like mean NASA effective dose and risk of exposure-induced death (REID) and cancer (REIC). Similar procedures are in place within RAE to compute dosimetric and risk-related quantities for upcoming Artemis missions, where the Artemis HERA will be the primary operational radiation detector.

Dosimetric impacts of the May and June 2024 Space Weather and Solar Particle events at the International Space Station and Biosentinel

S.P. George, T.C. Campbell-Ricketts, N. Stoffle, E. Semones

The Space Weather events of 10-11 May 2024 created headlines around the world for their intense geomagnetic activity and the associated dazzling auroral displays observed as far south as Mexico and India. Less well publicized was the accompanying solar particle event, which while minor did create measurable dosimetric impacts on the International Space Station due to the compression of the magnetic field and the observation of solar enegetic particles in the ISS at magnetic latitudes much further south than would normally be observed. In addition the geomagnetic activity created a temporary particle belt that persisted for several days after the cessation of geomagnetic activity. We report on dosimetry in different ISS modules and at the Biosentinel cubesat in free space measured by Timepix based instruments and compare this event to data from prior combined geomagnetic storms and solar particle events.

We also examine the paradoxical impacts of the much larger solar particle event of June 8th 2024. This SPE which was created by the same active region that created the May geomagnetic storm on its return around the solar disk was the largest particle event of the solar cycle thus far, passing S3 on the NOAA solar particle scale. At ISS there was almost no measurable dosimetric impact due to the phasing of the space station with regards to the Earths magnetic field, while at the lightly shielded Biosentinel satellite the June event contributed the highest daily dose of any event seen during its flight of almost 75 mGy.

Updates on Radiation Data Analysis for MARE and other Orion Science Payloads

[1,2]Ramona Gaza
On behalf of the Space Radiation Analysis Group

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The Space Radiation Analysis Group (SRAG) at NASA Johnson Space Center (JSC) has provided active instruments, such as the Crew Active Dosimeters (CAD), and passive luminescence radiation detectors in support of multiple Artemis I science payloads. This presentation will provide a progress update on the Matroshka AstroRad Radiation Experiment (MARE) measurement results for both external and internal sensors.

In addition, a comparison of radiation data from Timepix based technology instruments and luminescence detectors for different LEO (ISS) and BLEO (Moon) destinations with different mission durations will be presented:

i. **ISS US Lab (6 months)**: ISS Hybrid Electronic Radiation Assessor (AHERA) and Radiation Area Monitors (RAM).

ii. **Orion Exploration Flight Test 1 (EFT-1) (4.5 hours)**: Battery-operated Independent Radiation Detector (BIRD) and co-located RAM.

iii. **Artemis I (25.5. day)**: Orion vehicle Hybrid Electronic Radiation Assessor (HERA) and RAM; BioExpt-1 science payload support using CAD and RAM.

on and satellite operations

Note:

This presentation could not be given. Instead Thomas Berger has given a short presentation on the "Status of the Mare Experiment"

Characterizing the Radiation Environment on Artemis I

M. Fragkopoulou[1], V. Alexiadis[1], and E. R. Benton[2],

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Abstract

The increasing complexity and miniaturization of space systems render them increasingly vulnerable to the harsh radiation environment. Accurate measurement of this environment is crucial for astronaut safety and mission success. HERADO dosimeters, has been integrated into the MARE experiment aboard the Artemis I mission to characterize the complex radiation field encountered during deep space travel. This presentation will provide an overview of the HERADO dosimeter, its integration into the MARE payload, and the anticipated scientific return from the mission. Understanding the radiation environment will contribute to the development of effective countermeasures for future human space explorati**on.**

Radiation Field Outside the ISS Observed by ARMAS Flight Module 9 March - December 2022

W. Kent Tobiska, Brad Gersey, Leonid Didkovsky, Kevin Judge, Seth Weiman, Dave Bouwer, Justin Bailey, Tsvetan Dachev, Borislav Tomov, Yury Matviichuk, Plamen Dimitrov, Malina Jordanova, Mityo Mitev, Nikolay Bankov, and Jordanka Semkova.

ARMAS Flight Module 9 instrument description: The design of the portable spectrometer Liulin-SET is not a new one. Similar devices have already flown on aircraft and stratospheric balloon and in space since 1988. Liulin-SET spectrometer contains one silicon-PIN diode of Hamamatsu with 0.3 mm thickness, one ultra-low noise charge-sensitive preamplifier of AMPTEK A225F type, two microcontrollers, a flash memory and an internal battery-operated clock-calendar. Lillian-SET starts to work with the time from the clock-calendar at each switch ON of the external voltage of ±28 V. Sixty switch ONs were registered between March 17 and December 9, 2022. The available in the flash memory 60 files contain data starting from few minutes and finishing with more than 1.5 months. The analysis of the data shows the existence of three radiation sources: galactic cosmic rays (GCR), inner radiation belt (IRB), protons in the region of the South-Atlantic anomaly and outer radiation belt (ORB) electrons in the high latitude regions of the ISS

orbit. The source selection is performed by the 1971 translations of J. W. Haffner's (1967, 1971) experimental formulation of the dependence between the incident energy of incoming protons and electrons and the dose to flux ratio. The variations of dose rates during quiet geomagnetic conditions are in the ranges: GCR from 0.4 mGy h-1 at geomagnetic equator to 25 mGy h-1 in the high latitude regions of the ISS orbit; IRB from 10 mGy h-1 to 2100 mGy h-1 and ORB from 10 mGy h-1 to 30 mGy h-1. During the magnetic storm from 3 to 12 September 2022, the GCR and IRB dose rates remain almost the same as during the quiet conditions, while ORB doses rise up in an enhancement to 2100 mGy h-1.

Radiation exposure measured with the DLR M-42 instrument during the ASTROBOTIC Peregrine 1 mission and an update on the DLR M-42 instrument family

Moritz Kasemann[1], Thomas Berger[1,*], Karel Marsalek[1], Bartos Przyblya[1], Daniel Matthiä[1], Joachim Aeckerlein[1], Maximilian Radenhäuser[1], Aleksandra Rutczynska[1], Markus Rohde[1], Michael Wirtz[1], Stephan Sous[2], Nico Maas[2], Oliver Küchemann[2], Cinzia Fantinati[2], Hans-Herbert Fischer[2,†], Hailey Moosbrugger[3], Jodi Coletti[3]

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The space radiation environment is the most complex natural radiation environment one can encounter. It not only poses a threat to spacecraft and their electronics, but can also harm humans who venture into deep space. A flight to the Moon or to Mars would first have to pass the Earth's radiation belts (Van Allen Belts) with the inner (proton and electron) and the outer (electron) belt and then in free space the relevant spacecraft (and possible humans inside) is exposed to the galactic cosmic radiation (GCR) environment. Measuring the radiation load in space provides valuable data which can further be applied to benchmark radiation transport codes and used to design new shielding materials.

Within the last decade the Biophysics working group of the Radiation Biology Department has developed, built, tested and flown a set of active radiation detector systems in various space missions. These consist of the *M-42* detector family - successfully applied on NASA balloon flights over Antarctica, the NASA Artemis I mission, the Astrobotic Peregrine I flight and within the RadMap experiment on-board the International Space Station (ISS)

Within the Astrobotic Peregrine 1 mission the DLR M-42 radiation detector was mounted on the Deck D of the spacecraft and measured the radiation environment during the time of the mission. Even though Peregrine 1 planned to land on the lunar surface but was not able to fulfill this mission goal, it ventured into free space reaching a distance of more than 400.000 km away from Earth before returning back to Earth. The M-42 instrument measured the radiation environment during the crossings of the outer Earth radiation belt (electron belt) and the subsequent deep space GCR environment. M-42 data was further on compared with other instruments measuring the radiation load in Earth orbit and in lunar orbit and on the lunar surface and also benchmarked with GEANT4 radiation transport calculations

Radiation Environments Beyond LEO

Cary Zeitlin, Leidos

Planning for human exploration missions to deep space destinations is well underway. Radiation environments outside the protection of Low-Earth Orbit are considerably harsher than the LEO environment, which is well protected by the geo-magnetosphere. The space radiation community now has long-term measurements from assets in lunar orbit and on the surface of Mars. These have been acquired by, respectively, the Cosmic Ray Telescope for the Effects of Radiation (CRaTER) aboard the Lunar Reconnaissance Orbiter and the Radiation Assessment Detector (RAD) aboard the Curiosity Mars Rover, also known as the Mars Science Laboratory (MSL). CRaTER has been operating in lunar orbit since 2009, and MSL-RAD on Mars since 2012, both providing more than a full 11-year solar cycle of data. This presentation will cover long-term trends in Galactic Cosmic Ray intensity as measured at the Moon and Mars (highly correlated, as expected), as well as Solar Particle Event intensities at the two locations (highly variable). We will also show detailed comparisons of SPE intensity vs. time profiles as measured in lunar orbit and in geostationary orbit by GOES satellites. The comparison of CRaTER and GOES data demonstrates that using real-time GOES data is a viable approach to monitoring the energetic particle environment outside a lunar orbiter (i.e., Gateway) or outside a surface habitat. The results show conclusively that there is no need to deploy additional detection systems outside inhabited volumes.

Models and Measurements from Earth to Mars during Artemis-I

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For all planned human spaceflight missions, accurate models and measurements are needed to assess human exposure and ultimately project and mitigate associated health risks. During Artemis-I, measurements of the absorbed dose-rate were simultaneously being taken inside the International Space Station (ISS) in low Earth orbit (LEO), inside the uncrewed Orion capsule in free space, inside the BioSentinel CubeSat in free space, and on the Martian surface. These measurements encompass human exploration destinations from Earth to Mars and highly diverse shielding conditions.

Computational models used to assess crew exposure and cancer risk have been extensively compared to spaceflight measurements over the past several decades, but for the most part, only single destinations and shield configurations were considered in each study (e.g. ISS in LEO). Never before have the models been compared to measurements collected *over the same time period* spanning locations from Earth to Mars and shield configurations from CubeSats (14 kg) to space stations (400,000 kg). Such a comprehensive study would be highly useful to establish a clear picture of combined model accuracy and systematic uncertainties.

In this work, combined environment, physics, transport, and shield geometry models are compared to measurements taken during the Artemis-I mission timeframe inside the ISS, Orion capsule, BioSentinel CubeSat, and on the Martian surface. All model calculations were performed blind, without having prior knowledge or access to the measurement data. The combined models are found to be in excellent agreement with measurements. Further improvement to combined model calculations necessitates additional ground-based cross sections measurements to reduce uncertainties for neutron, pion, and light ion (isotopes of hydrogen and helium) production.

60 years of radiation monitoring in space

Martin Kroupa

Los Alamos National Laboratory might not be best known for space exploration. However, first satellite from LANL, called Vela, was launched in 1963. Indeed, from detection and reporting of nuclear detonations, and first discovery of Gamma Ray burst to measurements of water on Moon and Mars, LANL has been on the frontier of the space radiation measurements. In this talk we will provide highlights of important missions and payloads LANL lead and participated on for the past 60 years.

The LEIA Mini-FND Fast Neutron Detector

B. Ehresmann, D. M. Hassler, M. Vincent

The Mini-FND (Miniaturized Fast Neutron Detector) is a successor of the highly successful ISS/RAD FND instrument that has been operating onboard the ISS since 2016.

To account for tighter restrictions in mass, volume, and power for an instrument designed for deep-space missions as compared to an instrument operating onboard the ISS, we have developed a new version of the FND reduced in mass, volume, and power draw. This was mainly achieved by replacing the ISS/RAD FND read-out detector, a rather large-sized Photomultiplier Tube (PMT), with an array of small-sized Silicon Photomultipliers (SiPMs), which, additionally, in contrast to the original PMT doesn't operate on high voltage.

This new development, termed Mini-FND, has been selected to fly on NASA's CLPS-22 Lunar lander mission, as part of the LEIA (Lunar Explorer Instrument for space biology Applications) instrument suite. Here, we provide an updated overview on the LEIA / Mini-FND program.

A synthetic diamond as Cerenkov detector

James J. Connell

University of New Hampshire

Late contribution, therefore no abstract available

RadLab: A Comprehensive Database and Graphical and Programming Interfaces for Space Radiation Data

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RadLab, a component of the NASA Open Science Data Repository (OSDR), is a database of radiation measurements from multiple instruments and spacecraft that provides visual and programmatic interfaces for interrogation and retrieval of these data.

The attributes of data available through RadLab include spacecraft, types of radiation sensing instruments, locations within the spacecraft (*e.g.* ISS modules), associated celestial bodies, trajectories, and spacecraft coordinates; the primary type of data is the absorbed dose rate, as well as flux and dose equivalent rate where available.

The application programming interface (API) implements a request syntax for retrieval of timestamped data filtered by various combinations of such attributes; the graphical user interface (GUI) extends this functionality with visualizations (time series plots, comparison plots, geospatial visualizations) which provide easy means to assess data availability, iteratively refine search parameters, interactively inspect the data, and export target data subsets.

Datasets are continuously being added to the RadLab database as part of the rolling release process. Investigators from multiple countries, including the US, Canada, Germany, Bulgaria, Hungary, Italy, Japan, Russia and the Czech Republic, have committed to provide data from their instruments in and beyond low Earth orbit. The current release contains datasets provided by US and international collaborators and includes readings from multiple modules of the ISS, the BioSentinel CubeSat, Chang'e 4, the Lunar Reconnaissance Orbiter, the ExoMars Orbiter, and the Curiosity rover. Datasets are associated with respective RadLab knowledgebase articles which include instrument descriptions and provide bibliographical references.

RadLab aims to provide a comprehensive, dynamic compendium of space radiation data, enabling the scientific community to perform analyses of data from multiple detectors and to determine the radiation environment of research missions and experiments. Some of its applications include inference of absorbed radiation dose for NASA GeneLab payloads, and training predictive models as part of the 2024 FDL-X challenge. The platform is actively expanding and seeking additional data, with plans to also cover past (*e.g.* Shuttle, Mir) and future (*e.g.* Artemis) missions.

The RadLab Working Group has been created to aid in this process as well as to foster collaborations among data contributors and users, to develop standards for data harmonization, and to guide the development of the platform, with the goal to establish the use of RadLab in space radiation research and to advance our understanding of the radiation environment in outer space.

DORELI 2024

Livio Narici[1], Giorgia Santi Amantini[1], Luca Di Fino[2], Virginia Boretti[3], Luca Lunati[3], Nicholas Stoffle[4], Thomas Campbell-Ricketts[5], Stuart George[5], Thomas Berger[6], Daniel Matthiä[6], Maximilian Bruedern[7], Soenke Burmeister[7]

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The radiation environment inside the International Space Station (ISS) is one of the most complex that humans encounter. Measuring the radiation inside the ISS and its changes along the orbit, while understanding the shielding effects is important for the radiation risk assessment. Using different detectors to measure radiation at the same time allows us to cross-check and improve the accuracy of the data, leading to a better overall understanding of the radiation environment. This approach also makes the data more reliable, independent from the specific features of each detector.

In 2021, we began a project to compare data from four radiation detectors in the COLUMBUS lab on the ISS. The detectors are:

- **LIDAL** (University of Rome Tor Vergata): A telescope with 18 striped silicon planes and 2 segmented scintillators.
- **REM** (NASA-JSC/SRAG): A hybrid silicon pixel detector (Timepix) with a matrix of 256 x 256 pixels.
- **DOSTEL-1 and DOSTEL-2** (DLR, CAU): Silicon telescopes with two Canberra PIPS round detectors.

These detectors are all based on silicon technology but feature different designs and different field of view. LIDAL is rotated periodically (together with REM, positioned flat on one of LIDAL’s lids) in one of the three ISS directions (X, Y, Z). DOSTEL-1 and DOSTEL-2 are fixed in the X and Y directions under the EPM rack in Columbus.

The data collected over more than four years (less for REM) cover a significant part of the solar cycle. The major differences in the measurements are mainly due to the varying field of view and consequently to the local shielding. Understanding these differences helps improve data analysis and achieve combined results that would not be possible with individual detectors alone.

Fluxes and dose rates over time are presented as well as their dynamics with the magnetic coordinate L. A specific focus will be given on the SPE of May 11th 2024. This project, called DORELI, is a use case of the RadLab effort within NASA Ames Research Center’s Open Science Data Repository (OSDR), which will be discussed elsewhere in the workshop.

Modeling Aided Measurements (MAM): a new vision for evaluation of the radiation environment in a space habitat

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Knowledge of the radiation environment in a space habitat is important for a number of reasons: i) to mitigate radiation impacts on crew health; ii) to optimize countermeasures, iii) to provide support for space based biological and/or physiological experiments; iv) to validate radiation transport models.

In this presentation we focus on the International Space Station, where a number of radiation detectors are in operation and several source models, vehicle CAD models and transport codes are available. However, the complexity and inhomogeneity of the shielding of the ISS (as is the case with all space habitats), as well as the distinct characteristics of each detector, producing measurements that depend on the detector itself and its location and orientation, are also evident.

We present here the Modeling - Aided - Measurements (MAM) vision leading to the best possible knowledge of the radiation parameters as a function of time and location within a space habitat.

Radiation source models, models of transport through shielding, an accurate description of the ISS shielding (CAD), radiation measurements in the ISS (including coordinates of the detectors) can be used together to provide the radiation parameters in any location, at any given time in the space habitat. In this vision, models will be iteratively compared to data and consequently adjusted while taking into account the detailed knowledge of the shielding distribution, using advanced big data analysis techniques including AI. This will also offer a tool to inter- / extrapolate the measurements to any location of the ISS.

This vision, developed for the ISS, can be applied to any space habitat (spacecraft, lunar or planet surface). MAM should eventually operate in real time in the space habitat.

Open radiation databases such as RadLab could provide the data for testing MAM up to a full dry run. RadLab would incorporate the results of MAM, becoming the most complete database for radiation relevant for human exploration.

We will describe the steps needed to realize this vision along with the challenges of this approach.

MSL/RAD Radiation Measurements on the Surface of Mars on the Way to Solar Maximum – New Findings & Updates

B. Ehresmann, D. M. Hassler, C. Zeitlin, R. F. Wimmer-Schweingruber, T. Berger, D. Matthiae, G. Reitz and the MSL/RAD Science Team

Mars possesses only a thin atmosphere with a few tens of g/cm^2 of vertical column depth. Thus high-energy particles (for example, protons with energies > 150 – 170 MeV) can penetrate deep into the atmosphere and ground. Thus, the radiation environment on the surface of Mars consists mainly of Galactic Cosmic Radiation (GCR) and their secondary particles created by interactions in the atmosphere or soil. Additionally, spontaneous Solar Energetic Particles (SEPs), emitted from the Sun during solar storms, can dominate the Martian surface radiation field on short time scales of hours to days. Protecting future human astronauts from exposure to this radiation remains one of the major challenges for the exploration of Mars.

To understand this radiation environment and how it changes over time, the Radiation Assessment Detector (RAD) has been measuring the radiation environment on the Martian surface aboard the Curiosity rover since landing in August 2012. The RAD measurements, thereby, provide vital information on the radiation exposure and potential health risks for future human explorers of Mars. As a space weather monitor on Mars at 1.5 AU, RAD measurements also provide valuable information for the space weather and helio-physics communities. For example, they provide insight into the intensity and timing of the arrival of SEPs, in particular their high-energy component.

Here, we present updated measurements of the evolution of the Martian surface radiation environment over the last few years during the rising phase of the current solar maximum. Thereby, we mainly focus on measurements of the absorbed radiation dose, and calculations of the dose equivalent based on the quality factor derived from RAD LET (Linear Energy Transfer) measurements. Furthermore, we present updated measurements of SEP events and other relevant solar features, such as Forbush decreases, that RAD was able to detect.

The May 2024 Solar Storms as seen at Mars by MSL/RAD

C. M. Hassler, R. F. Wimmer-Schweingruber, C. Zeitlin, B. Ehresmann, and the MSL/RAD Science Team

D.

We present measurements of the Radiation Assessment Detector (RAD) onboard NASA's Curiosity rover on the Mars Science Laboratory Mission (MSL). Here, we focus on presenting new measurements of Solar Energetic Particle Events (SPEs) measured by RAD in the past year. We will present dose rate measurements and put them in context with measurements from other instruments / spacecraft to highlight how RAD can provide important data and information to better understand the propagation of Solar Energetic Particles (SEPs) within the solar system. These data are crucial for the preparation of human exploration to Mars and farther out in the solar system.

Regolith Shielding as Observed by MSL/RAD on the Surface of Mars

B. Ehresmann, D. M. Hassler, C. Zeitlin, R. F. Wimmer-Schweingruber and the MSL/RAD Team

Exposure to space radiation remains one of the major risks for human space exploration. On Mars this exposure mainly stems from Galactic Cosmic Radiation (GCR) and spontaneous Solar Energetic Particles (SEPs) emitted from the Sun during Coronal Mass Ejections (CMEs) or solar flares. As the Martian atmosphere is comparably thin, GCRs and SEPs can penetrate deep into the atmosphere and even reach the surface. Note here that, even while the atmosphere is thin, protons need about 150 – 170 MeV to be able to reach the surface. To characterize the resulting Martian surface radiation environment and how it changes over time with the solar cycle, the Mars Science Laboratory (MSL) Radiation Assessment Detector (RAD) has been measuring this radiation in Gale Crater on Mars aboard NASA's Curiosity rover since August 2012.

Here, we present RAD measurements of the observed radiation shielding effect provided by local terrain surrounding the Curiosity rover. If the rover is situated close to massive terrain, such as canyon walls or cliff sides, part of the incoming radiation from the upper hemisphere can be blocked from reaching the rover, resulting in a decrease of the measured radiation dose. To qualify and quantify this shielding effect we present an overview of all instances that RAD was able to measure. Based on orbital altitude maps and rover localization data, we can calculate the amount of hemisphere that is blocked by a terrain feature and correspondingly the average zenith angle of obstruction for each instance. These data sets of obstruction angles and corresponding decrease in radiation dose provide valuable ground-truth proof to validate radiation transport models. These models can then be used to determine the effectiveness of planned radiation or storm shelters to be utilized by future Mars explorers. Here, it is important to note that it will most likely be more efficient to utilize existing terrain on Mars, such as crater walls or lava tubes, to build operation bases and emergency radiation shelters.

Variations in the Radiation Environment and Observed Biological Consequences on the Long-Term Stored Embryonic Stem Cells in the Kibo Module of the ISS

Kayo Yoshida [1], Megumi Hada [2], Masami Hayashi [1], Akane Kizu [1], Kohei Kitada [1], Kiyomi Eguchi-Kasai [3], Toshiaki Kokubo [3], Takeshi Teramura [4], Hiromi Suzuki [5], Hitomi Watanabe [6], Gen Kondoh [6], Aiko Nagamatsu [7], Sachiko Yno[7], Premkumar Saganti [2], Masafumi Muratani [8], Francis A. Cucinotta [9] and Takashi Morita [1]

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Presented by – Premkumar B. Saganti, Regents Professor of Texas A&M University System and Professor of Physics, Prairie View A&M University, Texas, USA.

Variations in the Radiation Environment and Observed Biological Consequences on the Long-Term Stored Embryonic Stem Cells in the Kibo Module of the ISS

One of the long-duration radiation biology studies on ISS was a joint collaborative space project between JAXA and NASA and is known as “Stem Cells - Study on the Effect of Space Environment to Embryonic Stem Cells to their Development” in the Kibo Module. Frozen Embryonic Stem (ES) cells were launched to ISS in March of 2013 and stored in the Minus Eighty Degree Laboratory Freezer for ISS (MELFI) through July 2017. Four different sets of cell samples were retrieved back to earth after periods of 443 days, 711 days, 1167 days, and 1584 days on the ISS along with the PADLES (Passive Dosimeter for Life-science Experiments in Space consisting of CR-39 and TLDs) dosimeters attached to the tubes containing the ES cell samples. After these cell stacks were brought back to the ground, they were thawed and cultured, and their gene expressions were comprehensively analyzed to elucidate the early response of the cells to long-time exposure to space radiation in microgravity conditions. The comparisons of gene expression involved in double-stranded break (DSB) repair were examined. Also, the expressions of most of the genes that were involved in homologous recombination (HR) and non-homologous end joining (NHEJ) were studied and compared between the ISS-stocked cells and ground-stocked control cells. It was noted that the transcription of Trp53inp1 (tumor protein 53 induced nuclear protein-1), Cdkn1a (p21), and Mdm2 genes increased in ISS-stocked cells. This phenomenon is similar to the cells that were exposed to the Fe ions in ground-based experiments at HIMAC Facility. This suggests that accumulated DNA damage caused by space radiation exposure would activate these genes.

The PADLES measured dose-equivalent values on ISS were ~ 250 mSv (for 443 days), 375 mSv (for 711 days), 575 mSv (for 1167 days), and 830 mSv (for 1584 days) between 2013 and 2017. We present and discuss on the model calculated dose-equivalent values at ISS during the same period and expand to the current solar cycle conditions of the space radiation environment.

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SpinSat, a platform for in situ studies of the effects of variable gravity and space radiation

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Investigating the effects of space radiation and reduced gravity on biological and physical systems presents multiple challenges. Neither space radiation's combined variety of particle types, energies and dose rates, nor reduced gravity, can be replicated on the ground, and access to space is limited. Consequently, substantial gaps remain in our knowledge of how to safely sustain crews and agriculture on extended exploration missions beyond low Earth orbit. The SpinSat spacecraft platform is designed to address these gaps by providing low-cost, reliable, and frequent access to space on a disk-shaped rotating spacecraft that can provide simultaneous artificial gravity and exposure to space radiation. SpinSat is designed to accommodate multiple payloads in a CubeSat form factor (with a total payload volume of at least 48U) providing power, communications, and a controlled thermal environment. It is orbit-agnostic, enabling access to a variety of radiation environments, including low and high Earth orbit and cis-lunar space. It provides for late loading of biological payloads and is well suited to host a wide range of biological and physical experiments, ranging from cells and human tissues and organoids to microorganisms and plants. It has the capacity to carry shielding to mimic lunar and Martian radiation environments for both short- and long-term experiments.

Potential SpinSat studies include fundamental radiation biology and DNA repair; cancer biology and countermeasure development; space agriculture; bioproduction of nutrients and pharmaceuticals; understanding regolith dynamics in low gravity; prebiotic chemistry and panspermia. We will discuss ideas for SpinSat-compatible experimental hardware, the artificial gravity levels available and the design of payloads to access them; potential radiation environments; and topics such as life support and experiment timing. We will present examples of potential experiment concepts for SpinSat, and discuss how various experiment designs can be accommodated on the platform.