Program WRMISS, 2012

Tuesday

Introduction (8:45)

2015 Welcome and Reorganization Overview
Weyland M. D.

Highlight talk (9:00-9:45)

2017 RAD Dosimetry Measurements During MSL's Cruise to Mars and on the Martian Surface
Zeitlin C.

1st Session (9:45-10:45)

2026 Practical Applications of Cosmic Ray Science: Spacecraft, Aircraft, Ground-Based Computation and Control Systems, and Human Health and Safety
Atwell W.

2028 Calculation of Radiation Exposure Levels in Low Earth Orbit and Beyond
Matthiae D.

Coffee Break (10:45-11:45)

2nd Session (11:45-12:45)

2003 ISSCREM: International Space Station Cosmic Radiation Exposure Model
El-Jaby S.

2031 CAD Model Shielding Analysis of the International Space Station
Stoffle N.

Lunch (12:45-14:15)

Tuesday cont.

3^{rd} Session (14:15-15:45)

2001 Estimates of Cosmic Rays Directional Dose for ISS
Badavi F. F.

2002 ISS Dose Estimates Due to Pions and Electromagnetic Cascade
Slaba T. C. oral

2032 The Energetic Heavy Ion Sensor (EHIS): An Energetic Ion Spectrometer for GOES-R
Connell J. J.

Coffee Break (15:45-16:30)

4^{th} Session (16:30 – 18.00)

2005 Comparison of tissue-like plastics in tissue equivalent proportional counters (TEPC) as exposed to energetic proton and heavy ions.
Collums T. L.

2016 Preliminary Results of Proton ICCHIBAN Experiments
Kitamura H.

2011 Ground-Based Measurement of Bubble-Detector Sensitivity to Protons
Machrafi R.

Wednesday

5th Session (8:45-10:15)

2007 First Results of the TriTel Space Dosimetry Telescope from the Mission on Board the BEXUS-12 Stratospheric Balloon
Hirn A.

2025 ISS Radiation Measurements 2008–2011
Welton A.

2006 Dose Measurements on Board the ISS with the Pille TLD System
Hirn A.

Coffee Break (10:15- 11:00)

6th Session (11:00-12:30)

2014 Radiation Dosimetry in the European Columbus Module
Demets R.

2008 The DOSIS and DOSIS 3D Experiments onboard the International Space Station – Results from the Active DOSTEL Instruments
Burmeister S.

2019 Radiation Survey in USLab and first Measurements in Columbus with the ALTEA Detector
Narici L.

Lunch (12:30- 14:15)

Wednesday cont.

7th Session (14:15-15:45)

2029 On-Orbit Status of the Intravehicular Tissue Equivalent Proportional counter (IV-TEPC) for ISS
Flore-McLaughlin J.

2013 Preliminary Results of Water Shielding Effect for Space Radiation in ISS Crew Cabin by means of Passive Dosimeters
Kodaira S.

2027 MATROSHKA — Results from the Exposure Inside the Japanese KIBO Module — and Comparison with previous Missions
Berger T.

Coffee Break (15:45-16:45)

8th Session (16:45- 18:15)

2010 Estimation of Organ Doses using PADLES in the Phase 2B_KIBO experiments of the MATROSHKA project
Nagamatsu A.

2012 GCR Anisotropy Effects on Dose Measurements with MTR/DOSTEL.
Labrenz J.

2009 First Results (Hopefully) from Medipix on the ISS
Pinsky L. S.

Thursday

9th Session (9:00-10:30)

2023 CRaTER Measurements of Tissue-Equivalent Shielding in the GCR
Zeitlin C.

2022 Medipix-Based Space Dosimetry at NASA: An Overview of Current Projects
Bahadori A. A.

2030 Particle Charge and Velocity Discrimination Using Silicon Timepix Detectors
Stoffle N. N.

Coffee Break (10:30-11:30)

10th Session (11:30-12:30)

2021 Advanced Dosimetry Data Analysis Using Tracking Information from Pixel Detectors
Kroupa M.

2004 Electronic Dosimeter for Space Applications Based on MOSFET Technology
Benton E.

Lunch (12:30-14:15)

11th Session (14:15- 15:45)

2024 Scintillation Detectors for Space Radiation and Dosimetry
Christian J. F.

2018 Prototype Spherical TECP Design for Dose Measurement in ISS
Lee J. J.

2020 Multifunctional Novel Boron-Carbon Fiber Polymer Composites for Mixed Radiation Field Space Applications
Wilkins R.

Break (15:45-16:45)

12th Session (16:45-17:45)

Discussions, Conclusions
all

RAD Dosimetry Measurements During MSL's Cruise to Mars and on the Martian Surface.
C. Zeitlin[1], D.M. Hassler[1], B. Ehresmann[1], E. Boehm[2], S. Boettcher[2], S. Burmeister[2], J. Guo[2], A. Kharytonov[2], J. Koehler[2], C. Martin[2], R.F. Wimmer-Schweingruber[2], D.E. Brinza[3], F.A. Cucinotta[4], A. Posner[5], G. Reitz[6]. [1]Southwest Research Institute, 1050 Walnut St., Boulder, CO 80302, [2]Christian Albrechts University, Kiel, Germany, [3]NASA Jet Propulsion Laboratory, Pasadena, CA, [4]NASA Johnson Space Center, Houston, TX, [5]NASA Headquarters, Washington, DC, [6]DLR, Koln, Gemany

Introduction: The Radiation Assessment Detector (RAD) was the first science instrument aboard the Mars Science Laboratory (MSL) [1] to start collecting data, with acquisition starting 10 days after launch and continuing until the final three weeks of the cruise phase. RAD resumed data-taking on the first sol on Mars, returning the first-ever detailed measurements of cosmic radiation from the surface of another planet.

RAD is an advanced and unique flight instrument [2, 3]. It combines charged- and neutral-particle measurement capabilities in an extremely compact, low-mass package. RAD contains six detectors, three of which (A, B, and C) are silicon diodes arranged as a telescope, with the other three (D, E, and F) being scintillators. Two of the scintillators, E and F, are made of Bicron BC-432m plastic; the other, D, is made of CsI for efficient gamma-ray detection. To minimize RAD's telemetry requirements, the instrument processes its data in real time and populates a number of histograms, sorting events into broad categories of penetrating charged particles, stopping charged particles, and neutral particles. There is also a group of histograms referred to as the "dosimetry" histograms. These include minute-by-minute totals of energy deposition in the B and E detectors, as well as LET spectra for charged particles in the telescope field of view. In this presentation, we will describe the methodology used to turn the onboard histograms into properly normalized dosimetric quantities, and show results expressed as time series of dose rates in silicon and tissue, and dose-equivalent rates in tissue.

Preliminary Results from Cruise: During MSL's cruise to Mars, RAD was shielded by a complex distribution of mass. Fuel tanks filled with hydrazine were partially in the charged telescope field of view. Work done by JPL indicates that the shielding distribution is complex, with roughly half the rays lightly shielded and the remainder having a very broad distribution going up to about 80 g cm^{-2} aluminum equivalent. The shielding strongly affected the dose rate during the five solar events that were observed, but had a modest effect during solar quiet times when the GCR is dominant.

The dose rate and dose-equivalent rate are influenced by the background from MSL's RTG power source. Careful study of this background is required; the effect on measured doses depends on threshold settings. Data were taken for about an hour with the fully-integrated rover at Cape Canaveral, prior to launch, and these data provide an essential reference for the background estimates. Using the current best estimate, the dose rate in the B detector (silicon) is found to average about 330 μGy/day. Conversion of the dose rate in silicon to a tissue dose rate depends on the calibration method, which will be explained in some detail; we find a factor of about 1.4 is appropriate for these data. This yields good agreement with the dose rate found in the tissue-like E detector. LET spectra in silicon have been obtained and have also been converted to tissue; this allows for estimation of the average quality factor, <Q>, and calculation of dose equivalent. Implications of the measured dose equivalent for the Design Reference Mission for a human trip to Mars will be discussed.

Surface Data: To first order, we expect a factor of two smaller dose rate on the surface than in cruise. Preliminary analysis of RAD data taken on the first three sols on Mars yield dose rates consistent with this expectation. Additional data are expected to be available and will be presented at the workshop. The shielding conditions on the surface are simpler than in the cruise configuration, but are comparable in depth, at least on average.

Acknowledgments: RAD is supported by NASA (HEOMD) under JPL subcontract #1273039 to SwRI, and by DLR in Germany under contract with Christian-Albrechts-Universitat (CAU).

References:

[1] http://mars.jpl.nasa.gov/msl/

[2] D.M. Hassler et al., *Space Science Reviews* (in press, 2012).

[3] http://mslrad.boulder.swri.edu

Practical Applications of Cosmic Ray Science: Spacecraft, Aircraft, Ground-Based Computation and Control Systems, and Human Health and Safety

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Abstract

Three twentieth century technological developments, 1) high altitude commercial and military aircraft; 2) manned and unmanned spacecraft; and 3) increasingly complex and sensitive solid state micro-electronics systems, have driven an ongoing evolution of basic cosmic ray science into a set of practical engineering tools needed to design, test, and verify the safety and reliability of modern complex technological systems. The effects of primary cosmic ray particles and secondary particle showers produced by nuclear reactions with the atmosphere, can determine the design and verification processes (as well as the total dollar cost) for manned and unmanned spacecraft avionics systems. Similar considerations apply to commercial and military aircraft operating at high latitudes and altitudes near the atmospheric Pfotzer maximum. Even ground based computational and controls systems can be negatively affected by secondary particle showers at the Earth's surface, especially if the net target area of the sensitive electronic system components is large. Finally, accumulation of both primary cosmic ray and secondary cosmic ray induced particle shower radiation dose is an important health and safety consideration for commercial or military air crews operating at high altitude/latitude and is also one of the most important factors presently limiting manned space flight operations beyond low-Earth orbit (LEO). In this paper we review the discovery of cosmic ray effects on the performance and reliability of microelectronic systems as well as human health and the development of the engineering and health science tools used to evaluate and mitigate cosmic ray effects in ground-based atmospheric flight, and space flight environments. Ground test methods applied to microelectronic components and systems are used in combinations with radiation transport and reaction codes to predict the performance of microelectronic systems in their operating environments. Similar radiation transport codes are used to evaluate possible human health effects of cosmic ray exposure, however, the health effects are based on worst-case analysis and extrapolation of a very limited human exposure data base combined with some limited experimental animal data. Finally, the limitations on human space operations beyond low-Earth orbit imposed by long term exposure to galactic cosmic rays are discussed.

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Calculation of Radiation Exposure Levels in Low Earth Orbit and Beyond

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The radiation exposure of astronauts in Low-Earth orbit is caused dominantly by galactic cosmic rays and trapped particles in the radiation belts and secondary particles produced in the atmosphere and spacecraft hull. Solar energetic particle events can have an influence on the dose rates depending on the strength and duration of the event and on the position and orbit of the spacecraft.

The radiation exposure can be estimated with numerical simulations applying different models for the galactic cosmic rays (GCR), trapped particles and solar energetic particles. Widely used GCR models – Badhwar-O'Neill2010, Burger-Usoskin, CREME2009 and CREME96, were evaluated by comparing the model spectra for light and heavy nuclei with measurements from various high-altitude balloon and space missions over several decades [1]. Additionally, a new GCR model was developed at the German Aerospace Centre (DLR) [2]. The differences arising in the radiation exposure by applying these models are quantified in terms of absorbed dose and dose equivalent rates using the GEANT4 Monte-Carlo framework. During certain epochs in the last decade, there are large discrepancies between the model and the measured spectra. All models exhibit weaknesses in describing the increased GCR flux that was observed in 2009-2010. The differences in the spectra, described by the models, result in considerable differences in the estimation of the radiation exposure [3]. Based on the results gathered within [1] to [3] the most appropriate GCR model was choosen and used for the calculation of organ doses and effective doses applying anthropomorphic and spherical phantoms. Results from Monte-Carlo simulations of the radiation exposure in LEO orbit are presented for different time periods and the contribution of different particle types is investigated as well as the influence of the geomagnetic conditions on the radiation exposure and contributions of solar energetic particles. The resulting dose rates calculated with a spherical water phantom are compared to simulations using anthropomorphic phantoms. A further outlook is given for the radiation exposure conditions and dose values encountered at the Lunar surface [4].

References:

[1] Mrigakshi, A., Matthiae, D., Berger, T., Reitz G., Wimmer-Schweingruber R.F., Assessment of Galactic Cosmic Ray models. Journal of Geophysical Research, (2012), http://dx.doi.org//10.1029/2012JA017611

[2] Matthiae, D., Thomas Berger, T., Mrigakshi, A., and Reitz, G., A Ready-to-Use Galactic Cosmic Ray Model. Advances in Space Research, (2012) (under review)

[3] Mrigakshi, A., Matthiae, D., Berger, T., Reitz G., and Wimmer-Schweingruber R.F., Galactic Cosmic Ray exposure outside and inside the Earth's magnetosphere between 1970 and 2011. Advances in Space Research, (2012) (under review)

[4] Reitz, G., Berger, T., Matthiae, D., Radiation Exposure in the Moon Environment. Planetary and Space Science, (2012) http://dx.doi.org/10.1016/j.pss.2012.07.014

ISSCREM: International Space Station Cosmic Radiation Exposure Model. S. El-Jaby[1], B. J. Lewis[1], L. Tomi[2], L. Sihver[3], T. Sato[4], K. Lee[5], S. Johnson[5], [1]Royal Military College of Canada (Department of Chemistry and Chemical Engineering, 17000 Station Forces, Kingston ON. Canada, K7K7B4, samy.el-jaby@rmc.ca), [2]Canadian Space Agency, [3]Chalmers University of Technology, Sweden, [4]Japan Atomic Energy Agency, [5]Space Radiation Analysis Group, NASA.

Introduction: The International Space Station Cosmic Radiation Exposure Model (ISSCREM) has been developed for the prediction of radiation exposure for possible use in radiation mission planning aboard the International Space Station (ISS). This software tool provides an estimate of the absorbed dose equivalent that space-crew may receive from galactic cosmic radiation (GCR) and trapped radiation (TR) sources. This semi-empirical model is derived from operational data obtained with a tissue equivalent proportional counter (TEPC) that were collected aboard the ISS from 2001 and 2008. The model has been further benchmarked against operational TEPC data collected in other years.

Galactic Cosmic Radiation Exposure. The GCR parametric model provides a correlation of the absorbed dose equivalent rate in μSv min^{-1} to the effective vertical cutoff rigidity magnetic shielding parameter at ISS altitudes as determined from the Smart and Shea RCINTUT3 model. Influences of altitude and localized shielding dependencies on the absorbed dose equivalent rate have been shown to be negligible. The absorbed dose equivalent rate is anti-coincident with solar activity. To account for moderate solar activity, the heliocentric potential parameter is used to provide a linear interpolation between solar maximum and minimum conditions. The GCR parametric model is valid for all locations inside the ISS.

Trapped Radiation Exposure. The TR parametric model provides a correlation of the absorbed mean daily dose equivalent rate in μSv min^{-1} to the mean atmospheric density at the crossing of the South Atlantic Anomaly (SAA), where the atmospheric density is determined from the NRLMSIS-00 model. Three parametric models are developed to specifically provide exposure estimates of the absorbed dose equivalent for: (1) all passes over the SAA, (2) ascending passes over the SAA, and (3) descending passes over the SAA. The TR model is valid for the TEPC located at Zvezda Service Module panel 327 (SM-327), and for an orientation perpendicular to the ISS velocity vector. Influences of the: (1) east-west asymmetry inside the SAA, (2) localized shielding dependencies, (3) atmospheric density changes with solar activity, and (4) detector orientation on the absorbed TR dose equivalent have been shown to be important effects and have been considered in the model development.

Benchmarking. ISSCREM has been benchmarked against TEPC data not used in the model development. This exercise includes TEPC data collected from 2000, 2002, 2007, 2009, 2010, and 2011 which span Solar Cycle 23 from solar maximum to minimum and the beginning of Solar Cycle 24. The model has successfully predicted the measured GCR and TR dose equivalent components, including ascending and descending trapped doses, to within ±10% and ±20%, respectively over periods of time ranging from daily dose predictions to a cumulative dose collected over several months.

Estimates of Radiation Protection Quantity. In addition to predictions of the absorbed dose equivalent, estimates of the protection quantity of effective dose have been made. Using the Particle and Heavy Ion Transport Code System (PHITS), effective-to-ambient dose equivalent ($E/H^*(10)$) conversion factors, using the new ICRP-103 conversion factors, have been determined for simple and complex representations of the ISS Zvezda Service Module. These conversion factors have been determined for GCR and TR sources at solar maximum and minimum conditions and at varying wall thicknesses ranging from 5.4 g cm^{-2} to 27.0 g cm^{-2}. The PHITS code was used to transport GCR ions (Z = 1 to 28) and trapped protons, as determined from the CREME-96 and AP-8 environmental models, through the ISS shielding. Preliminary results indicate that the operational quantity of dose equivalent measured by the U.S. TEPC provides a conservative estimate of the protection quantity of effective dose for mission planning purposes.

Future work. Study how uncertainties in the CREME-96 model, when used for calculations of space environment for 1998 onwards, influence the calculated results. Expand the ISSCREM model for space radiation exposure analysis to include parameters for shielding and geometry changes, and dose estimations from Solar Particle Events (SPE) which would make the model very usable for any deep space exploration mission, e.g. for the planning of future missions to the Moon, Asteroids, and to Mars.

CAD Model Shielding Analysis of the International Space Station. N. Stoffle[1], A. Welton[1], J. Barzilla[1], R. Gaza[1], K. Lee[2], N. Zapp[2], [1]Lockheed Martin, Bioastronautics Operation, 1300 Hercules MC C46, Houston, TX 77258, nicholas.n.stoffle@nasa.gov, [2]NASA Johnson Space Center, 2101 NASA Parkway, Houston, TX 77058

The Space Radiation Analysis Group (SRAG) maintains CAD models of the entire International Space Station. These modes include details such as the external structure, pressure shells, module structure, and detailed approximations for the internal racks. Ten-thousand ray shielding distributions have been used for shielding analysis at points along the central axes of the ISS modules as well as for locations where Radiation Area Monitor (RAM) measurements have been made. These distributions are presented here along with comparisons of recent measurements and calculated doses based on the 2010 HZETRN radiation transport code for the LEO environment.

Estimates of Cosmic Rays Directional Dose for ISS

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The International Space Station (ISS) provides the proving ground for future long duration human activities in space. Radiation measurements at Low Earth Orbit (LEO) in general, and at ISS in particular, form an appropriate tool for the experimental validation of radiation environmental models and nuclear transport code algorithms. Prior measurements onboard the Space Transportation System (STS; shuttle) have provided vital information impacting both the environmental models and the nuclear transport code development by requiring time dependent models of the LEO environment. In addition, past studies using Computer Aided Design (CAD) models of ISS have demonstrated that the exposure prediction for a spacecraft at LEO requires the description of an environmental model with accurate directional as well as time dependent behavior. Within the framework of an environment code named GEORAD (GEOmagnetic RADiation), this presentation describes the time dependency and directional capabilities of GEORAD as applied to the interaction of Galactic Cosmic Rays (GCR) with the geomagnetic field at LEO. The described model is a component of GEORAD which computes directional cutoff rigidity and the corresponding transmission coefficient, both of which are used as input into a deterministic particle transport algorithm for exposure estimation within ISS. The GEORAD capability to compute directional cutoff rigidity and transmission coefficient provides a useful tool to validate GCR exposure measurements by solid state particle telescopes which inherently have directional sensitivity. The presentation concentration is on the directional characteristics of GCR ions at LEO and at quiet solar periods. GEORAD interest is in the study of the geomagnetic environment from a long term point of view, and therefore it does not account for any short term distortion of the geomagnetic field due to solar activity (e.g. CMEs, flares, etc…). With the concentration of the presentation on the study of GCR ions at LEO; for the formation flying ISS, the presentation presents the directional profile of GCR ions at different angular distribution with respect to zenith. While the magnitude of the GCR directionality at LEO depends on a multitude of factors such as the ions rigidity, transmission, attitude and orientation of the spacecraft along the velocity vector; the presentation draws quantitative conclusions on the effect of GCR directionality at LEO.

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ISS Dose Estimates Due to Pions and Electromagnetic Cascade

Tony C. Slaba[1], Steve R. Blattnig[1], Ryan B. Norman[2], Francis F. Badavi[3]

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Abstract

Recent work has indicated that pion production and the associated electromagnetic (EM) cascade may be an important contribution to the total astronaut exposure in space. In this work, extensions to the deterministic space radiation transport code HZETRN to allow the production and transport of pions, muons, electrons, positrons, and photons are described. The extended code is compared to International Space Station data on a minute-by-minute basis over a seven day period in 2001. The impact of pion/EM production on exposure estimates is clearly shown. The Badhwar-O'Neill (BO) 2004 and 2010 codes are used to generate the galactic cosmic ray boundary condition at each time-stamp allowing the impact of environmental model improvements on validation results to be quantified as well. It is found that the updated BO2010 model noticeably reduces overall exposure estimates from the BO2004 model, and the additional production mechanisms in HZETRN provide some compensation.

THE ENERGETIC HEAVY ION SENSOR (EHIS): AN ENERGETIC ION SPECTROMETER FOR GOES-R.
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Abstract: The Energetic Heavy Ion Sensor (EHIS), to be flown on the GOES-R series of weather satellites, will measure fluxes of 10-200 MeV protons and heavier ions, helium (He) through nickel (Ni), for energies with comparable penetrations. EHIS thus measures cosmic rays and Solar energetic particles in the energy range of greatest relevance to manned space dosimetry. Elemental fluxes derived from EHIS data will be provided in five approximately logarithmically-spaced energy bands. Using the Angle Detecting Inclined Sensors (ADIS) technique [1,2], EHIS will provide single-element charge resolution from protons through Ni. The ADIS technique also allows on-board processing of >2000 events per second in high flux conditions, providing histograms on one minute cadence with exceptional statistics. The first flight model EHIS has been delivered for environmental testing, to be followed by accelerator calibrations. Once launched and operational, the instrument will provide new, very high quality measurements of the near-Earth radiation environment. Similar instruments would be very suitable for monitoring the radiation environment for manned missions..

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References::

[1] Connell J. J., Lopate C. and McKibben R. B. (2001) *NIM 457*, 220-229. [2] Connell J. J., Lopate C., McKibben R. B. and Enman A. (2007) *NIM A570*, 399-413.

COMPARISON OF TISSUE-LIKE PLASTICS IN TISSUE EQUIVALENT PROPORTIONAL COUNTERS (TEPC) AS EXPOSED TO ENERGETIC PROTON AND HEAVY IONS. T. L. Collums[1], M. R. Islam[1], E. R. Benton[1], Y. Zheng[2], Y. Uchihori[3], H. Kitamura[3], S. Kodaira[3] and. A. C. Lucas[1], [1]Oklahoma State University Radiation Physics Laboratory, 1110 S. Innovation Way, Stillwater, OK 74074 USA, [2]ProCure Proton Therapy Center, Oklahoma City, OK USA, [3]National Institute of Radiological Sciences, Chiba, Japan

We are currently investigating alternatives to A-150 tissue equivalent plastic for use in the construction of tissue equivalent gas-filled detectors for the measurement of dosimetric quantities. This study looks at four different alternative plastics: acrylic, Nylon, polyethylene, and polystyrene. These alternative materials are more readily available and easier to machine than A-150 tissue equivalent plastic. In this study they are compared to A-150 tissue equivalent plastic to determine how they compare in the measurement of lineal energy spectra from energetic protons and heavy ions as found in the space radiation environment, as well as at relevant clinical energies used in proton and heavy ion therapy.

In experiments carried out at the ProCure proton therapy center in Oklahoma City a, five proportional counters possessing ionization cavities constructed of five different materials (A-150 tissue equivalent plastic, acrylic, Nylon, polyethylene, and polystyrene) were used to measure the lineal energy spectra of energetic proton beams of 87 MeV, 162 MeV, and 222 MeV. Exposures to energetic heavy ions were carried out at HIMAC in Japan using beams of 150 MeV/amu He, 290 MeV/amu C, 490 MeV/amu Si, 500 MeV/amu Ar, and 500 MeV/amu Fe. Monte Carlo simulations using FLUKA were also done for each detector for each proton beam and are currently being done for the heavy ions beams.

Comparison of the measured data obtained at ProCure and HIMAC, as well as simulation results using the Monte Carlo code FLUKA, indicate that the responses of the four alternative plastics tested are very similar to the response of A-150 tissue equivalent plastic. FLUKA simulations done for a detector made of ICRU muscle are also shown to have a response similar to that of all five plastics.

Preliminary Results of Proton ICCHIBAN Experiments.

H.Kitamura[1], Y.Uchihori[1], S.Kodaira[1], N.Yasuda[2], E.Benton[3], T.Berger[4], M.Hajek[5], I.Ambrozova[6], O.Ploc[6,7] and ICCHIBAN Participants, [1]National Institute of Radiological Sciences (NIRS), Chiba, Japan, [2]Fukui University, Tsuruga, Japan, [3]Oklahoma State University, Stillwater, USA, [4]German Aerospace Center (DLR), Institute of Aerospace Medicine, Cologne, Germany, [5]Institute of Atomic and Subatomic Physics, Vienna University of Technology, Vienna, Austria, [6]Nuclear Physics Institute, Prague, Czech Republic, [7]Chalmers University of Technology, Gothenburg, Sweden

Since the 1st ICCHIBAN (Inter-Comparison for Cosmic-rays with Heavy Ion Beams At NIRS) experiment was kicked off in 2002, the ICCHIBAN Working Group (ICWG) has been promoting ground-based and spaceborne experiments using various accelerators and the International Space Station (ISS), respectively. The purpose of the Proton ICCHIBAN experiment series was to intercompare the responses of space radiation dosimeters for low-LET particles using accelerators.

The 2nd and 3rd Proton ICCHIBAN experiments (PI-2 and PI-3) were carried out in Jan. and Feb. 2010 and Feb. 2011, respectively. They were targeted primarily at passive detectors such as TLDs, OSLDs and glass dosimeters, which have capability to measure low-LET particles.

Table 1. Properties of beams used in PI-2 and PI-3 experiments

Particle	Energy from Accelerator (MeV)	Measured Energy (MeV)	LET (keV/ µm)	Facility
Proton	30	26	2.1	NIRS
Proton	40	36*	1.6	NIRS
Proton	70	69	0.97	NIRS
Proton	235	205	0.45	NCCHE

* Calculated value from primary energy and energy losses through materials in the beam line.

We carried out the four beam experiments listed in Table 1 using two cyclotron facilities [1,2]. The proton beams with energies of 30, 40 and 70 MeV were available from the National Institute of Radiological Sciences (NIRS) AVF 930 cyclotron [3]. The other facility was a cyclotron in the National Cancer Center Hospital East (NCCHE) [4] delivering 235 MeV proton beams. Unfortunately, absolute doses were not precisely measured at the NCCHE cyclotron because the beam monitor was not designed not measure the low-dose rates used to calibrate the dosimeters.

The detectors collected from the participants (Table 2) were assembled in holders prepared by the ICWG to verify identical exposure conditions. The holders were made of 1 mm-thick polycarbonate. Dosimeters were exposed to absorbed doses in water of 1, 10, 50 and 100 mGy (10, 20, 100 and 300 mGy for 235 MeV proton beams).

Each dosimeter system was investigated regarding linearity of dose response and LET dependence of efficiency. We will present preliminary results of comparisons between dosimeters.

Table 2 List of the percipients

Institute	Country	Dosimeter
ATI	Austria	TLD
AUTH	Greece	MOS-FET
DLR	Germany	TLD
IFJ-PAN	Poland	TLD
IMBP	Russia	TLD
JAXA	Japan	TLD
JSC-NASA	USA	OSLD
KFKI (ERI)	Hungary (USA)	TLD
NIRS	Japan	TLD, OSLD, glass
NPI	Czech	TLD, glass
OSU	USA	OSLD
SCK-CEN	Belgium	TLD, OSLD
YPI	Armenia	Nuclear emulsion

References: [1] Y. Uchihori, et al., (2010) *15th WRMISS*, [2] H. Kitamura, et al., (2011) *16th WRMISS*, [3] Kanazawa, et al., (2010) *Proc. of CYCLOTRON 2010*, 96-99, [4] T. Nishio, et al., (2006) *Phys. Med. Biol.*, 51, 5409-5417

Ground-Based Measurement of Bubble-Detector Sensitivity to Protons

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Abstract

In order to improve understanding of bubble-detector readings in the space environment, the Canadian Space Agency is supporting ground-based testing of the bubble detector. Recently, nine sessions of experiments with bubble detectors were conducted with high-energy proton beams at the ProCure proton therapy facility at Oklahoma State University, USA. Ten bubble detectors, with sensitivity similar to the detectors used aboard the ISS, were irradiated with 78, 162 and 226 MeV protons in three different configurations. A bubble detector reader was used for automatic bubble counting. The proton sensitivity has been obtained after exposing the detectors to proton fluences from 2 to 15.10^7 p cm^{-2}.

This paper outlines and discusses results of the conducted experiments and compares the data with other measurements reported in literature. The bubble-detector response to protons is also compared to the response of the detector for neutrons.

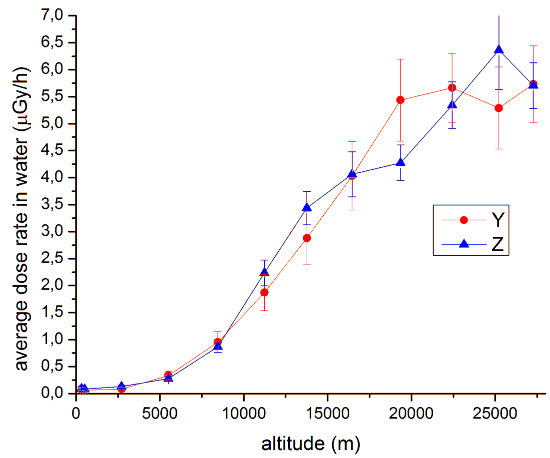
FIRST RESULTS OF THE TRITEL SPACE DOSIMETRY TELESCOPE FROM THE MISSION ON BOARD THE BEXUS-12 STRATOSPHERIC BALLOON. B. Zábori[1,2], A. Hirn[1], I. Apáthy[1], L. Bodnár[3], A. Csőke[1], S. Deme[1], T. Pázmándi[1], and P. Szántó[1], [1]Centre for Energy Research, Hungarian Academy of Sciences (P.O. Box 49, H-1525, Budapest, Hungary, balazs.zabori@energia.mta.hu), [2]Budapest University of Technology and Economics (Műegyetem rkp. 3., H-1111 Budapest, Hungary), [3]BL-Electronics Ltd. (Sport u. 5., H-2083 Solymar, Hungary).

Introduction: Due to significant spatial and temporal changes in the cosmic radiation field, radiation measurements with advanced dosimetric instruments on board spacecrafts, aircrafts and balloons are very important. Development of a 3D silicon detector telescope, called TriTel, began in the Hungarian Academy of Sciences KFKI Atomic Energy Research Institute in the last decade in order to determine the average quality factor of the cosmic radiation. The instrument is capable of providing the LET spectrum of heavy charged particles (protons, alpha particles and heavier ions) and the evaluation software converts the LET spectrum to an average quality factor. The final output of the system – including the necessary ground evaluation as well – is the dose equivalent characterizing the stochastic biological effectiveness of the cosmic radiation. [1]

From January 1, 2012, the Hungarian Academy of Sciences Isotope Research Institute is embedded into the Hungarian Academy of Sciences KFKI Atomic Energy Research Institute which continues its activity under the name "Centre for Energy Research, Hungarian Academy of Sciences". The Centre is the legal successor of both institutes of the Hungarian Academy of Sciences with all the respective obligations.

The CoCoRAD experiment: The Hungarian CoCoRAD Team was selected to take part in the BEXUS (Balloon Experiment for University Students) 12&13 project of the European Space Agency. In the frame of the BEXUS programme Hungarian students from the Budapest University of Technology and Economics carried out a radiation and dosimetric experiment on board a research balloon launched from Northern Sweden in September 2011.

The results presented: The present paper gives a brief description of the TriTel system already flown on board the BEXUS-12 balloon and presents the most important results of the CoCoRAD experiment. An outlook to future's experiment with TriTel in different space missions is also given.



Acknowledgement: The BEXUS CoCoRAD experiment was funded by the PECS contract No. 4000103810/11/NL/KML.

References: [1] Pázmándi T., Deme S., and Láng E. (2006) *Rad Prot Dosim, 120,* 401-404.

ISS Radiation Measurements 2008-2011

Andrew Welton[1,2], Ramona Gaza[1,2], Audrey Dunegan[1,2], Janet Barzilla[1,2], Dan Fry[2], Kerry Lee[2], Eddie Semones[2]

This presentation evaluates passive radiation dosimetry measurements made on the International Space Station (ISS) during expeditions 18-28, spanning from 2008 to 2011. This evaluation is based on comparing the daily dose values received by TLD-100 flight samples with past ISS dosimetry data, and noting any significant deviations from historical trends. Also included is new data for ISS locations within Node 2, JAXA JLP, and Cupola. Dosimetry data from multiple missions at these locations will provide new insight for historical trending that was not previously available.

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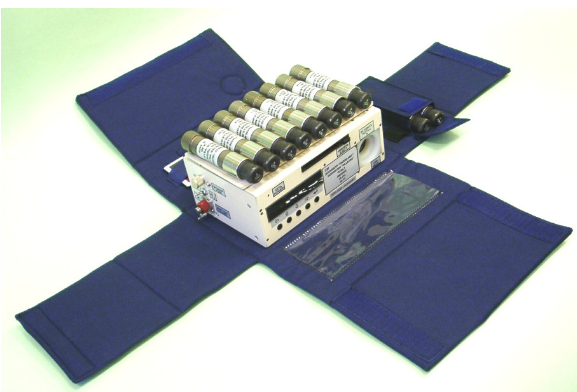
DOSE MEASUREMENTS ON BOARD THE ISS WITH THE PILLE TLD SYSTEM. P. Szántó[1], I. Apáthy[1], Yu. A. Akatov[2], V. V. Arkhangelsky[2], I. Nikolaev[3], S. Deme[1], A. Hirn[1] and T. Pázmándi[1], [1]Centre for Energy Research, Hungarian Academy of Sciences (P.O. Box 49, H-1525, Budapest, Hungary, peter.szanto@energia.mta.hu), [2]Institute for Biomedical Problems (IBMP), State Research Center of the Russian Federation (Khoroshevskoye Shosse 76 A, Moscow 123007, Russia), [3]S.P. Korolev Rocket and Space Corporation «Energia» (4A Lenin Street, Korolev, Moscow area 141070, Russia)

Introduction: The Pille system [1] was developed by the KFKI Atomic Energy Research Institute as the first and to date the only TLD system containing an on-board reader designed specifically for use by cosmonauts and astronauts while traveling in space. From January 1, 2012, the Hungarian Academy of Sciences Isotope Research Institute is embedded into the Hungarian Academy of Sciences KFKI Atomic Energy Research Institute which continues its activity under the name "Centre for Energy Research, Hungarian Academy of Sciences". The Centre is the legal successor of both institutes of the Hungarian Academy of Sciences with all the respective obligations.

History: 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 [2]. In the past nine years the dosimeter system was utilized for routine dose measurements inside the ISS, and as personal dosimeter system during Extra-vehicular Activities (EVAs).



With the system consisting of a lightweight reader device and a number of TL dosimeters, more than 30 000 read-outs were carried out until now. The Pille system provides monthly dose data from locations of the space station including Matroshka while two dosimeters are dedicated to EVA measurements, and one is read out in every 90 minutes automatically to provide high time resolution data.

Results to be presented: In the present paper the measurement data (including several EVA measurements) from the latest expeditions (Expeditions 27-28 and 29-30, April 2011 – April 2012) obtained by the Pille system is presented. The results are compared with previous measurement results.

References: [1] Fehér I., Deme S., Szabó B., Vágvölgyi J., Szabó P. P., Csőke A., Ránky M., and Akatov Yu. A. (1981) *Adv. Space Res., 1,* 61-66. [2] Apáthy I., Akatov Yu. A., Arkhangelsky V. V., Bodnár L., Deme S., Fehér I., Kaleri A., Padalka I., Pázmándi T., Reitz G., Sharipov S. (2007) *Acta Astronaut 60,* 322-328.

RADIATION DOSIMETRY IN THE EUROPEAN COLUMBUS MODULE

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Introduction: Inside the European Columbus module two sets of radiation detectors are currently deployed, with a third one expected to be added soon. All detectors are part of research dosimetry; no permanent operational dosimetry is foreseen by ESA to cover the entire operational phase of Columbus. The first set of detectors supports the DOSIS-3D experiment, the second one ALTEA-SHIELD, the third TRITEL (see Table). This report in focussed on the scientific objectives of the three experiments and how these objectives are expected to be reached. This report does not include recorded data or scientific results.

Experiments: The three experiments are named DOSIS-3D (Dose Distribution inside the International Space Station - 3D), lead investigator Thomas Berger, ALTEA-SHIELD (Anomalous Long-Term Effects in Astronauts: Radiation Shielding), lead investigator Livio Narici, and TRITEL (New complex method for determining the equivalent dose of astronauts), lead investigator Attila Hirn.

Scientific Objectives: DOSIS-3D deals with area dosimetry and is intended to identify and quantify radiation gradients across the Columbus module. The results will be compared and combined with similar measurements in other modules of the ISS. ALTEA-SHIELD measures and compares the protective characteristics of two different shielding materials. TRITEL features a novel detector assembly destined to scan the radiation environment in all directions (4π, the solid angle of a complete sphere).

Hardware location in Columbus: DOSIS-3D consists of eleven passive detector packages, strategically distributed over the cylindrical Columbus module, accompanied by a twin set of active DOSTEL detectors on the Utility Interface Panel of the EPM rack. ALTEA-SHIELD is furnished with a trio of active detectors, all pointing in the same direction, accommodated inside the locker of Express Rack 3. Two detectors are fitted with shielding tiles, the third one is for reference. TRITEL, equipped with a three-piece array of active detectors plus one passive package, will be placed next to the DOSTELs of DOSIS-3D.

Timing: The radiation detectors of DOSIS-3D, ALTEA-SHIELD and TRITEL are deployed according to the individual time requirements of the three experiments. DOSIS-3D is expected to remain in action during several succesive six-month increments, with the passive detectors being renewed during each increment. ALTEA-SHIELD is planned to complete two recording periods of 40-60 days each. TRITEL will be active during one six-month run.

ESA and industry: ESA provides the flight opportunity including upload, download and flight operations. The flight hardware is developed, manufactured and financed at national level by Germany, Italy and Hungary.

	Lead scientist	*Proposal*	*Active dectors*	*Passive detectors*
DOSIS-3D	Thomas Berger (DE)	ILSRA 2009 - 0778	yes (2x)	yes (10 + 1 packages)
ALTEA-SHIELD	Livio Narici (IT)	AO-2004 PCP-110	yes (3x)	no
TRITEL	Attila Hirn (HU)	SURE-AO-2006-018	yes (3x)	yes (1 package)

THE DOSIS AND DOSIS 3D EXPERIMENTS ONBOARD THE INTERNATIONAL SPACE STATION – RESULTS FROM THE ACTIVE DOSTEL INSTRUMENTS. Soenke Burmeister[1], Johannes Labrenz[1], Rudolf Beaujean[1], Onno Kortmann[2], Thomas Berger[3], Matthias Boehme[4], Lutz Haumann[4] and Guenther Reitz[3], [1] Institute for Experimental and Applied Physics, Kiel University, Kiel, Germany, [2] Space Science Lab, University of California, Berkeley, CA, USA, [3] German Aerospace Center, DLR, Institute of Aerospace Medicine, Cologne, Germany, [4] OHB System AG, Bremen, Germany.

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

For the investigation of the spatial and temporal distribution of the radiation field inside the European COLUMBUS module the experiment DOSIS (Dose Distribution Inside the ISS) under the lead of DLR was launched on July 15th 2009 with STS-127 to the ISS. The experimental package was transferred from the Space Shuttle into COLUMBUS on July 18th. It consists of a combination of passive detector packages (PDP) distributed at 11 locations inside the European Columbus Laboratory and two active radiation detectors (DOSTELs) with a DDPU (DOSTEL Data and Power Unit) in a Nomex pouch (DOSIS MAIN BOX) mounted at a fixed location beneath the European Physiology Module rack (EPM) inside COLUMBUS. The DOSTELs measured during the deepest solar minimum conditions in the space age from July 18th 2009 to June 16th 2011. In July 2011 the active hardware was transferred to ground for refurbishment and preparation for the DOSIS-3D experiment. The hardware has been relaunched with the Soyuz 30S flight to the ISS on May 15th 2012 and then been activated on May 21st.

Data is transferred from the DOSTEL units to ground via the EPM rack which is activated approximately every four weeks for this action. First Results for the active DOSIS-3D measurements such as count rate profiles, dose rates and LET spectra will be presented in comparison to the data of the DOSIS experiment as well as the DOSMAP experiment which has been performed during solar maximum in 2001.

RADIATION SURVEY IN USLAB AND FIRST MEASUREMENTS IN COLUMBUS WITH THE ALTEA DETECTOR. L. Di Fino, M. Larosa, P. Picozza, V. Zaconte and L. Narici. Department of Physics, Unversity of Rome Tor Vergata and INFN-Roma Tor Vergata, viale della Ricerca Scientifica 1, Rome, Italy

Introduction: Mitigation of the risks due to radiation exposure is one of the most important issues for the future long space voyages for human exploration. The ongoing studies aimed at the detailed understanding of the radiation effects on humans are showing a panorama of risks strongly dependent on the specific characteristics of the radiation. For example high Linear Energy Transfer (LET) charged radiation have been shown to produce cellular/molecular damages leading to a higher risk determination than the same dose of low LET radiation [1]. The knowledge of the radiation environment where the astronauts are going to spend their time is therefore of high importance. It is conceivable that most of this radiation information will be provided by detailed simulation and modeling. The needed ingredients for a successful radiation modeling are the radiation sources (outside the spacecraft) the transport algorithms (to describe the interaction of the radiation with the intervening materials) and the distribution in quality and dimension of such materials (the spacecraft hull and all the operational/experimental racks and items inside). The ISS is a quite important test platform for these issues. Radiation measurements in the ISS can in fact be used to test both the correctness of the ISS models and to study the effects on radiation risk assessments of the likely limited knowledge of the total shielding distribution. Detailed radiation measurements in the ISS are therefore of paramount importance for several reasons. Firstly to provide the needed data for a correct risk assessment. Secondly to give essential information to develop proper radiation countermeasures. Thirdly for tests of ISS simulations and models.

In this paper we present data acquired with the ALTEA particle detector in the ISS, launched in the ISS-USLab in 2006 and still operating (now in Columbus).

The ALTEA detector: The ALTEA detector is a system of six silicon particle telescopes [2]. Each one (Silicon Detector Unit or SDU) is composed by six planes each including 2 silicon wafer (each 8 x 8 cm^2, 380 μm thick) side by side, striped either along the short side of the plane or along the long side (X and Y directions). Two X and Y planes are close to each other and each SDU is therefore composed by three couples of XY planes, and it is able to reconstruct the trajectory of each impinging ion. Under certain circumstances the charge and the kinetic energy of the impinging ion can be calculated. In sum the ALTEA system can measure in 3D the radiation environment and perform nuclear identification. In the current configuration the detector is able to measure LET (in silicon) from 3 to 800 keV/μm. [3-6]. ALTEA is therefore able to measure most of the characteristics of the radiation (*radiation quality*) needed to perform risk assessment.

Results: The data presented here come from several experiment (ASI, ESA or NASA sponsored) and are relative to the last four years of ALTEA meausurements, from 2009 to 2012 (see table). The combination of these data gives a good assessment of the radiation environment in the USlab (5 sites, 4 years), discriminating ions and directions of the radiation [5], in the different geographical zones (and therefore different geomagnetic cutoffs). Recently ALTEA has been moved in Columbus where it is performing a set of measurements of the effects of different shielding materials. Preliminary results in Columbus will also be shown.

year	*location*	*ALTEA experiment*
2009	Lab1P1	DOSI (ASI-NASA)
2010	Lab1O2	DOSI (ASI-NASA)
2010	Lab1S1	shield/survey pos 1 (ESA)
2010	Lab1O2	shield/survey pos 2 (ESA)
2011	Lab1P4	shield/survey pos 3 (ESA)
2011	Lab1S6	shield/survey pos 4 (ESA)
2012	Lab1S6	shield/survey pos 4 (ESA)
2012	Columbus	shield/shield (ESA)

Table 1 summary of the ISS (USLab and Columbus) measurements

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[4] Di Fino L., Zaconte V., Ciccotelli A., Larosa M. and Narici L. (2012) Adv. Space Res. 50:408-414.

[5] Di Fino L., Casolino M., De Santis C., Larosa M., La Tessa C., Narici L., Picozza P., Zaconte V. (2011). Radiat. Res.. http://dx.doi.org/10.1667/RR2179.1

[6] Narici L., Casolino M., Di Fino L., Larosa M., Larsson O., Picozza P., Zaconte V. Radiation Measurements (2012), http://dx.doi.org/10.1016/j.radmeas.2012.07.006

On-Orbit Status of the Intravehicular Tissue Equivalent Proportional Counter (IV–TEPC) for ISS. J. Flores-McLaughlin[1], E. Semones[3], A. S. Johnson[2], R. Gaza[2] and D. Fry[3], [1]University of Houston – Downtown, [2] Lockheed Martin Corporation[3] NASA Johnson Space Center

Introduction:

The first manifested ISS IV–TEPC detector apparatus (Figure 1) was launched to ISS on March 23, 2012 onboard the ATV3 ISS resupply flight. The detector apparatus is composed of two spherical A150 plastic proportional counters of 5mm (large) and 3mm (small) wall thickness respectively. Each is filled with propane gas simulating a tissue equivalent volume of two micrometers.

Figure 1. ISS IV–TEPC Flight Unit 1

The detector apparatus has subsequently been unpackaged and placed in operation. Microdosimetric comparisons between IV–TEPC detectors and the previous ISS TEPC instrument, a cylindrical counter geometry are indicative of strong dependence of locational and built-in shielding on dosimetric results.

Initial Results:

Initial placement of IVTEPC was close to the ISS TEPC device allowing for comparative measurement of dose (Figure 2).

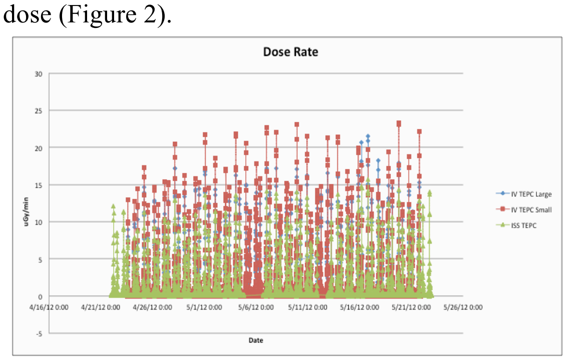

Figure 2. Dose Rates for ISS TEPC and IV-TEPC within the ISS Service Module

Initial IV–TEPC dose rate measurements within the ISS Service Module (SM) are roughly 15% and 7.5% greater than ISS TEPC dose rates for the small and large detectors respectively. These variations were mostly attributed to trapped radiations within the South Atlantic Anomaly (SAA), composed primarily of relatively low energy protons.

Microdosimetric Spectra:

Initial microdosimetric spectra (Figure 2 and 3) for IV–TEPC are indicative of a large y*d(y) discrepancy for trapped radiation within the SAA. However, microdosimetric spectra attributed to Galactic Cosmic Radiation (GCR) has indicated relative minimal discrepancy. This is most likely due to the relatively energetic GCR spectra as opposed to differences in detector wall thickness, which would have minimal influence.

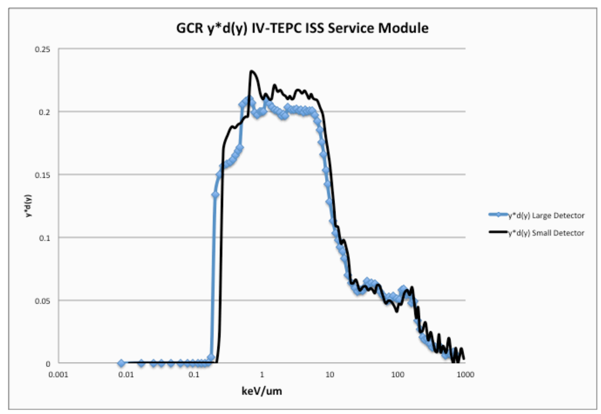

Figure 2. Microdosimetric Spectra Attributed from GCR

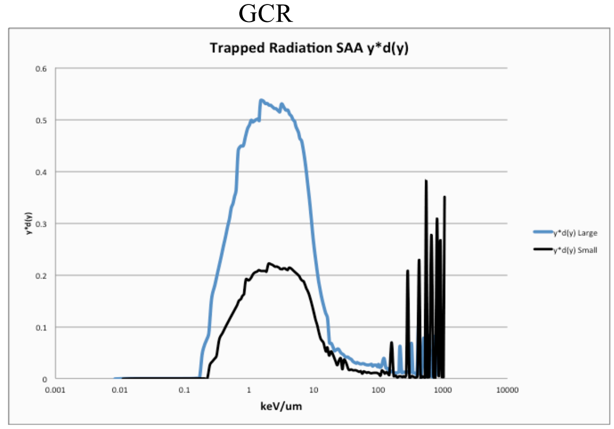

Figure 3. Microdosimetric Spectra Attributed to Trapped protons in the South Atlantic Anomaly

Further Observations and Work:

Subsequent relocations and different orientations of IV–TEPC resulted in changes of dose rate and microdosimetric spectra. In some orientations, overall dose rate in the large detector was larger than in the small detector. It is hypothesized that ISS and IV-TEPC self-shielding have primary influence on these discrepancies. Analysis utilizing ISS and IV-TEPC shielding structure will be utilized in the future to help explain these discrepancies.

Preliminary Results of Water Shielding Effect for Space Radiation in ISS Crew Cabin by means of Passive Dosimeters. S. Kodaira[1], R. V. Tolochek[2], I. Ambrozova[3], H. Kawashima[1], N. Yasuda[1], M. Kurano[1], H. Kitamura[1], Y. Uchihori[1], I. Kobayashi[4], A. Suzuki[4], I.S. Kartsev[2], E.N. Yarmanova[2], I.V. Nikolaev[5], and V. A. Shurshakov[2], [1]Radiation Measurement Research Section, National Institute of Radiological Sciences, Chiba, Japan, [2]State Scientific Center of Russian Federation, Institute of Biomedical Problems, Russian Academy of Science, Moscow, Russia, [3]Nuclear Physics Institute, Academy of Sciences of Czech Republic, Prague, Czech Republic, [4]Nagase Landauer Ltd., Ibaraki, Japan, [5]Rocket Space Corporation, Energia, Moscow region, Russia

Introduction: Measurements of absorbed dose during manned space missions such as International Space Station (ISS) at low earth orbit (LEO) are important for evaluating radiation risk of astronauts in complicated space radiation environment, in which a lot kind of charged particles with various energy and composition are filled. The linear energy transfer (LET) with such particles is widely ranging from ~ 0.1 to 1000 keV/μm. The precise measurements of LET with extremely wide range are required to validly evaluate the personal dose for the protection from space radiations [1].

ISS crew is constantly exposed to space radiation of daily dose of 0.5 ~ 1 mSv. The effective dose limits (10 yr career) for Astronauts are recommended to be 400 mSv (female) and 700 mSv (male) for 25 yrs old [2]. At the current status, the radiation protection on ISS is depending on the shielding effect with vehicle wall and instrument. However, a possible "active" radiation protection should be verified for not only reduction of integrated dose but also coming long-term missions at Lunar and Mars. In this study, we verified the dose reduction rate for space radiation by the additional installation of water shielding (the hygienic wipes and towels containing water) in ISS crew cabin.

Experiment: The dose reduction rate for space radiation by the additional installation of water shielding was measured with the passive dosimeter packages consisting of thermoluminescence detector (TLDs) and CR-39 plastic nuclear track detectors (PNTD). The water shielding was stored into the protective curtain at 4 layers, which is corresponding to the additional shielding thickness of about 8 g/cm^2. The total mass of the protective curtain was to be 65 kg. That was installed along the outer wall of the starboard crew cabin in Russian Service Module. The dose reduction effect by water shielding was experimentally measured with the totally 12 passive dosimeter packages. Half of packages were located on the protective curtain surface and the other half packages were located on the crew cabin wall behind or aside the protective curtain. Two experiments for different duration were carried out onboard ISS crew cabin, Session#1: from June 16 to November 26, 2010 (163 days) and Session#2: from December 15, 2010 to May 24, 2011 (160 days).

Results: The mean absorbed dose rate and dose equivalent rate are 224 μGy/day and 575 μSv/day for the shielded side and 327 μGy/day and 821 μSv/day for the unshielded side during Session#1. The observed dose reduction rate by the additional water shielding material through two durations was found to be ranging from 15 to 44 % in dose equivalent depending on the material thickness. The observed data was compared with the calculation by PHITS code [3]. The calculated reduction rate of ~36% for 8 g/cm^2 water shielding is roughly consistent with the observation.

Summary: The dose reduction rate for space radiation by the additional installation of water shielding in ISS crew cabin was measured with the passive dosimeter packages consisting of TLD and CR-39 during two different durations (Session#1 and #2). The observed dose reduction of 15 ~ 44 % in dose equivalent was roughly consistent with the calculation. The properly utilization of protective curtain will effectively reduce the radiation dose for crew living in space station and more long-term mission in the future.

We will have more two different sessions, Session#3 (Dec., 2011~ May, 2012) detectors and Session#4 (June, 2012~, now onboard ISS). The dose variation and dose reduction effect will be summarized though totally four Sessions (#1~#4). We will compare with precise simulation based on the experimental condition and set-up.

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MATROSHKA – Results from the exposure inside the Japanese KIBO Module – and comparison with previous missions.

Thomas Berger[1], Michael Hajek[2], Pawel Bilski[3], Tomasz Horwacik[3], Monika Puchalska[3], Christine Koerner[1], Eduardo Yukihara[4], Eric Benton[4], Ramona Gaza[5], József K. Pálfalvi[6], Julianna Szabó[6], Luke Hager[7], Nakahiro Yasuda[8], Yukio Uchihori[8], Hisashi Kitamura[8], Satoshi Kodaira[8], Aiko Nagamatsu[9], Vyacheslav A. Shurshakov[10], Sönke Burmeister[11], Lembit Sihver[12], Vladislav M. Petrov[10], Guenther Reitz[1]

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The radiation environment encountered in space differs not only in nature but also in its high biological effectiveness from that on Earth, resulting in radiation levels far exceeding the ones encountered on Earth for occupational radiation workers. For Low Earth Orbit (LEO) missions the current career dose limits for astronauts, recommended by the National Council on Radiation Protection and Measurements (NCRP), are based on a three percent excess lifetime risk of fatal cancer. These limits may easily be approached or even exceeded for long duration human space travels – e.g. a human mission to Mars. From a radiation protection point of view the baseline quantity for radiation risk assessment is the effective dose E. For space applications the effective dose can be determined by using radiation transport codes with anatomical human models or by applying tissue-equivalent phantoms with dedicated radiation detectors within certain radiosensitive organs. One phantom approach is the ESA facility MATROSHKA (MTR), under the scientific and project lead of DLR. It is dedicated to determine the radiation load on astronauts inside and outside the International Space Station (ISS), and was launched in January 2004. MTR, which mimics a human head and torso, is an anthropomorphic phantom containing over 6000 passive and seven active radiation detectors to determine the depth dose and organ dose distribution in the body. In its 1st exposure phase (MTR 1: 2004 – 2005) MTR measured the depth dose distribution of an astronaut performing an EVA – mounted outside the Zvezda Module. In its 2nd and 3rd exposure phase (MTR 2A: 2006 and MTR 2B: 2007 - 2009) the phantom was positioned inside the Russian part of the ISS to monitor the radiation environment and measure the depth dose distribution in dependence on the inside shielding configurations. In the year 2010 the MTR facility moved to the Japanese KIBO module (see Fig.1) to start the 4th exposure (MTR 2 KIBO: 2010 - 2011). The presentation will focus on the latest results gathered within the MTR 2 KIBO experiment and on the comparison with the previous mission accomplished in the Russian part of the ISS.

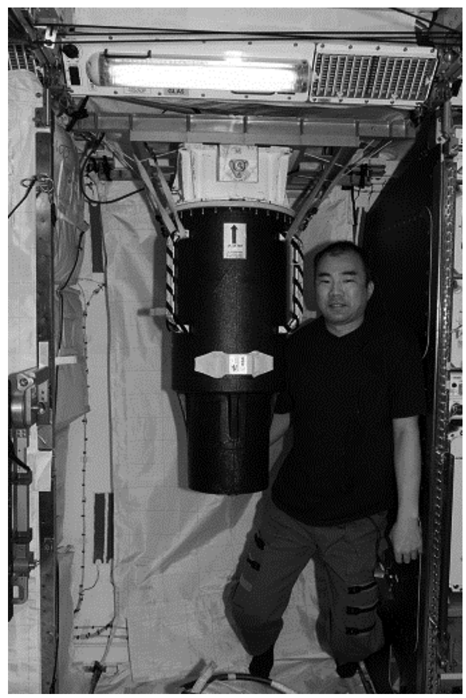

Fig. 1 Astronaut Noguchi with MATROSHKA in the KIBO module

Acknowledgements:

The MATROSHKA 2 KIBO space experiment was conducted under 'ESA/ROSCOSMOS and JAXA Payload Integration Agreement (PIA) For MATROSHKA' approved on 19 Aug. 2009 and revised on 2 Sep. 2010, as part of Kibo utilization framework.

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GCR Anisotropy Effects on Dose Measurements with MTR/DOSTEL.

J. Labrenz[1], T. Berger[2],S. Burmeister[1], G. Reitz[2]
[1]Christian Albrechts Universität zu Kiel, (CAU), Kiel, Germany; [2]German Aerospace Center, (DLR), Cologne, Germany.

MATROSHKA (MTR) is an ESA experiment for the determination of radiation exposure to humans in space under science and project lead of DLR-Cologne. The exposure of a human phantom (fig. 1) is determined with active and passive detectors. One of the instruments is the active DOSimetry TELescope (DOSTEL), developed by CAU Kiel together with DLR Cologne. The instrument is installed on the head of the phantom.

DOSTEL consists of two silicon detectors (Canberra PIPS) in telescope geometry. The detectors have a diameter of 2.97 cm and form a telescope with an opening angle of 120°. The DOSTEL measures energy loss spectra with (telescope mode) and without (single mode) coincidence condition.

In this work the differences of count rates as well as absorbed dose and dose equivalent rates for the GCR component, measured in telescope and single mode, during the first exposure phase (MTR 1, outside ISS) will be presented and analyzed.

It turned out, that geometric factors calculated for an isotropic radiation field [1] can not explain the differences in count and dose rates between telescope and single mode.

To investigate the discrepancies, a geometric Monte Carlo simulation was used to calculate count rate and mean path length differences between telescope and single mode for different angular distribution.

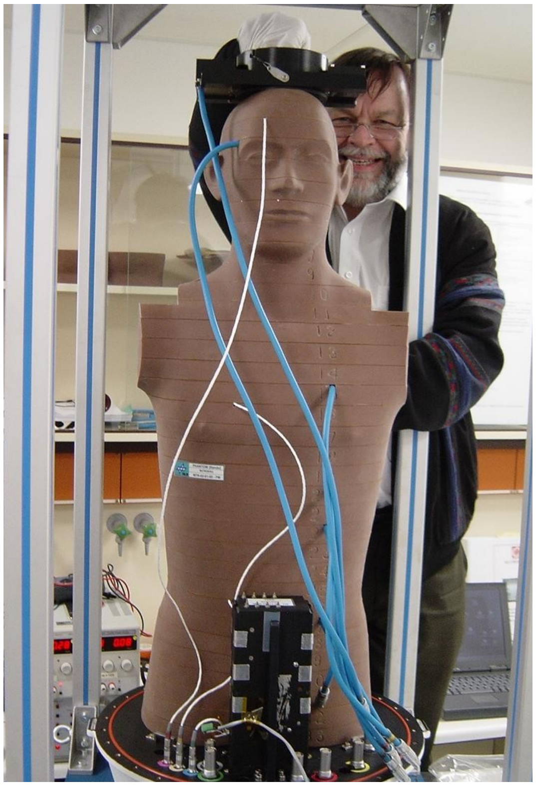

Figure 1: MATROSHKA-Phantom with DOSTEL above the Head, in the background Dr. Reitz (PI of MATROSHKA)

References:

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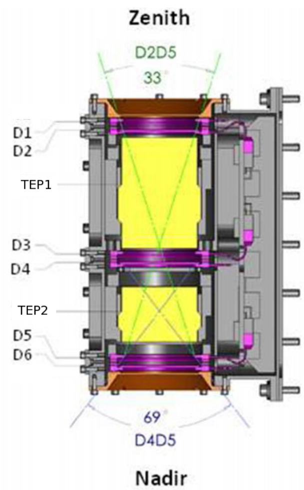
The first Medipix-based technology radiation measuring devices are scheduled for launch to the ISS on July 31. Assuming that this occurs as scheduled and that the devices are deployed in a reasonably timely manner, we should be able to report the initial preliminary results from at least one of the five units being sent up. This initial test will serve to provide inputs for modifications in future iterations of the technology and its supporting software. The current devices are similar in appearance to USB "memory sticks," and will be deployed via the USB ports on selected ISS laptops. The laptops will run the software to control and readout the devices as well as to provide power. Future plans for these devices include employing them to assess the radiation environment inside the inflatable Bigelow module to be deployed from the ISS. Additional Medipix-based devices are being designed to fly on the EFT-1 mission to evaluate the radiation environment inside the Orion module during that mission, as well as low power versions as prototypes of potential battery-powered, wireless, personal active dosimeters for general dosimetric uses.

CRaTER Measurements of GCR and Shielding Effects. C. Zeitlin[1], A. Case[2], N. Schwadron[3], H. Spence[3], J. Wilson[3], J. Kasper[2]. [1]Southwest Research Institute, 1050 Walnut St., Boulder, CO 80302, [2]Harvard Smithsonian Astrophysical Observatory, Cambridge, MA, [3]University of New Hampshire, Durham, NH

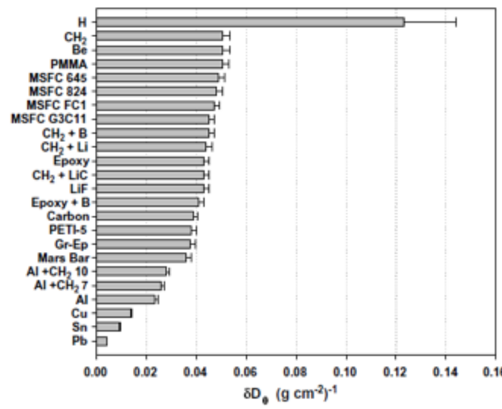
Introduction: The CRaTER instrument [1] on the Lunar Reconnaissance Orbiter spacecraft (LRO) has been collecting GCR and SPE data in lunar orbit since 2009. The design of CRaTER is novel: it consists of three pairs of silicon detector, with cylinders made of Tissue-Equivalent Plastic (TEP) in between detector pairs, as shown in the figure below. Each detector pair



consists of a thin detector (148 μm) used to measure high-LET particles, and a thick detector (1000 μm) used to measure low-LET particles. In LRO's nominal orientation, one end of CRaTER points skyward (zenith) and the other end points towards the lunar surface (nadir). Relatively few charged particles are backscattered by the lunar surface, so coincidence events (defined as those in which two or more thick detectors register a hit significantly above noise) are dominated by energetic particles coming from the zenith direction.

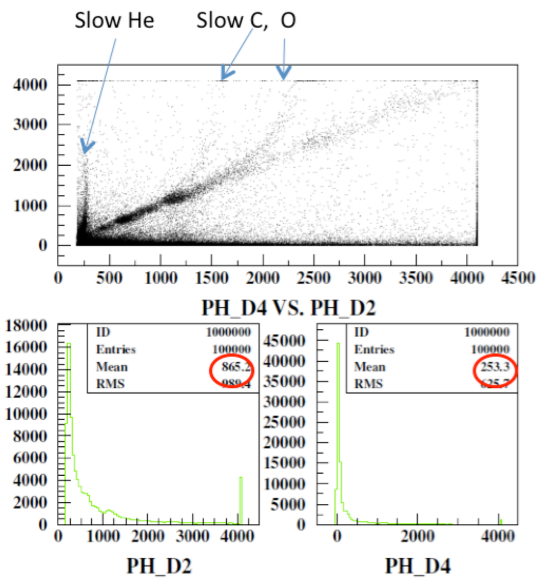
Shielding Effect of TEP: There is no universally-accepted definition of shielding effectiveness. In beams tests of candidate materials for spacecraft construction, we devised a metric based on dose, rather than dose equivalent as suggested by Wilson et al [2]. We define it as $\delta D_n = (1 - \langle LET\rangle_{after}/\langle LET\rangle_{before})/\rho x$ where "after" and "before" refer to a target of areal density ρx. In principle, LET refers to energy loss in water. But as a practical matter, the average LET values can refer to either energy deposited in water, or in silicon – any conversion constant used drops out of the ratio.

δD_n is a purely physical quantity and does not depend on quality factors that are subject to revision. For a given beam ion, beam energy, and shield material, the ground-based data show that δD_n as a function of depth x falls exponentially, presumably as a result of attenuation (by fragmentation) of the primary beam ions. That is, we can express the relation as $\delta D_n(x) = \delta D_0 \exp(-bx)$ where b depends on the target material and δD_0 should be interpreted as the shielding effectiveness of the first infinitesimal slice of the target. This allows us to put all the beam measurements with different materials on an equal footing. Results [3] are shown in the second figure. We can use this same method with CRaTER data to measure the shielding effectiveness of TEP against the Galactic Cosmic Rays.



There are a few important points to note in the δD_0 results shown above. First, the hydrogen data were obtained using carbon and polyethylene targets. This method yields a relatively large error bar. Second, of all the materials directly tested, polyethylene gave the largest value of δD_0, about 0.05 $(g\ cm^{-2})^{-1}$. Because H is the most effective shielding element, and TEP has a somewhat lower H content than polyethylene, we expect to find a smaller value of δD_0 for TEP. Third, in other studies [4, 5], we found that δD_0 is only weakly dependent on ion species and energy for ions having charge of 8 and above, and energy of 1 GeV/nuc and above. That is – at least for CH_2 targets – any high-charge, high-energy beam gives approximately the same value of δD_0.

Complexities of CRaTER Data: Analysis of the CRaTER flight data is much more complex than the analysis of ground-based data. The main complication arises from the definition of the view cones formed by different detector coincidences. For instance, a naïve approach to understanding the shielding effect of TEP1 would be to select a sample of events in the D1/D2 detector pair, get the average energy deposit in that pair, and find the average energy deposit in the D3/D4 pair. That approach fails because a large majority of the particles that hit D1 and D2 are outside the viewing cone defined by D3 and D4; there will therefore be many events with no energy in D3/D4, yielding a very large (but incorrect) value of δD_n. A slightly more sophisticated approach requires non-zero energy deposition in the D3/D4 pair, but this also fails because energetic ions that traverse TEP1 but are outside the D1-D4 viewing cone can produce energetic delta-rays and/or projectile fragments that deposit energy in D3/D4 that is sufficient to pass a selection cut. The result for δD_n is therefore influenced by out-of-cone events with small but non-zero LET in D3/D4. It also has inherent dependence on the value chosen for the selection cut.



The data shown in the above figure are for illustrative purposes only. The scatter plot at the top compares the pulse height (proportional to LET in silicon) in D4 to that in D2. (In the full analysis, D1 and D2 are combined to give a single value of LET in the first pair, and similarly for D3 and D4 for the second pair.) The histograms show the mean pulse heights before and after the TEP1 target; this would yield δD_n of 0.12 (g $cm^{-2})^{-1}$, about a factor of 3 larger than the value obtained at similar depths of CH_2 in heavy-ion beams. This is due to the excessive number of events in the D4 distribution with little or no energy deposited. All or nearly all of these events are due to out-of-cone particles that hit D2 but miss D4. This demonstrates the inadequacy of the simple, first-order analysis one might try to do with these data.

Resolution: A detailed study of the sensitivity of the result to the cut values in underway. An internal consistency check can be performed computing results with the additional requirement of significant energy deposition in the D5/D6 detector pair. Two additional inputs are used to resolve the conundrum: beam data taken with the flight spare unit, rotated at various angles with respect to the beam axis, and simulations with the BBFRAG transport model. As of this writing, all indications are that it is necessary to make a rather severe cut on the energy in the downstream detector pairs in order to obtain self-consistent results. This in turn affects the value of δD_0 one obtains, but that aspect can be modeled and the true value of δD_0 for TEP in the GCR can be estimated.

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MEDIPIX-BASED SPACE DOSIMETRY AT NASA: AN OVERVIEW OF CURRENT PROJECTS. A. A. Bahadori[1], N. N. Stoffle[2], M. Kroupa[2], J. Idarraga[2], S. M. Hoang[3], D. Turecek[4], Z. Vykydal[4], J. Jakubek[4], S. Pospisil[4], A. Empl[2], L. S. Pinsky[2], and E. J. Semones[5], [1]University of Houston-Downtown, Department of Natural Sciences, One Main Street, Houston, TX 77002, amir.a.bahadori@nasa.gov, [2]University of Houston, Department of Physics, 4800 Calhoun Boulevard, Houston, TX 77204, [3]University of Houston, Department of Computer Science, 501 Philip G. Hoffman Hall, Houston, TX 77204, [4]Institute of Experimental and Applied Physics, Czech Technical University in Prague, Horska 3a/22, Prague, 128 00, Czech Republic, [5]NASA Johnson Space Center, 2101 NASA Parkway, Houston, TX 77058

Introduction: The Medipix family of chips has undergone several changes from its first iteration in the 1990s [1]. Initially used for photon counting applications such as X-ray radiography, the Medipix chip is now also being used for high energy physics measurements, such as particle tracking [2]. Presently, its utilization is being extended to measurements of space radiation by NASA, among others [3]. Several projects involving the Medipix chip family are underway at NASA Johnson Space Center; these include an ISS technical demonstration, a flight hardware project for the first flight of the Orion crew capsule, and development for advanced area and personal dosimetry.

ISS Radiation Environment Monitor (REM): The ISS REM project was initiated for the purpose of demonstrating the ability to use a number of small, low-power, active radiation sensors to provide a real-time characterization of the radiation environment within a vehicle in space [4]. ISS REM consists of a Timepix chip coupled with a silicon sensor (collectively known as an assembly) and a USB interface for communication with ISS Station Support Computers (SCCs) [5]. A Pixelman-based software package is used for data transmission between the ISS REM and the associated SSC [4].

ISS REM hardware and software were subjected to a series of tests prior to final delivery. These tests were performed on-site at NASA Johnson Space Center and at off-site facilities, such as the Heavy-Ion Medical Accelerator in Chiba (HIMAC). Five ISS REM units were assembled in a kit and launched aboard Progress 48 on 1 August 2012. They are scheduled to be unpacked and deployed in five separate SSC locations sometime during the week of 20 August 2012. Once data arrives on the ground, it will be processed using cluster pattern recognition algorithms to return relevant dosimetric quantities [6]. ISS REM results will be presented as available.

Battery-operated Independent Radiation Detector (BIRD): The next-generation NASA spacecraft, Orion Multi-Purpose Crew Vehicle (MPCV), is being developed in cooperation with Lockheed Martin [7]. The first test flight of this capsule, Exploration Flight Test-1 (EFT-1), is scheduled for 2014. While the primary objective is to test the vehicle at high-speed reentry, the flight provides a unique opportunity to perform space radiation measurements in the Orion MPCV on an uncommon trajectory.

The BIRD is being developed through the Advanced Exploration Systems (AES) Radworks project. The primary objective of the BIRD is to demonstrate the ability to obtain data using a Timepix-based radiation detector with all phases of operation independent of data and power interfacing. BIRD will perform data acquisition in-flight and all analysis will be ground based. Challenges for the BIRD project include ensuring the maximum possible frame rate is sufficient to characterize the changes in the radiation environment along the EFT-1 trajectory, managing battery consumption, ensuring data integrity, accounting for potential temperature changes, and surviving launch and landing loads.

Hybrid Electronic Radiation Assesor (HERA): The HERA is also being developed through the AES Radworks project. While BIRD includes only data acquisition, HERA will perform acquisition and data analysis. The goal of HERA is to demonstrate an active radiation detector that is completely integrated into the vehicle, including power, communication, and potentially structure. On-board analysis will provide detailed information directly to the crew, eliminating the need for ground analysis. Timepix has been identified as appropriate for HERA, but the current design strategy is to remain flexible to potentially incorporate more advanced Medipix chips as they are developed. The intent of HERA is to provide the capability for active area dosimetry; the use of Timepix chips for active personal dosimetry is being investigated by Invocon in cooperation with NASA Johnson Space Center through the NASA Small Business Innovation Research program [8].

Conclusion: While the Medipix family of chips have been used for quite some time for Earth-based applications, the use of this technology for space radiation environment monitoring has only recently become a reality. Operational issues, both known and unknown, must be overcome before true active dosimetry can be achieved. However, we are confident that the current suite of projects involving Medipix-based hardware will solve these issues and contribute to the success of future space missions.

Acknowledgements: The authors gratefully acknowledge the Medipix Collaboration for providing access to the Medipix technology in the form of hardware, software, and outstanding technical and science support.

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Particle Charge and Velocity Discrimination using Silicon Timepix Detectors. N. N. Stoffle[1], L. S. Pinsky[1], M. Kroupa[1], J. Idarraga[1], S. M. Hoang[2], A. A. Bahadori[3], D. Turecek[4], A. Empl[5], and E. J. Semones[6], nicholas.stoffle@mail.uh.edu, [1]University of Houston, Department of Physics, 4800 Calhoun Boulevard, Houston, TX 77204, [2]University of Houston, Department of Computer Science, 501 Philip G. Hoffman Hall, Houston, TX 77204, [3]University of Houston-Downtown, Department of Natural Sciences, One Main Street, Houston, TX 77002, [4]Institute of Experimental and Applied Physics, Czech Technical University in Prauge, Horska 3a/22, Prague, 128 00, Czech Republic, [5]University of Arkansas at Little Rock, 2801 S. University Avenue, Little Rock, AR 72204 , [6]NASA Johnson Space Center, 2101 NASA Parkway, Houston, TX 77058

The Timepix Application Specific Integrated Circuit (ASIC) is a version of the hybrid pixel detector technology developed by the Medipix2 Collaboration [1]. Within the 256 by 256 pixel matrix, the electronics for each of the 55µm individual pixels are contained in the footprint of that pixel. The Timepix has a charge-sensitive pre-amp and an associated discriminator attached to a logic unit capable of being employed in one of several different modes. For the present work, the Time-Over-Threshold mode was used to allow measurement of deposited energy in the silicon detector layer. The general properties of a Timepix-based device with a Silicon sensor layer have been described in [2], [3], and [4].

Ionization along particle tracks in the Silicon detector produces free charge carriers in the depletion region of the detector. The charge carrier motion under the influence of an applied bias voltage results in clusters of charge collected at the Timepix-sensor interface. Initial results [5] indicate that there are sufficient signatures within these charge clusters to begin to separate individual particle tracks based on charge and velocity. Current progress on such particle identification will be presented with particular emphasis on the application of this technique to data from the ISS Radiation Environment Monitor project.

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ADVANCED DOSIMETRY DATA ANALYSIS USING TRACKING INFORMATION FROM PIXEL DETECTORS

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Introduction: Recent developments in the field of the microelectronics allow for creating more sophisticated and complex semiconductor pixel detectors. One of the exciting possibilities which these detectors present is their application for dosimetry [1]. Currently, a technical demonstration [2] project, the goal of which is to deploy a number of Medipix-based Radiation Environment Monitor (REM) devices [3],[4] on the ISS, is one of the first space radiation projects utilizing such state-of-the-art semiconductor detectors. With more than 65,000 pixels and the possibility to measure the energy in each pixel, REM can be thought of as an energy sensitive digital cloud chamber in the solid state. As with the cloud chamber, the particles interacting with the detector creates tracks which can be investigated (see Figure 1). The characteristics of the track differ depending on the type of the particle and its energy. In this contribution we will propose some advanced data analysis techniques which allow us to obtain additional information regarding the incident radiation and improve the dosimetry measurements.

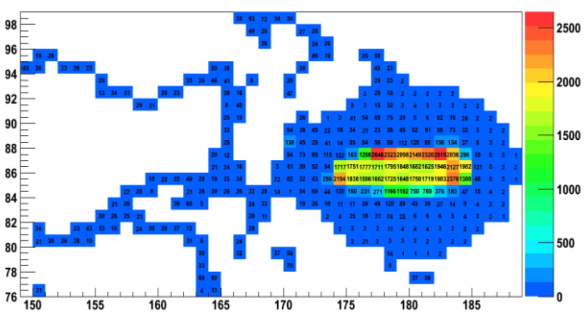

Figure 1 An example of the track of the 400 MeV/A Fe ion which entered detector at 60 degrees. The delta rays are clearly visible. The numbers in each pixel represents deposited energy.

Methods: The REM uses the Timepix detector for radiation measurement. When calibrated [5], the Timepix detector allows direct measurement of the energy deposition of the particle. Reconstruction algorithms then calculate the entry angle for each particle providing the LET. Our new proposed algorithms utilize shape and structure of the track. The evaluation consists of two parts – delta ray analysis and the track's core shape analysis. The delta rays are identified and classified. We evaluate the occurrence of the delta rays in the track as well as the delta rays path length and energy. The track's core characteristics, together with the results of the delta ray analysis, allow us to distinguish the type of the particle and estimate it velocity. These data are then used for equivalent dose calculation. All mentioned algorithms were carefully evaluated using the beam data from HIMAC accelerator and will be used to analyze the data from ISS REM.

Acknowledgement: We acknowledge Medipix Collaboration for the effort in developing new pixel detectors.

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Electronic Dosimeter for Space Applications based on MOSFET Technology

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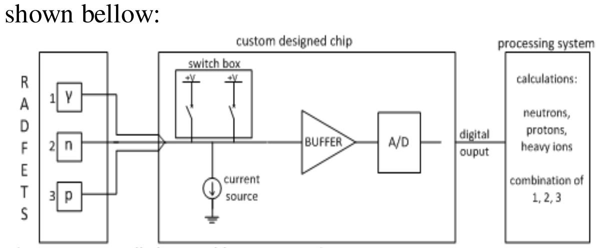
Introduction. MOSFET is a promising technology for its application in space dosimetry since they fulfill the main requirements for a real time dosemeter used in space missions (extra-vehicular as well as intra-vehicular crew exposure). Transistors MOS have been used as radiation dosemeters in space applications [1-2]. Their use was limited to the detection of protons and electrons [1-6], due to the fact that they are the primary particles of cosmic rays [3].

Instrumentation. The MOSFET used in the present study has been developed at LAAS (CNRS), Toulouse, France in corporation to Electronics Laboratory, School of Physics, AUTH, Greece [2]. Introducing an innovative technology with very thick SiO_2 insulator the sensitivity of the device has been enhanced so it is able to measure radiation doses from all types of radiation. The p-MOSFET transistors are developed following a process designed for improving both sensitivity to radiation dose and stability. A thin Cr layer will be deposited on the top of the gate. Due to the thickness of the Cr layer and the long range of the high energy charge particles, the device is additionally sensitive to electrons, alpha and heavy ions at energies spanning the range of importance during space missions. Moreover, applying the appropriate converters such as ^{6}Li and Cd(^{6}Li) or ^{7}Li and polyethylene the p-MOSFET are able to measure thermal and fast neutrons.

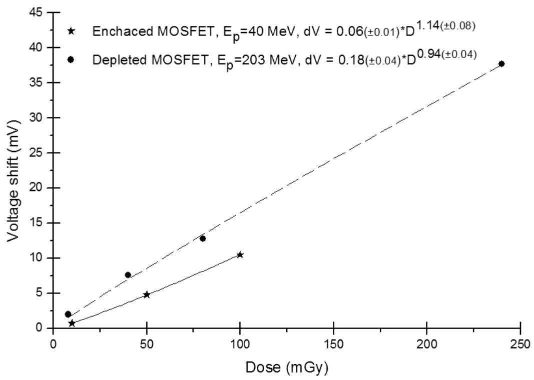
The p-MOSFET can operate biased (a voltage applied to its gate) as a real time dosemeter and unbiased as a passive dosemeter with high performance. Since the system is aimed to be used for space applications it requires being low weight, low volume and reliable and low power consumption. These requirements lead to integrate on a chip all the circuits needed, which can be integrated by ensuring adequate complexity, low power consumption and reliability A compact automated instrumentation configuration based on a microcontroller, a memory, A/D converters and a custom designed chip to implemented all other needed functions has been designed. The measurement system dedicated to collect data from the new p-MOSFET device has been manufactured and tested experimentally at the Electronics and Computer Laboratory of the University of Thessaloniki. The high sensitivity system is being able to measure the threshold voltage shift due to radiation dose with precision at the order of 100 μV. Regarding to ensure low power consumption, low weight and low volume of the measurement system, which is crucial for space applications, a number of circuits have been integrated in one chip. The chip has been fabricated with an appropriate technology offered by EUROPRACTICE organization (Electronics Lab. of AUTH is a member of the EUROPRACTICE). A block diagram of the complete dosimetry system is shown bellow:



(RADFETS = Radiation Sensitive MOSFETs)

Results. The electronic dosimeter has irradiated at neutron, photon and proton fields. Regarding the response to high-energy protons irradiations have been performed at HIMAC accelerator (Japan), through the frame of ICCHIBAN collaboration. The dosemeter have been operated in passive mode. Two types of p-MOSFET, the depleted and the enhanced one have been tested, during proton irradiations.

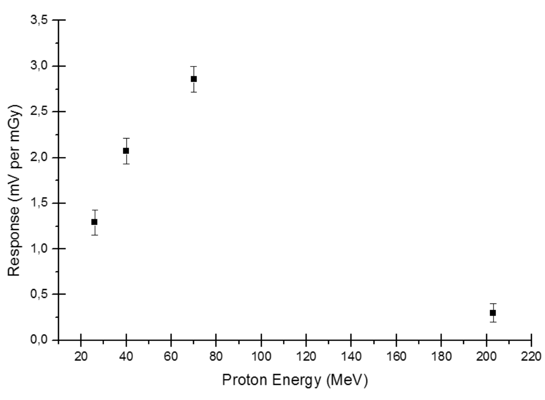
The response curve of the p-MOSFET dosemeters has an almost linear behavior without saturation up to 250 mGy. The response of the enchased sensors present a supralinear behavior while the depleted one a sub-linear. The response of depleted p-MOSFET even at high energy proton fields (E_p=203MeV), where lower energy is expected to be deposited in the sensor, is considerable higher than the enhanced one at low energy proton fields (E_p=40MeV).



During proton irradiations, an irradiation to alpha particles 2.2 keV/μm has been performed as a blind at 50 mGy. Using the response of 70 MeV protons (0.1 mV/mGy) the results of the p-MOSFET range at 47 mGy indicating that the same response could be applied to light particle like deuteron and alpha, as well.

Depleted p-MOSFETs with and without ^{6}LiF converters have been irradiated at proton field, as well. The response of the sensors with ^{6}LiF converter is always higher (1.5-3 times depending from the exposure dose) than the one without ^{6}LiF converter. This might be attributed to the contribution of any proton induced reactions in Li that increase the energy deposited in the sensor.

The response measured using a stack of two depleted p-MOSFET with ^{6}LiF converter to protons, as presented below, has a rapid increment up to ~100 MeV and then degreases significantly at proton energies > 200 MeV.



The response to protons at energy > 200MeV is comparable to the response measured for fast neutrons and photons [11]. The response to slow neutrons < 1 eV is ten times higher (57 mV/mGy) than fast neutrons [11] and considerable higher than the corresponding reported in literature up to now [7-10].

Irradiations to heavy ions have been performed to HIMAC using depleted p-MOSFET with ^{6}LiF converter in 290 MeV/n C and 500 MeV/n Fe fields. The response to 290 MeV/n C particles measured (0.13 mV/mGy) is lower than to 200 MeV protons. In the case 500 MeV/n Fe an almost same threshold voltage shift has been observed for all doses studied. This result is due to high recombination effect occurred in the silicon oxide in these cases.

Conclusion and Perspective. The depleted p-MOSFET sensor presents better response to charge particles than the enhanced one. A dosimeter based on a depleted sensor with ^{6}LiF converter is more sensitive to high energy protons up to 200 MeV. The sensitivity to protons is about two times higher than previously reported in literature [7].

The response to light charged particles like protons, deuterons and alphas with few decades of MeV energy is one order of magnitude higher than to fast neutrons, photons and protons >200 MeV. In case of heavy ions the response to 290 MeV/n C is lower than to light particles with the same energy. In case of 500 MeV/n Fe no results have been obtained due to high recombination effect occurred. The recombination effect can be reduced if a V_{bs} is applied to the source of the MOSFET. Using a real time dosimeter as the one presented above this demand can be realized.

The dosimeter has to be irradiated at high energy protons 100-200 MeV protons and low energy < 10 MeV. A better study on heavy ions response has to be organized including both irradiations and calculation with MCNPX and SRIM codes as well as the study of the influence of a voltage applied at the source of p-MOSFET. The response to high energy electrons is needed regarding to cover the primary spectrum of cosmic radiation.

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SCINTILLATION DETECTORS FOR SPACE RADIATION AND DOSIMETRY. J F. Christian[1], E. B. Johnson[1], C. M. Whitney[1], X. J. Chen[1], S. M. Vogel[1], E V. D. van Loef[1], R. Hawrami[1], J. Glodo[1], L. S. Pandian[1], K. S. Shah[1], T. H. Prettyman[2], and E. Benton[3], [1]Radiation Monitoring Devices, Inc; 44 Hunt Street; Watertown, MA 02472 (JChristian@RMDInc.com), [2]Planetary Sciences Institute; 1700 East Fort Lowell Rd., Suite 106; Tucson, AZ 85719 (prettyman@psi.edu), [3]Oklahoma State University, Radiation Physics Laboratory; 1110 S. Innovation Way, Stillwater, OK 74074 (eric.benton@okstate.edu).

Introduction: High-energy protons, galactic cosmic rays, and secondary particles, such as neutrons, contribute to the dose received by astronauts in space. Scintillation materials traditionally measure the energy deposited in the material, or absorbed dose, which is generally proportional the amount of light produced. New scintillation materials, e.g., CLYC and DPA, exhibit characteristics in the emission time that can be correlated to the type of radiation, e.g., electron (gamma-ray), proton, or neutron, as well as the linear energy transfer (LET) associated with the interaction. The radiation type and the LET are important for assessing the relative biological effectiveness (RBE) of the dose. The RBE is a well-defined and very specific quantity; therefore, it depends on many factors, such as the endpoint, cell death (deterministic) or cancer (stochastic), the type of cell, dose rate or fractionation (the dose delivery regime), the LET, the ionization density, and the radiation type.

Summary: The overall goal of our work is to develop a compact neutron dosimeter for use in space. In this effort, we characterize the response of the scintillation material with respect to its ability to identify the type of radiation and assess the LET on an event-by-event basis. In addition, we analyze the integrated scintillation response in terms of Birk's formula, which describes the LET dependence of the emission amplitude.

PROTOTYPE SPHERICAL TEPC DESIGN FOR DOSE MEASUREMENT IN ISS. J. J. Lee[1], J. H. Pyo[1], U. W. Nam[1], S. H. Kim[2], H. O. Kim[3], C. H. Lim[3] and K. J. Park[1]. [1]Korea Astronomy and Space Science Institute, [2]Cheongju University, [3]Korea Atomic Energy Research Institute.

The International Space Station (ISS) orbits the Earth within the inner radiation belt, where high-energy protons are produced by collisions of cosmic rays with the upper atmosphere. About 6 astronauts stay in the ISS for a long period, and it should be important to monitor and assess the radiation environment in the ISS. Tissue Equivalent Proportional Counter (TEPC) is an instrument to measure the impact of radiation on the human tissue. Korea Astronomy and Space science Institute (KASI) has developed a TEPC as a candidate payload of the ISS. In this presentation, we will briefly introduce of the prototype TEPC which was made of 2.7 mm thickness A150 plastic and filled by tissue equivalant gas in the sphere of 29.2 mm. Before manufacturing the TEPC, we performed simulations to test whether our conceptual design of the TEPC will work properly in the ISS and to predict its performance. We calculated high energy electron and proton spectra with AE/AP-8 model. The simulations was performed by GENT-4 and estimated that the TEPC will measure the dose equivalent of about 1.1 mSv a day in ISS, which is consistent with previous measurements.

Multifunctional Novel Boron-Carbon Fiber Polymer Composites for Mixed Radiation Field Space Applications . R. Wilkins[1,2], B. B. Gersey[1], K.K. Rangan[3], Norm Johnston[3,*], T.S. Sudarshan[3], R. Skoda[4], Y.-T. Choi[5] and Norman M. Wereley[5], [1]NASA Center for Radiation Engineering and Science for Space Exploration, P.O. Box 509 MS 1010, Prairie View, TX 77446, rtwilkins@pvamu.edu, buddyhme@hotmail.com, [2]Department of Electrical and Computer Engineering, Prairie View A&M University, P.O. Box 519 MS 2520, Prairie View, TX 77446, [3]Materials Modification Inc., 2809-K Merrilee Dr., Fairfax, VA 22031, kris@matmod.com, sudarshan@matmod.com,[4]Nuclear Science Center, Texas A&M University, College Station, TX 77843 rskoda@tamu.edu, [5]Department of Aerospace Engineering, University of Maryland, College Park, MD 20742. (*deceased)

Introduction: Radiation shielding on the International Space Station (ISS) is enhanced with hydrogen-rich high density polyethylene (HDPE) for the purpose of "as low as reasonably achievable" (ALARA) radiation exposure to astronauts [1]. The ISS structure also serves to shield electronic instrumentation against radiation effects and damage [2]. The long term mission profile of the ISS and its occupants requires continued study of the ISS radiation environment and consideration of radiation mitigation strategies.

It is widely accepted that long-term deep space missions, including planetary habitats, will require new multi-functional materials that have suitable structural, thermal, electrical, and radiation shielding properties [3]. Polymer composites reinforced with carbon fiber are candidate materials for these space applications [4]. The radiation shielding properties of these multi-functional material candidates would ideally combine the shielding properties similar to HDPE for solar and galactic cosmic rays (GCR) charged particle radiation and the structural properties of aluminum, the current common structural material for spacecraft. In addition, the power considerations for deep space missions will probably rely on nuclear processes as available solar power will likely be insufficient to power complex human or robotic missions [5]. Nuclear power sources such as reactors and radioisotope thermoelectric generators (RTG) will contribute thermal neutrons to the already complex mixed radiation field of a spacecraft or planetary habitat [6]. Other possible sources of thermal neutrons include thermalized secondary neutrons from GCR interactions with vehicle materials and albedo neutrons from a planetary surface.

It is well known that boron has a high capture cross section for thermal neutrons such as those that may be encountered in these long term deep space missions. In this work, we present radiation shielding and material structural characteristics for novel carbon-fiber reinforced polymer composite that incorporates various levels of boron. The shielding experiments include 200 MeV protons and reactor neutron results. Structural properties as a function of boron content are also presented. The data indicates the following: 1. The composites have shielding properties similar to that of HDPE with the 200 MeV protons; 2. Even the lowest boron level shows significant shielding of reactor neutrons, with higher boron levels not providing significantly better shielding; and 3. The composites with the lower boron content have the better structural properties. These results indicate that composites, such as the one studied, have are potential candidates for future deep space missions.

Materials and Methods: The composites used in this study were fabricated by a non-autoclave process using the UN-10 high hydrogen epoxy resin with boron fiber and carbon fiber prepregs.

Material Strength Measurements: Non-irradiated samples of the composites were tested according to ASTM standard methods D3039 (tensile), D790 (flexural), and D2344 (SBS).

Radiation Experiments: The basic experimental configuration of the radiation shielding experiments is shown in Figure 1. The 200 MeV proton experiments were conducted at the Loma Linda University Medical Center proton facility. A tissue equivalent proportional counter (TEPC) was used to measure adsorbed dose and dose equivalent with and without various density thicknesses of shielding targets. The shielding targets included the composites and "standard" spacecraft materials such as HDPE and aluminum. The reactor experiments were conducted at a research reactor at Texas A&M University. A He-3 detector was used to measure the number of neutrons transported through the various shield targets at constant reactor power. Except for the front of the detector closest to the shield targets, the He-3 detector was sheathed in Cd to exclude scattered thermal neutrons.

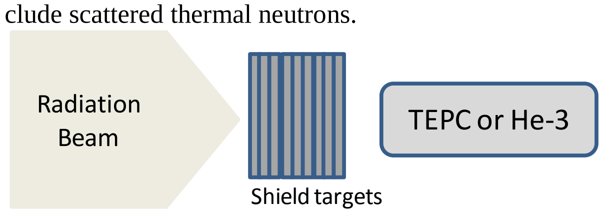

Figure 1: Schematic of the shielding experiments.

Results and Discussion: The results of the material strength measurements showed that the composite with the lower boron level (14.3%) has the strength similar to that of carbon fiber/UN-10 epoxy composite. Increasing the boron content to 25% from 14.3% decreases the tensile strength by 22% and SBS by 10%.

Figure 2 shows the adsorbed dose results of the 200 MeV experiments. At density thicknesses <15.5 g/cm^2, all targets are similar to HDPE with the HDPE having a higher value because it is more effective at slowing the incoming protons. For higher density thicknesses, based on these results and previous data on HDPE and Al under similar experimental conditions, it is observed that the composites with lower boron levels are more “poly-like”, and the higher boron level composites are more like aluminum. This is likely due to the higher percentage of higher Z elements in these composites.

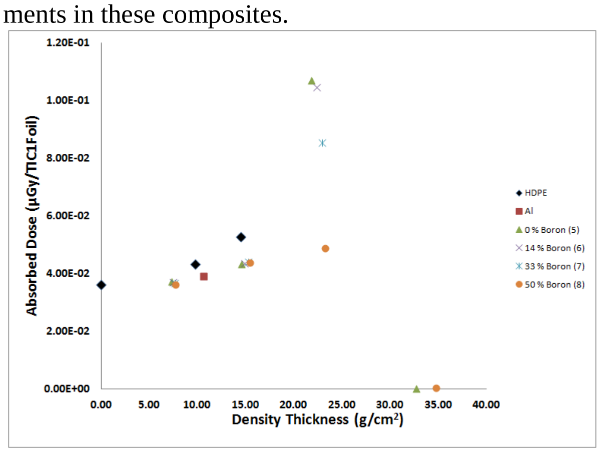

Figure 2: Adsobed dose measured by the TEPC for various shield targets.

Figure 3 shows a graph of neutron counts from the Cd-sheathed He-3 detector. The shield targets include the composites (with various boron levels) and HDPE. Note that the neutron attenuation at constant reactor power is roughly the same for all composites containing boron, and that the composite with 0% boron is roughly the same as HDPE.

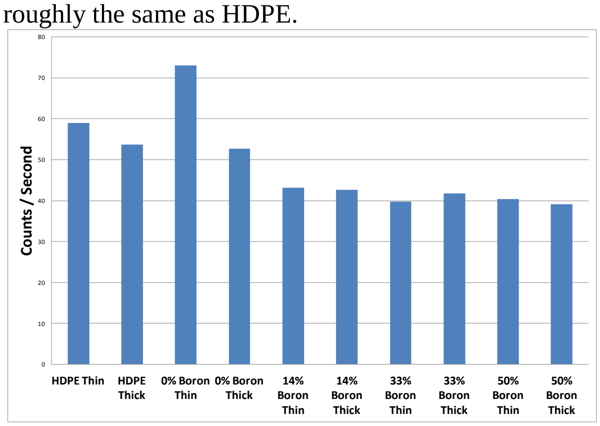

Figure 3: Neutron counts behind HDPE and the composites as measured by a He-3 detector.

Summary: Radiation shielding for future long-term human space missions similar to ISS will likely include hydrogen-rich materials such as HDPE and multifunctional composites. For spacecraft and habitats associated with missions that include nuclear process for power, thermal neutrons may contribute to the mixed radiation field affecting austronauts and their instruments. We will present data that indicates the following: 1. The composites have shielding properties similar to that of HDPE with the 200 MeV protons; 2. Even the lowest boron level shows significant shielding of reactor neutrons, with higher boron levels not providing significantly better shielding; and 3. The composites with the lower boron content have the better structural properties.

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