13th Workshop on Radiation Monitoring for the International Space Station

8-10 September 2008, Polish Academy of Arts and Sciences
Krakow, Poland

Chairman	**Guenther Reitz, DLR**
Organizing Committee:	**Paweł Bilski, IFJ**
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13^{th} Workshop on Radiation Monitoring for the International Space Station

Final Program

Sponsors: Institute of Nuclear Physics, Kraków, Poland
RadPro International, Wermelskirchen, Germany

Monday 8th Sept

08.45 - 10.15	Scientific Session
10.15 – 11.00	Coffee/Tea
11.00 - 12.30	Scientific Session
12.30 – 14.15	Lunch Break
14.15 - 15.45	Scientific Session
15.45 - 16.30	Coffee/Tea
16.30 - 18.00	Scientific Session

Paweł Olko — Welcome

Paweł Bilski — Organizational Issues

Guenther Reitz — Introduction/Actions of last meeting

Introductory Talks

P. Olko — Proton beams at IFJ Krakow - present status and future developments

L. Sihver, — Physics/Accelerator Experiments Needed for Improving Particle/Heavy Ion Transport Codes
- What has been done and what should be done

L. Narici — Light Flashes in space: does low LET radiation have effects on brain functions

Radiation Monitoring

Environmental Measurements

N.V Kuznetsov., — Trapped proton fluxes observed by LEO satellites in 23d solar cycle

A.N., Petrov — COSRAD complex of interactive programs for prediction of space radiation environment and radiation effects onboard spacecraft

Ts. Dachev	Characterization of near Earth radiation environment by Liulin type instruments
V.V. Benghin	Exploitation results of the radiation monitoring system onboard the Service Module of the ISS
E. Semones	ISS TEPC Measurement Results
E.M. Doensdorf	First preliminary Results from EuTEF DOSTEL
M. Casolino	Status and results of the Altcriss Project
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I. Apathy	TL Measurements Onboard the ISS with the Pille TLD System (Expedition 15 and 16)
F. Spurny	Dosimetry and LET spectrometry onboard ISS with TLD's and LET spectrometers exposed during 2007
B. Dudas	HZE measurements by PADC track etch detectors during the Foton M2 and Photon M3 missions (BIOPAN-5 and BIOPAN-6 results)
Ts. Dachev	High Dose rates by relativistic electrons: Observations on Foton M2/M3 satellites and on ISS
M. Larosa	Estimate of ion absolute fluxes in the ISS (USLab): ALTEA Measurements in 2006-7 and during December 2006 SPE, results of latest analysis
L. Di Fino	A novel method to discriminate Z and kinetic energy of pass-through ions in active silicon telescopes: off line and real time capabilities for ALTEA detector
C. La Tessa	The importance of Delta rays when simulating silicon telescopes of submillimeter thickness: a cross test with several Monte Carlo Codes

Note: Presentation time shall not exceed 30 minutes

Tuesday 9th Sept

08.45 - 10.15	Scientific Session
10.15 – 11.00	Coffee/Tea
11.00 - 12.30	Scientific Session
12.30 – 14.15	Lunch Break
14.15 - 15.45	Scientific Session
15.45 - 16.30	Coffee/Tea
16.30 - 18.00	Scientific Session
19.00	Departure for Dinner

MATROSHKA Results

T. Berger	MATROSHKA Overview – Data of MTR I and MTRII
A. Nagamatsu	Space radiation dosimetry by PADLES in the Phase 1 and Phase 2 of the MATROSHKA project
M. Hajek	Thermoluminescence neutron Dosimetry in the ESA MATROSHKA facility
M. Puchalska	Further analysis of the MTR I and MTR II results
S. Burmeister	First Results from MATROSHKA Phase IIB inside the ISS
K. Gustafsson	PHITS simulations of the MATROSHKA experiment
M. Latocha	MATSIM – Numerical simulations of the radiation exposure of the MATROSHKA phantom
I.V. Chernykh	ISS attitude influence on the dose rate measured with detectors of the LIULIN 5 instrument

Note: Presentation time shall not exceed 30 minutes

Calibration Results

Y. Uchihori	Current and future status of ICCHIBAN project and reanalysis of dosimetric data from ICCHIBAN-1 and ICCHIBAN-3
H. Kitamura	Future ICCHIBAN Experiments Using Proton Beams
N. Yasuda	Brief results from the ICCHIBAN/Space intercomparison 2 and ongoing experiments to resolve differences in CR-39 PNTD measurements
I. Jadrnickova	Studies of various influence of various factors on dose quantities measured with CR-39 detectors onboard spacecraft
S. Kodaira	Variation od dose quantities from CR-39 detectors onboard ISS Russian segment: etching and angelur correction
J. Szabo	Preliminary results of S12 experiment obtained by PADC track etch detectors
R. Facius	Three dimensional determination of etch track parameters in plastic nuclear track detectors: findings on bulk etch rate and implications for dosimetry

Note: Presentation time shall not exceed 30 minutes

Wednesday 10th Sept

09.00 - 10.30	Scientific Session
10.30 - 11.00	Coffee/Tea
11.00 - 12.30	Scientific Session
12.30 - 13.30	Lunch Break
13.30 - 15.00	Scientific Session
15.00 - 15.30	Coffee/Tea
15.30 - 16.30	Conclusions

Calibration Results (continued)

J. Palfalvi	High energy proton detection by PADC track etch detectors
L. Hager	Developments in the determination of the charged particle LET threshold of the HPA-RPD neutron PADC dosemeter, and its relevance to the estimation of neutron doses on the ISS
F. Spurny	Dosimetry and LET spectrometry in C 290 MeV/ama HIMAC ion beam by different TLD's and TED based LET spectrometers
F. Spurny	Fragmentations as seen in 290 MeV/u and Ne 400 MeV/u HIMAC ion beams by MDU-Liulin energy deposition spectrometer
C.. Zeitlin	Calibration of the Radiation Assessment Detector (RAD) for the Mars Science Laboratory

New Instruments / Future Activities

E. Benton	Development of tissue equivalent detectors for space crew Dosimetry and characterization of the space radiation environment
E. Semones	A possible new generation personal dosimeter Tissue Equivalent Plastic Scintillator Counter (TEPSC)
R. Rutledge	Next Generation Radiation Monitoring for the ISS

M. Luszik-Bhadra P. Beck G. Reitz	European Crew personal Active Dosimeter (EuCPAD) 1. Review on existing devices 2. Microdosimetric calculations 3. First design
D. O'Sullivan	Comments and suggestions for space radiation research
All	Round table discussion
All	Recommendations/Conclusions

Note: Presentation time shall not exceed 30 minutes

Proton beams at IFJ Krakow - present status and future developments

Pawel Olko and Jan Swakoń

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At the Institute of Nuclear Physics at Krakow 60 MeV proton beam from AIC-144 home built isochronous cyclotron is delivered to the facility of the proton radiotherapy of eye melanoma. The facility is under the commissioning and the first patient will be treated in 2009. The maximal energy of 60 MeV beam can be degraded up to energy of a few MeV using the mechanical range-shifter. The dosimetry is carried on using several dosimetric systems including miniature ion chambers, plane parallel- Markus chambers, diamond detectors and TLD 2-D system. The calibration of dosimetric instruments are performed on–site using Theratron-780 ^{60}Co therapy unit. The facility can be used for calibration of response of cosmic–ray dosimeters in low-energy proton beam. In 2013 a new cyclotron facility will be in operation at IFJ Krakow with the maximal energy 230-250 MeV protons . The cyclotron will be equipped with the energy selector, able for fast selection of the required energy. The setup for calibration of radiation dosemeters with proton beams will be available for the cosmic dosimetry community.

Physics/Accelerator Experiments Needed for Improving Particle/Heavy Ion Transport Codes - What has been done and what should be done

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To improve the radiation risk assessment of future LEO and interplanetary space missions, the radiobiological effects of cosmic radiation before and after shielding must be well understood. However, cosmic radiation is very complex and includes both low and high LET components of many different neutral and charged particles. The understanding of the radiobiology of the high energetic charged particles, associated with the GCR and SPE, is still a subject of great concern due to the complicated dependence of their biological effects on the type of ion and energy, and its interaction with various targets both outside and within the spacecraft and the human body. In order to estimate the biological effects of cosmic radiation, accurate knowledge of the physics of the interactions of both charged and non-charged particles is necessary. Since it is practically impossible to measure all secondary particles from the interactions of all projectile-target-energy combinations needed for a correct radiation risk assessment in space, accurate particle and heavy ion transport codes must be used. These codes must be carefully validated to make sure they fulfil preset accuracy criteria, e.g. to be able to predict particle fluence and dose distributions within a certain accuracy. When validating the accuracy of the transport codes, both space and ground based accelerator experiments are needed. This paper will present examples of ground based experiments which have been performed to improve and validate the particle and heavy ion transport codes, and present suggestions of accelerator experiments still needed to be done. Examples of suitable accelerator facilities where these experiments could be performed will also be presented.

Light Flashes in space: does low LET radiation have effects on brain functions?

L. Narici[a], A. Ciccotelli[a], L. Di Fino[a], M. Larosa[a], C. La Tessa[a], P. Picozza[a], A. Rinaldi[a], V. Zaconte[a], S. Carozzo[b], W.G. Sannita[bc]

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c Department of Psychiatry, SUNY, Stoony Brook, NY, USA

Astronauts in space have been observing phosphenes in the shape of *light flashes* (*LF*) in absence of known visual input. Investigations in space and on ground showed that *LF* can originate with the action of ionizing radiation on the eye.
We performed measurements on 3 astronauts in the International Space Station, monitoring the charged ionizing radiation impinging in their brain concurrently to their electrophysiological brain and retinal activity. The times at which the astronauts perceived a LF was signaled with the pressure of a pushbutton. The aim of the experiment was to demonstrate that these anomalous perceptions had associated electrophysiological potential and to individuate the particles causing their perceptions defining their charges and energies.
We show that these interactions triggers retinal potentials. All ions identified as responsible for these effects are of low Z and low LET.
While apparently in contrast to what often claimed in the literature, these results are supportive of the hypothesis that low LET radiation may indeed have a large impact on the visual sensory function. Following a recently described model we suggest that this low LET efficiency may depend on the lower concentration of radicals generated by the low LET radiation which increases the probability they diffuse and damage other cells, before recombining.
This "inverse LET" behavior may also help explaining a previously reported decay of the effectiveness in producing retinal responses in mice when increasing the radiation dose.
Inverse LET dependency will have an impact in the design of countermeasures, mainly shielding, for future space missions.

Trapped proton fluxes observed by LEO satellites in 23d solar cycle

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For over forty years of the investigation of the Earth radiation belts a great amount of the experimental data was collected and the main features of energetic and spatial distributions of trapped particles were described. These data have been used for development of empirical models for prediction of the radiation environment in the near-Earth space.

Nowadays, for the practical purposes the most widely used models are the AP8 and the AE8 models that establish particle fluxes of trapped protons and electrons, accordingly, in geomagnetic (LB) coordinates for minimum and maximum of the solar activity. These models are based on satellite data obtained from 1960 to 1980 and the model of the geomagnetic field for the epoch of 1960th. Discrepancies between the predicted and measured particle fluxes are well known [1-3]. Therefore AP8 and AE8 models as well as newly developed models [4,5] require further verification considering modern experimental data.

Proton fluxes registered in 23d cycle of solar activity by NPOES-15, -17 satellites (altitude is 810-820 km, inclination is 98 deg.) and Coronas-F satellite (altitude is 500-350 km, inclination is 83 deg.) are discussed in the report. Distributions of proton fluxes with energies from 30 keV up to 140 MeV on L-shells ($L < 4$) are analyzed depending on intensity of the "quiet" geomagnetic field calculated for a modern epoch. The great attention is paid to the comparison of trapped proton fluxes for solar minimum (2007) and solar maximum (2002).

The new experimental results are compared with the AP8 and other models. For low orbits the considered experimental data coincide satisfactory with AP8 model data for trapped proton fluxes energy more than ~10 MэB. At the same time the AP8 model considerably underestimates fluxes of protons with energy less than ~10 MэB on drift shells $L < 1.4$.

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COSRAD complex of interactive programs for prediction of space radiation environment and radiation effects onboard spacecraft

Petrov A.N., Kuznetsov N.V., Panasyuk M.I.

Nowadays there are several information systems like CRÈME (http://creme96.nrl.navy.mil), SPENVIS (http://www.spenvis.oma.be/spenvis) and OMERE (http://www.trad.fr). They unite numeric models for calculation of radiation environment and radiation effects onboard satellites and space stations. The current work presents the Russian program complex (named COSRAD) developed in SINP MSU for the same purpose. COSRAD allows to calculate energy spectra of averaged and maximal fluxes of trapped electrons and protons and fluxes of galactic and solar cosmic rays for long-term flights. COSRAD compute energy spectra of the average and maximal fluxes of trapped electrons and protons, and also streams of particles of galactic and solar space beams for long-term space orbital flights (from 1 to 20 years of flight).

Algorithms for calculation of particle fluxes are based on

- the Tsyganenko89 model of magnetic field in which the DGRF model for a modern epoch (2000) is used [1],
- maps of protons (AP8) and electrons (AE8) fluxes depending on LB-coordinates [2],
- the dynamic model of GCR particle fluxes including of a low-energy component of a solar origin [3],
- the probability model of SEP particle fluxes [4],
- the calculated procedure for function of penetration of cosmic ray fluxes inside the Earth magnetosphere [5].

Particle fluxes calculated for "open space" are used to compute energy spectra and LET spectra (for GCR and SEP only) of particle fluxes behind Al spherical shielding with defined depth (from 0.01 to 100 g/cm^2) taking into account a generation of secondary protons and neutrons. These spectra serve as the initial data for forecasting the adsorbed or equivalent dose and the SEU rate (number) in integrated circuitries of an onboard equipment. To compute the SEU rate algorithms of the generalized model [6] which takes into account as direct (from ions), and nuclear (from protons) mechanisms of SEU occurrence are used.

The interactive version of COSRAD is placed on a site http://smdc.magnetosphere.ru/. Results of computations are written in text files which can be kept on a local computer and then can be used for the analysis of results.

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Characterization of Near Earth Radiation Environment by Liulin Type Instruments

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Comprehensive study of the dose, flux and spectra form data obtained by Liulin MDU measurements on spacecrafts (4 different experiments) and aircrafts since 2001 is performed with the aid to understand how well these parameters can characterize the near Earth radiation environment. The value of the deposited energy where the maximums of spectrum is observed depends by the type and energy of the incoming radiation. Spectra generated by GCR protons or their secondary's are with linear falling form in the coordinates deposited energy/deposited dose. The position of the maximum of the spectra inside of the of South Atlantic anomaly region are in dependence of the incident energy of the incoming protons. Spectra generated by relativistic electrons in the other radiation belt have a wide maximum in the first 6 channels. For higher energy depositions the spectra are similar to the GCR spectra. Mixed radiation by protons and electrons and/or bremsstrahlung is characterized by spectra with 2 maximums. All type of spectra has a knee close to 6 MeV deposited energy, which correspond to the stopping energy of protons in the detector. Dose to flux ratio known also as specific dose is another high information parameter, which is giving trough the Heffner's formulas the exact incident energy of the particles. New space research projects are also shortly presented.

EXPLOITATION RESULTS OF THE RADIATION MONITORING SYSTEM ONBOARD THE SERVICE MODULE OF THE INTERNATIONAL SPACE STATION

V.V. Benghin [1)], V.M. Petrov[1)], M.I. Panasyuk [2)], A.N. Volkov[3)], O.Yu. Nechaev [2)], A.P. Aleksandrin[3)], A.G. Myasnikov[2)], S.G. Drobyshev[1)], A.E. Lishnevski[2)],

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Data on exploitation results of the radiation monitoring system (RMS) onboard the Service module of the ISS in the period from August 2001 to July 2008 are presented in the report. Dose variations in 4 different locations of the Service module are analyzed in correlation with solar activity variations. It is demonstrated that the dose variations measured onboard ISS in the decay phase of the 23-d cycle of solar activity are essentially smaller than the dose variations measured onboard the MIR orbital station in the decay phase of the 22-d cycle of solar activity. ISS attitude influence on the RMS detector readings is also considered. Absorbed doses caused by large solar proton events are presented; dose rate dynamics during space station crossing of the high latitude trajectory regions in disturbed radiation conditions is also considered.

ISS TEPC Measurement Results

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During the past year, the NASA JSC Tissue Equivalent Proportional Counter made measurements throughout the ISS including Node 2, Service Module, US Lab, Columbus, and the JPM. Absorbed dose and dose equivalent due to galactic cosmic rays (GCR) and particles trapped in the SAA (South Atlantic Anomaly) will be presented. Results from CR-39 track detectors attached to the TEPC will be shown for comparison.

First preliminary Results from EuTEF-DOSTEL

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DOSTEL is in operation as part of the European Technology Exposure Facility (EuTEF) since February 25th 2008. The EuTEF platform is mounted outside the European COLUMBUS module of the ISS. The EuTEF DOSTEL consists of a telescope of two Canberra PIPS (Passivated Implanted Planar Silicon) detectors and two additional Hamamatsu PIN diodes. The PIN diodes are arranged perpendicular to the telescope. The detector signals are amplified by separate logarithmic amplifiers to achieve a broader dynamic range. The data of the DOSTEL (dose rate and LET Spectra) are downlinked to earth.
The two Canberra PIPS detectors are measuring in the LET range from 0.144 keV/µm to 173 keV/µm and from 0.048 keV/µm to 209 keV/µm.
A more detailed description of the EuTEF DOSTEL design and first results as LET spectra, dose rates and dose equivalent will be presented.

Status and results of the Alcriss project.

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The Altcriss project aims to perform long term measurement of the radiation environment in different points of the International Space Station. To achieve this goal, it employs an active silicon detector, Sileye-3/Alteino, to monitor nuclei up to Iron in the energy range above 40 MeV/n. Both long term modulation of galactic cosmic rays going toward solar minimum and solar particles events will be observed. A number of different dosimeters are being employed to measure the dose and compare it with the silicon detector data. Another aim of the project is to monitor the effectiveness of shielding materials in orbit: a set of polyethylene tiles is placed in the detector acceptance window and particle flux and composition is compared with measurements in the same locations without shielding. Dosimeters are thus placed behind the shielding material and in an unshielded location to cross-correlate this information. Another set of multimaterial shielding is also being tested with various dosimeters. The observation campaign begun in December 2005 and has been running for almost three years. In this work we will describe some results obtained with the detectors and in-flight intercomparison with Altea and Matroska experiment. We will also report on the status of realization of Sirad experiment.

Radiation Measured with Passive Dosimeters during STS-120 Space Mission

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Radiation in LEO (Low Earth Orbit) is composed mainly of galactic cosmic rays (GCR), solar energetic particles, particles trapped in the SAA (South Atlantic Anomaly) and the albedo neutrons from the Earth's atmosphere.

To measure the complicated radiation field in LEO with LET from ~ keV/μm water to ~1000 keV/μm water, a dosimeter system composed of TLDs (Thermoluminescence Dosimeters) and OSLDs (Optically Stimulated Luminescence Dosimeters) as well as CR-39 PNTDs (Plastic Nuclear Track Dosimeters) is needed. Research indicates that TLDs and OSLDs are sensitive to low LET and CR-39 PNTDs are sensitive to high LET and then the combined passive dosimeters are for all LET. NASA-JSC has been successfully using the combination passive dosimeters to measure the radiation experienced by astronauts with CPDs (Crew Passive Dosimeters) and the radiation in the different monitored areas inside the spacecrafts with PRDs (Passive Radiation Dosimeters) for all STS and ISS space missions since STS-114.

Radiation LET spectra (differential and integral fluence, absorbed dose and dose equivalent) for high LET (≥ 5 keV/μm water) were measured with CR-39 PNTDs and the absorbed dose were measured with TLDs and OSLDs for astronauts and for the different monitoring areas during the STS-120 space mission (23 Oct. - 7 Nov. 2007, inclination 51.6^{o}).

This paper introduces briefly the LET spectrum method using CR-39 detectors, the method to combine results from TLDs/OSLDs and CR-39 PNTDs and presents the experimental results measured and combined from different passive dosimeters of PRDs.

TL Measurements Onboard the ISS with the Pille TLD System (Expedition 15 and 16)

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The original Pille system was developed by KFKI AEKI in the late 1970's and was used by the first Hungarian cosmonaut, Bertalan Farkas, in 1980 during his flight aboard the Russian Salyut-6 orbital station. Pille was the first and to date the only TLD system designed specifically for use by cosmonauts and astronauts while traveling in space. Since the first time it was launched, the Pille system has worked onboard every space station.

The Pille TL dosimeter system has been continuously used on board the International Space Station since October 2003 under the supervision of the Institute for Biomedical Problems (IBMP) as the service dosimeter system of the Russian Zvezda module. In the past nearly five years the dosimeter system was utilized for routine dose measurements inside the ISS, and as personal dosimeter system during EVAs. With the system consisting of a lightweight reader device and ten small, durable dosimeters, about 20 000 read-outs were carried out until now. The Pille system provides monthly dose data from seven locations of the space station, while two dosimeters are dedicated to EVA measurements, and one is read out in every 90 minutes to provide high time resolution data.

The measurement data (including several EVA measurements) from the latest expeditions (Expedition 15 and 16, April 2007 – April 2008) obtained by the Pille system will be presented. The results will be compared with previous measurement results.

Dosimetry and LET spectrometry onboard ISS with TLD's and LET spectrometers exposed during 2007

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The sets of track etched detectors (TED) spectrometers of the linear energy transfer (LET) have been, together with two types of thermoluminescent detectors (TLD), exposed onboard of International Space Station (ISS) during 2007.
Part of them have been exposed in SPD containers composed by colleagues from IBMP Moscow, another sets of TED spectrometers and TLD detectors have been exposed in the frame of SI2 intercomparison prepared and organized by colleagues from NIRS, Chiba.
All detectors were exposed onboard of ISS in the period from 12/05 to 22/10/07, total exposure time was 163 days. The contribution will present:

- Direct readings of TLDs for different positioning, and, also the type of TLDs (three types of them have been used).
- Spectra of LET as measured with different TED, two types of them were used for each of experiment. Obtained LET spectra permitted also to estimate values of total dose and dose equivalent from particles with LET above the threshold of each TED used.

The results of evaluation of TLDs and TED based LET spectrometers have been combined together to obtain total dosimetric characteristics during the onboard ISS exposure.
It was found that total values of daily rates vary from 200 to 270 µGy for the dose, from 400 to 700 µSv for the dose equivalent. As far as QF is concerned, its values vary between 2.0 and 2.9. The values for SI 2 experiment are much more consistent, probably due to the exposure in the same container.

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HZE measurements by PADC track etch detectors during the Foton M2 and Foton M3 missions (BIOPAN-5 and BIOPAN-6 results)

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In the frame of the two Foton M space missions external containers called BIOPAN were loaded with facilities for biology and dosimetry. The BIOPANs were opened to expose their contents directly to the space environment at an altitude of about 300 km. The AERI research group participated in both BIOPAN-5 and BIOPAN-6 projects with RADO (radiation dosimetry) experiments.

The objective of this presentation is to describe the measurements of High Atomic Number and Energy particles (HZE) made by solid state nuclear track detectors (SSNTD) and present some results.

HZE particles ($Z \geq 6$) despite being a tiny fraction of the total particles in space play a significant role in dose contribution. They represent a considerable hazard due to their deep penetrating, ionizing nature and high linear energy transfer (LET).

HZE particles also may damage equipments and measuring instruments as happened during the BIOPAN-5 mission, therefore in the BIOPAN-6 container two additional PADC stacks, complementing the original SSNTD assembly used in BIOPAN-5, were placed on active devices to map HZE particles.

The tracks of HZE particles have been evaluated manually by an image analyzer after 15 hours etching. The preliminary data have shown that the fluence of HZE particles was much higher during the BIOPAN-5 than the BIOPAN-6 experiment. The processing of the large amount of data is still in progress.

High Dose Rates by Relativistic Electrons: Observations on Foton M2/M3 satellites and on International Space Station

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The paper analyse all data where by the R3D-B2/B3 instruments during the flights of the Foton M2/M3 satellites in 2005 and 2007 and by the R3DE instrument situated at EuTEF facility of European Columbus module of ISS in period 20th of February – 28th of April 2008, relativistic electrons are observed. On Foton M2/M3 satellites relativistic electrons are observed most frequent than on ISS. At both satellites usual duration of the observation is few minutes. On ISS the duration usually is about 1 minute and less. The places of the observations of high doses are distributed for Foton M2/M3 satellites mainly at latitudes above 50 degree geographic latitude in both hemispheres. Strong maximum is found in southern hemisphere in the longitudinal range 0°-60°. At Columbus module of ISS the maximums are observed between 45° and 52° geographic latitude in both hemispheres at longitudes equatorward from the places of magnetic poles. These places coincide well with the AE-8 MIN model predictions. The measured absolute maximums of the doses generated by relativistic electrons are as follows: 304 μGy/h behind 1.75 g/cm^2 shielding at Foton M2, 2314 μGy/h behind 0.81 g/cm^2 shielding at Foton M3 and 19195 μGy/h (Flux is 8363 cm^{-2} s^{-1}) behind les than 0.4 g/cm^2 shielding at ISS.

Estimate of ion absolute fluxes in the International Space Station (USLab): ALTEA measurements in 2006-7 and during the December 2006 SPE, results of latest analyses.

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ALTEA (Anomalous Long Term Effects on Astronauts) is a multidisciplinary project aimed at studying the cosmic rays and their effects on the astronauts during space missions, with a focus on the Light Flashes phenomenon. The ALTEA-Space is the main space experiment of the ALTEA project and one of its goals is the characterization of the radiation environment inside the International Space Station (ISS). It includes a stack of six silicon telescope particle detectors arranged in a 3D structure, capable to determine the energy loss and the trajectory of the cosmic radiation. ALTEA-Space is on board the ISS since July 2006 and collected data continuously between August 2006 and July 2007.

We present here the first analysis of the whole dataset, giving a first assessment of the absolute radiation fluxes measured in the ISS.

We identified ions from Boron to Iron. Absolute fluxes for all discriminated elements are presented.

Solar Particles Events (SPEs) represent one of the major hazards in space missions, the characterization of radiation environment inside the International Space Station during a SPE plays an important role in the assessment of the radiation risk. ALTEA-Space experiment has recorded the most recent 2006-December Solar Particle Event. We present here the measurement's results and the abundances of the various nuclear species, during the SPE (as compared to normal conditions).

A comparison with external data from other available instruments is presented in the energy region where the devices are sensitive.

A novel method to discriminate Z and kinetic energy of pass-through ions in active silicon telescopes: off line and real time capabilities for ALTEA detector.

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Silicon telescopes provide information about energy released in silicon by each impinging ion. ALTEA internal trigger needs all planes to be hit. One of the major analysis task is to retrieve information about the charge Z and the input energy Ein of these particles. The major challenge (for non stopping ions) is that the same energy on each plane of the telescope can be delivered by different combinations of Z and Ein. However if considered all planes together (six in the case of ALTEA, discussed here) the solution for an ideal noiseless situation should be unique. A real case is more difficult to treat.

In this presentation we show a new approach to this recognition problem.

We prepare a simulated matrix of data, containing in each line the energy released on each of the six planes by ions of different Z (1-26) and different Ein (up to 10 GeV/n). Data from our ALTEA telescopes are than compared to all lines of the matrix and the best fit is chosen.

Several parameters which can be optimized are discussed:

i) the energy step in the simulated matrix;

ii) the matching algorithm

iii) the sorting and ranking of the results

Test results with simulated and real data are presented.

The importance of Delta Rays when simulating silicon telescopes of submillimiter thickness: a cross test with several Monte Carlo codes.

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Monte Carlo codes have been used to simulate measurements performed with silicon telescopes, which can discriminate particles according to their charge and energy.
Validation tests have been done by comparing simulated spectra to spectra either from accelerator and/or from space measurements.
A non optimal outcome of one of these tests in the cross check between ALTEA data (space measurements & calibrations) and simulation with PHITS code prompted further tests to define and solve the discrepancies between simulated and measured data.
One of the first issues to be investigated is the importance of delta rays.
The interaction of heavy ions with matter produces delta rays whose number and energy spectrum depends strongly on the energy and charge of the incoming particles. Among the Monte Carlo codes developed to simulate the interaction of particles with matter, some take into account the physics of the delta electrons while others neglect it. In this work, beside PHITS that neglects delta rays (assuming that all the energy lost by the incoming particles gets absorbed by the detector), we considered two other Monte Carlo codes, Geant4 and FLUKA (both of which include models for delta rays) and simulate the interaction of several beams (C 100, C 600, C 1000 and Ti 200 MeV/nucleon) with 6 silicon planes of thickness equal to 0.38 mm each.
The simulated energy spectra are compared with experimental data (ALTEA) to understand the importance of delta rays in the range of projectile energies and charges considered.

MATROSHKA 1 – MATROSHKA 2 A: TLD Data Intercomparison

T. Berger, G. Reitz on behalf of the MATROSHKA Team

DLR - German Aerospace Center, Institute of Aerospace Medicine, Radiation Biology, Cologne, Germany

The talk will give a brief overview concering the status of the MATROSHKA experiment, summing up MTR 1 and MTR 2 A as well as giving the newest information about the MTR experiment phase 2B. The main focus will be on the data intercomparison of TLD absorbed dose data for MTR 1 and especially for MTR 2 A. The TLD data intercomparison for MTR 2A will first focus on the TLD data gathered by the different groups participating in the MATROSHKA experiment from the reference, organ and poncho boxes. The second intercomparison will deal with the 3D dose distribution established with TLDs from the Atomic Institute of the Austrian Universities (ATI), Vienna, Austria, the Institute of Nuclear Physics (IFJ), Krakow, Poland, and DLR. For the first time the whole data set of 3D dose distribution data from an anthropomorphic phantom experiment exposed outside (2004 – 2005) and inside (2006) the International Space Station will be compared and the differences between the out- and the inside exposure will be discussed in detail.

Space radiation dosimetry by PADLES in the Phase 1 and Phase 2A experiments of the MATROSHKA project

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We have developed a PADLES (Passive Dosimeter for Life-Science Experiments in Space) system for monitoring radiation environments in the Japanese Experiment Module 'Kibo' of the ISS. The PADLES package includes antioxidant-doped CR-39 plastic nuclear track detectors (Fukuvi Chemical Industry, HARZLAS TD-1) and thermoluminescence dosimeters (Kasei Optonix, TLD-MSO-S). The PADLES was applied for radiation dosimetry in the Phase 1 and Phase 2A experiments of the MATROSHKA project.

In the Phase 1 and Phase 2A experiments, PADLES packages were installed in the box on the head of the MATROSHKA human phantom. In the Phase 1 experiment (01/19/2004 ~ 10/11/2005), the phantom was located at the exposed area of the ISS Russian segment for 538 days and was located at the inside of the Russian segment for 83 days. In the Phase 2A experiment (12/21/2005 ~ 12/22/2006), the human phantom was located inside the Russian segment for 370 days. During both experiments, PADLES packages for "space control" were attached on the inside wall of the Russian segment and PADLES packages for "ground control" were stored in a laboratory of DLR.

The HARZLAS TD-1 plastic plate has incident dip-angle dependence in track formation sensitivity. We recently proposed a correction method for such dip angle dependence to improve accuracy in LET distribution measurements [1] We will report dosimetry results of the Phase 1 and Phase 2A experiments using the present correction method.

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1. H. Tawara, M. Masukawa, A. Nagamatsu, K. Kitajo, H. Kumagai, N. Yasuda: Measurement of a Linear Energy Transfer Distribution with Antioxidant Doped CR-39 Correcting for the Dip Angle Dependence of Track Formation Sensitivity, Jpn. J. Appl. Phys. (2008), in press.

Thermoluminescence neutron dosimetry in the ESA Matroshka facility

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Thermoluminescence detectors are well suited to thermal neutron dose assessment in complex radiation environments of mixed composition. ^{6}LiF:Mg,Ti, which has been commercialized as TLD−600 and MTS−6, is able to detect thermal neutrons due to the high ^{6}Li(n,α)^{3}H reaction cross section at energies below 200 keV. In contrast, ^{7}LiF:Mg,Ti (TLD−700, MTS−7) is relatively insensitive to thermal neutrons, but responds similarly as ^{6}LiF:Mg,Ti to any other type of radiation. When arranged in pair, dose contributions from radiations other than thermal neutrons can be eliminated to allow for thermal neutron dosimetry. This method has also been calibrated for higher neutron energies, but is condemned to fail if the neutron spectrum is not accurately known—as it is the case with the majority of space missions. An alternative indicator of the presence of thermal neutrons is readily available from the high-temperature ratio (HTR) in TLD−600. The very high linear energy transfer (LET_∞ H_2O) of the 2.05 MeV alpha particle (162.1 keV/µm) emitted in the non-elastic collision of a neutron with a ^{6}Li nucleus yields a remarkable enhancement in the HTR. Both techniques are applied to thermal neutron dosimetry in the European Space Agency (ESA) Matroshka facility. Thermal neutron dose profiles are shown for selected slices and sagittal planes of the phantom body. Significantly lower neutron doses were found for the less shielded experimental phase 1 where the facility was attached to the outside hull of the International Space Station, compared with the inside exposure of phase 2A.

Further analysis of the MTR-1 and MTR-2a results

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The MATROSHKA experiment consists of exposures at the ISS of an anthropomorphic Rando phantom equipped with radiation detectors. The main part of the experiment was dose distribution measurement performed with thermoluminescent detectors within a 2.5 cm grid inside of the phantom torso. Institute of Nuclear Physics (IFJ) provided TL detectors for nearly half of measuring locations inside the phantom (785 of 1631 locations in total). Two phases of this experiment: MTR-1 (exposure outside ISS) and MTR-2a (exposure inside ISS) are already finished and point dose results were presented at the previous workshops.
Within current presentation the further analysis of these data will be described. This includes: interpolation of the point doses into a continuous distribution within the phantom volume, creating a 3D voxel model of the Rando phantom (based on the CT scans) and finally calculation of organ doses.

First DOSTEL Results from MATROSHKA phase IIb inside the ISS

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The DOSimetry TELescope (DOSTEL) measures the dose and LET spectra at the head of the MATROSHKA phantom. The MATROSHKA DOSTEL consists of a telescope of two 300µm Canberra PIPS (Passivated Implanted Planar Silicon) detectors and two additional Hamamatsu 300 µm PIN diodes. The circular PIPS detectors have an active area of 6.93 cm^2 and the rectangular PIN detectors active area is 2.31 cm (2.1 x 1.1 cm). The PIN diodes are arranged perpendicular to each other and the telescope axis.
This year the MATROSHKA IIb phase started so the MATROSHKA facility is now mounted inside the Russian Module (Zvezda) of the International Space Station ISS and electrically connected. The MATROSHKA DOSTEL is active since May 2008. A description of the MATROSHKA DOSTEL, mean dose rates, LET spectra and deduced dose equivalent rates will be presented.

PHITS simulations of the Matroshka experiment

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The radiation environment in space is very different from the one encountered on Earth and it is known to be harmful to both humans and electronics. It is therefore important to understand the interaction of materials such as space vehicles walls, human organs and electronics when hit by ionizing radiation consisting of particles of different Z and with energies ranging from keV up to hundreds of GeV. The radiation exposure and its consequences need to be estimated and we are therefore developing a tool based on PHITS, the Particle and Heavy-Ion Transport code System, a three dimensional Monte Carlo code which can calculate interactions and transport of particles and heavy ions in matter. PHITS is developed and maintained by a collaboration between RIST (Research Organization for Information Science & Technology), JAEA (Japan Atomic Energy Agency), KEK (High Energy Accelerator Research Organization), Japan and Chalmers University of Technology, Sweden. To benchmark and validate PHITS, we are simulating the ESA project Matroshka (MTR) designed and manufactured by DLR. MTR focus on the determination of the radiation load on astronauts inside and outside the ISS by using an anthropomorphic upper torso, equipped with active and passive radiation detectors positioned throughout the whole phantom. Preliminary results, which already show a reasonable agreement with the measurements will be presented and discussed. The future work will especially focus on the incorporation of the exact shielding geometries of the International Space Station.

MATSIM - Numerical Simulation of the Radiation Exposure of the MATROSHKA Phantom

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The Austrian Research Centers (ARC), the Vienna University of Technology (ATI) and the German Aerospace Center (DLR), collaborate on the project MATSIM to perform the full numerical simulation of the MATROSHKA phantom using Monte Carlo codes. MATROSHKA is an ESA facility, designed and manufactured by DLR, to determine the radiation exposure of an astronaut during an extravehicular activity (EVA) at the International Space Station (ISS). For this purpose, several thousands passive and seven active radiation detectors measured the dose distribution within an anthropomorphic upper torso exposed outside the ISS during the MATROSHKA experiment Phase 1. The MATSIM project is carried out in two project phases A and B. During MATSIM-A the numerical modelling of the MATROSHKA phantom is done using the high energy particle transport Monte Carlo code FLUKA. The code simulates with high accuracy the interaction and propagation of ionizing radiation in a wide energy range such as photons and electrons from 1 keV to thousands of TeV, hadrons up to 20 TeV, neutrons down to thermal energies, and heavy ions, all of them in customized energy spectra and spatial distributions. A Computer Tomography (CT) scan of the MATROSHKA phantom has been converted into a 3-dimensional voxel phantom with about $5 \cdot 10^7$ voxels in total. The imparted energy and dose at the surface and in specified locations inside the phantom is determined for reference radiation conditions. The gathered information will be used in MATSIM Phase-B, for the verification of the numerical dose distribution applying reference measurements and the simulation of the radiation transport under ISS conditions. The aim of MATSIM is the provision of comprehensive risk assessment of radiation hazard to humans in space due to the highly complex mixed radiation field and the support of current and future exposure phases of the MATROSHKA experiment on board the ISS.

ISS ATTITUDE INFLUENCE ON THE DOSE RATE MEASURED WITH DETECTORS OF LIULIN-5 INSTRUMENT

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The data demonstrating variations in the Liulin-5 instrument readings after ISS attitude changes are presented in the report. Location and attitude of the Liulin-5 instrument in relation to the ISS coordinate system during the Matroshka-R experiment is considered in detail. Shielding estimations of the detectors are presented for Liulin-5 detector unit inside the spherical phantom. Typical ISS attitudes during Liulin-5 measurement sessions are considered. Minimal shielding zone attitudes of the instrument detectors are presented in relation to maximum intensity direction in the SAA region. Liulin-5 dose rate measurements are correlated with spatial attitude of the detector unit. It is demonstrated that anisotropy of the radiation field in the SAA region gives an essential influence on the dose distribution inside the spherical phantom.

Current and Future Status of ICCHIBAN Project and Reanalysis of Dosimeteric Data from ICCHIBAN-1 and ICCHIBAN-3

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We present a status report on the ICCHIBAN project, including the ongoing CR-39 ICCHIBAN and ICCHIBAN/Space-Intercomparison experiments and the effort to compile and analyze results from ICCHIBAN-5 and more recent experiments. The ICCHIBAN Working Group (ICWG) has realized the need to prepare and release reports on a more timely basis. To this end, we have adopted a new format for participants to report their results. We discuss this new reporting format and the data we are asking that each participant provide. Future plan of ICCHIBAN projects also will be presented.

The ICWG has taken another look at the results provided by participants of the ICCHIBAN-1 and -3 experiments and is now determining LET distributions, as well as dose and dose equivalent values, based on those results. In the HIMAC Report-78 and -128, the dosimeteric data from different active detectors were not compared to one another because they were analyzed over different LET regions. In order to make a more direct and useful comparison, this data is being reanalyzed by the ICWG over the same LET region. In this presentation, we discuss the reanalysis of this data and the methods we are using, while asking for the cooperation of ICCHIBAN-1 and -3 participants. Also, we show a direction of summarization for report of the past and future ICCHIBAN experiments.

Future ICCHIBAN Experiments Using Proton Beams

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In past ICCHIBAN experiments, we intercompared the response of the dosimeters mainly using high LET particles. The ICCHIBAN working group is planning experiments to intercompare the low LET response of dosimeters using proton beams in the near future. NIRS not only has the HIMAC, a heavy ion synchrotron ideal for high LET irradiations, but also a cyclotron which has the capability to accelerate protons of energy up to 70 MeV with a 10 cm diameter beam spot which we plan to use in ICCHIBAN experiments for low LET irradiations. We describe instrumentation and the characteristics of the radiation fields of the NIRS-Cyclotron facility, and discuss our objectives and experiment design of the upcoming Proton-ICCHIBAN.

Brief results from the ICCHBAN/Space Intercomparison 2 and ongoing experiments to resolve differences in CR-39 PNTD measurements

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Currently, the world's space agencies (NASA, JAXA, RSA/Energia, and ESA) participating on the International Space Station (ISS) use a combination of CR-39 plastic nuclear track detector (PNTD) and thermoluminescence detector (TLD) to determine the dose and dose equivalent received by crew during spaceflight. Previous experiments have shown that the results obtained onboard spacecraft using CR-39 PNTDs exposed under identical conditions can differ signifcantly between different laboratories. One conclusion of the 12th Workshop on Radiation Monitoring for the International Space Station (WRMISS-12) was that the space dosimetry community needs to resolve the discrepancies in dose and dose equivalent measurements made using CR-39 PNTD in space. The ICCHIBAN/Space Intercomarison-2 (IC/SI-2) experiment was performed in 2007 and included the participation of 12 laboratories. We present brief results from the IC/SI-2 experiment, and discuss strategies to clarify the discrepancies in dosimetric measurements made with CR-39 PNTD through ongoing experiments in space (Space Intercomparison-3 and space-based CR-39 ICCHIBAN) and on the ground (ground-based CR-39 ICCHIBAN).

Studies of influence of various factors on dose quantities measured with CR-39 detectors onboard spacecraft

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For the determination of LET spectra, absorbed dose, and dose equivalent onboard of spacecraft, many laboratories use the combination of thermoluminescence detectors and CR-39 plastic nuclear track detectors (PNTD). Previous experiments have shown that the results obtained onboard spacecraft using CR-39 detectors can differ in large extent among different laboratories. One conclusion of the 12th Workshop on Radiation Monitoring for the International Space Station (WRMISS-12), held in September 2007, was that the space dosimetry community needs to resolve the discrepancies between CR-39 PNTD dose and dose equivalent measurements made in low Earth orbit (LEO). There are a variety of possible causes for the discrepancies seen between dose and dose equivalent measurements. The discrepancies can come from: use of different CR-39 material, choice of etching time, selection and measurement of etched pits, personal skills and experience, and methodologies for calculation to get dose and dose equivalent. At first, we checked variations of dosimetric values from 5 different positions on one piece (3 cm x 3 cm) of CR-39. Further, based on appropriate size of etched pit images, we have compared the differences in dose quantities coming from human dependence, selection of etch pits, and also calculation method between two laboratories (NIRS and NPI). The second part of this contribution deals with intercomparison of results from the experiment MATROSHKA-R III, performed onboard of ISS from December 2005 to September 2006. During this experiment, the detectors from NIRS and NPI were placed at the same position (in 8 pockets on the surface of the spherical phantom), which enabled us to compare directly the obtained results.

Variation of dose quantities from CR-39 detectors onboard ISS Russian segment: etching and angular correction

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We performed the radiation monitoring experiment for passive radiation dosimeters as a part of the BRADOS experiment on the International Space Station (ISS) in 2004. Five dosimeters boxes with passive detectors from IMBP and NIRS were exposed on the Russian segment of the ISS during the period of the BRADOS II space experiment sessions from Jan. 29 to Oct. 24 in 2004. The dosimeter package consists of TLDs, Glass detectors and CR-39 detectors with some Al targets. In this study, we employed CR-39 detector named HARTZLAS TD-1 and verified the variation of LET spectra by several bulk etch conditions (multi-step) from 5 - 53 μm at the same position of a TD-1 detector. All etch pit was traced at each step of etching time. We also verified correction methods of incident angle dependence on track registration sensitivity of TD-1 detector. The preliminary results on variation of dose quantities from CR-39 detector will be presented.

Preliminary results of SI2 experiment obtained by PADC track etch detectors.

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The Radiation and Environmental Physics Department of the Atomic Energy Research Institute (Hungarian Academy of Sciences) participated in the Space-Intercomparison-2 experiment with 5 PADC (polyallyl-diglycol-carbonate) nuclear track detector sheets. Right after their arrival in March 2008, the detectors were etched in 6 n NaOH at 70 ˚C for 6 hours. This is the first etching step applied in our standard method used for the evaluation of space detectors, which results in an 8 µm thick surface removal and the development of tracks with LET higher than ~17 keV μm^{-1}. Semi-automatic measurements were carried out by the VIRGINIA image analyzer system on each side of each detector sheet. Beside these investigations, manual HZE track analysis was also performed. The preliminary results as LET spectra, absorbed dose, dose equivalent and average quality factor values obtained based on these measurements will be presented.

Three dimensional determination of etch track parameters in plastic nuclear track detectors: findings on bulk etch rate and implications for dosimetry.

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Historically, visual nuclear track detectors found originally most widespread application in probing the space radiation field. For dosimetric purposes, the focus of work with plastic detectors was on the contribution to dose from the high end LET range of genuine HZE particles, i.e., energetic heavy ions from alpha particles to iron ions with an LET above say 1000 and up to 15000 MeV cm^2 / g. A second major application of visual nuclear track detectors was the determination of the trajectories of cosmic heavy ions in order to identify biological test organisms which might have been affected by such ions. Ideally, the impact parameter of such trajectories with respect to radiobiologically sensitive structures would be determined. For many such radiobiological studies - e.g. with bacterial spores - sufficient precision of these trajectories was a challenging task. For such radiobiological applications also the identification of the HZE article was usually required which in turn required rather precise determination of track lengths.

For such high precision work microscopic "workstations" were developed which allowed position measurements of microscopic features in all three dimensions with an accuracy in the order of 0.1 μm. Only recently this equipment was employed for personnel dosimetry of astronauts within the EuCPD project. For dosimetric work with CR 39 plastic detectors, conventionally the etch tracks are analysed only in terms of their entrance ellipse, i.e., the size of their minor and major semi-axes are determined. Provided that the etch rate of the undisturbed detector material, the bulk etch rate, M', is constant throughout the detector material and throughout the etch process, such 2-dimensional measurements are sufficient for the determination of the cone angle of the etch cone which is the feature of the etch track which carries the information on the LET of the particle which generates the track. When the etch track geometry is determined by exploiting the full tree dimensional shape of the etch track, then the bulk etch rate M' can be determined locally for the individual track analysed this way.

I present details about the measurement techniques and the analysis of etch track parameters in 3 dimensions including hard- and software components. Results on the distribution of the local bulk etch rate M' as determined from such 3 dimensional measurements on individual tracks will be presented. Finally their implications for dose determinations via the conventional 2-dimensional measurement of etch track parameters will be discussed.

High energy proton detection by PADC track etch detectors. (Results from Loma-Linda, NSRL-BNL proton IICHIBAN exposures and experiments at TSL accelerator, Uppsala, Sweden.)

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The purpose of the investigations was to determine the number and linear energy transfer (LET) of target fragments produced by high energy protons in a close tissue equivalent solid state nuclear track detector (SSNTD) material. The importance of such studies explained by the fact that protons are the most abundant cosmic ray particles and they can contribute to the dose burden of astronauts via fragmentation interaction.
The chemical formula of the applied SSNTD (polyallyl-diglycol-carbonate, PADC) is $C_{12}H_{18}O_7$, which indicates that p → ^{12}C is the most important fragmentation interaction, however, in practice the ^{16}O fragmentation also may play a considerable role. Sample results obtained from the p → ^{12}C interaction investigations using protons of different energies from 70 to 1000 MeV are presented.
The PADC detectors (TASL, Bristol, UK) are etched in a 6n NaOH solution at 70 ^{o}C for 6 hours, which results in a 8 µm thick layer removal and the development of the latent tracks induced by fragments and recoils.
In an actual case when a detector was exposed perpendicularly to 170 MeV protons with a fluence of 5.5 x 10^8 cm^{-2} the measured track density was found to be 3.8 x 10^4 cm^{-2}. Model calculation showed, however, that the number of fragmentation events in unit volume (1 cm^3) is 2.8 x 10^6, which means that the detection efficiency is around 1.4%.
The track parameters (as diameters, excentricity, area, etc.) are investigated by a semi-automated image analyzer and the track and bulk etch rate ratio (V) is computed. This value is converted to LET applying a calibration function. Investigating many tracks on a large detector area the LET spectrum can be obtained. The track area distribution and LET spectra showed similar feature, having distinct peaks, however, these could not be clearly related to the mass or charge of the fragments. It is observed, that above 300 keV/µm up to ~1000 keV/µm, apart from the fluctuation, the spectra are nearly constant, only slightly decreasing.
Finally, LET spectra of proton induced target fragments were compared to spectra measured in open space during two Foton-Biopan experiments, where the detectors had a thin shielding only. Similar comparisons were made also to LET spectra measured on detectors exposed onboard the ISS, where they were more significantly shielded.

Developments in the determination of the charged particle LET threshold of the HPA-RPD neutron PADC dosemeter, and its relevance to the estimation of neutron doses on the International Space Station.

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Recent exposures to ^{4}He, ^{12}C, and ^{56}Fe ions performed at the HIMAC facility in Japan are being used to give a better understanding of the charged particle LET threshold of the PADC neutron dosemeter using the electrochemical etch method. It is hoped ultimately to obtain a better understanding of the proton LET threshold, so that the unwanted contribution to the total track count from direct protons can be estimated, and discarded from the dose assessment. This will be used to provide a better determination of the neutron and high energy proton dose.

Dosimetry and LET spectrometry in C 290MeV/amu HIMAC ion beam by different TLD's and TED based LET spectrometers

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The sets of track etched detectors (TED) spectrometers of the linear energy transfer (LET) were, together with two types of thermoluminescent detectors (TLD), exposed in ion beam of C 290/MeV/amu at the HIMAC installation at NIRS, Chiba, Japan. The experiment was performed in the frame of NPI project 20P241 agreed by HIMAC PAC at the beginning of 2008 year.
Sets of TED spectrometers and TLD detectors were exposed in 19 depths in the C-ion beam with expected LET values of primary particles from 13 keV/µm in water, through the Bragg peak area up to two depths behind the Bragg peak.
The contribution will present:

- Direct readings of TLDs along the depth, including the estimation of the relative responses (RR);
- Spectra of LET as measured with one type of used TED, again along the depth up to the region behind the Bragg peak.

The results obtained with TLDs will be analyzed from the point of view of the dependences of their RR, they will be compared with regressed dependence obtained previously in heavier charged particle beams during ICCHIBAN program and other occasions.
LET spectra will be compared with the expectation based on some independent estimation (calculations by means of SRIM, and PHITS codes), particular attention will be devoted to the importance of fragments and other secondary particles to the energy deposition in the beam

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Fragmentations as seen in C 290MeV/u, and Ne 400 MeV/u HIMAC ion beams by MDU-Liulin energy deposition spectrometer

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MDU-Liulin equipment is spectrometer of the energy deposited in Si-detectors. For a long time it has been widely used for the measurements in high-energy charged particle beams, onboard space- and aircraft.

Contribution will describe the results of measurements with this equipment performed recently in the beams of HIMAC at Chiba, Japan. The studies have been performed in the beams of:

- Carbon ions with the nominal energy of 290 MeV/amu, and
- Neon ions with the nominal energy of 400 MeV/amu.

The Liulin equipments have been exposed to perpendicularly incident ions with energies up to the limit of their range.

The spectra of energy deposition will be presented for 7 different C-ions entrance energies, resp. 4 for Ne-ions. In some cases, quite good resolution of fragment's charge has been acquired.

The contribution of fragments to total number of events and to the energy absorbed in Si has been determined, when possible separately for different fragments. In all cases also total contribution of fragments (and other secondary particles) to the total number of energy deposition events and to the absorbed dose has been estimated.

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Calibration of the Radiation Assessment Detector (RAD) for the Mars Science Laboratory

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The Radiation Assessment Detector, RAD, is scheduled for launch to Mars aboard the Mars Science Laboratory rover in 2009. RAD will make the first measurements of the radiation environment on the surface of Mars. The environment is expected to be a complicated mix of primary and secondary radiation, with some of the secondaries produced in the thin atmosphere above the surface (approximately 16 g cm^{-2} of CO_2), and others produced in the Martian soil. The environment will be somewhat different from those found in deep space or low-Earth orbit, since a significant fraction of high-energy GCR heavy ions will undergo nuclear interactions in the atmosphere, yielding comparatively high fluxes of light particles including pions and muons. The Pfotzer maximum, which is a maximum of dose rate, is observed at altitudes that correspond to depths of about 50 g cm^{-2} in Earth's atmosphere, so that the Martian surface is effectively "above" the Pfotzer maximum. The RAD team has met the challenging task of building an instrument capable of measuring the many components of this environment while staying within severe constraints on mass, power, and the volume of data that can be returned. We will present results of an ongoing campaign to calibrate and characterize the performance of the instrument.

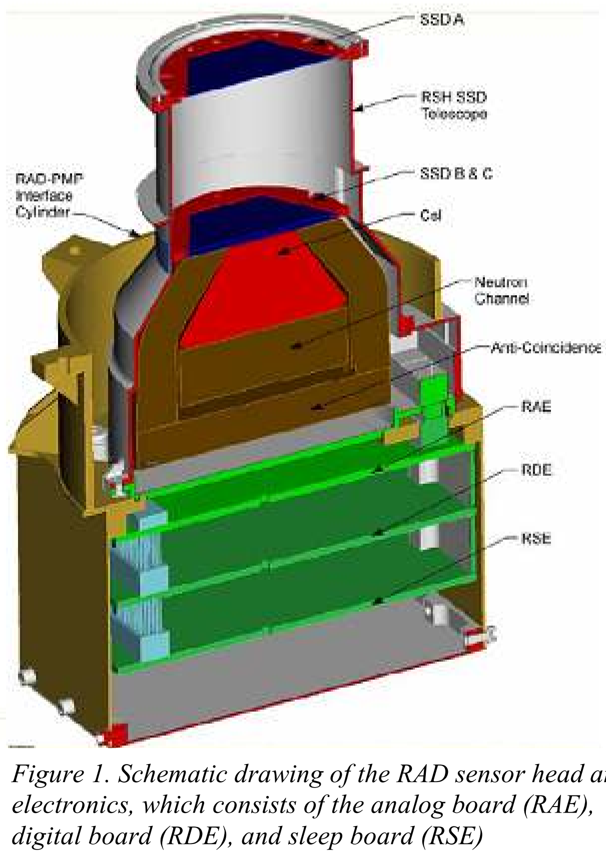

Figure 1. Schematic drawing of the RAD sensor head and electronics, which consists of the analog board (RAE), digital board (RDE), and sleep board (RSE)

The RAD Sensor Head (RSH) consists of six detectors, labeled A through F. The top of the detector stack contains three silicon detectors, A, B, and C. Each is 300 μm in depth, each mounted on a circuit board containing a low-noise charg

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amplifiers (one low gain, one high gain). The D, E, and F detectors are scintillators. All are optically coupled to silicon diodes (made from the same batch of silicon as A, B, and C) which collect scintillation light. These diodes are read out in the same way as A, B, and C. The D detector is CsI(Tl). The E and F detectors are organic scintillators. These detectors are sensitive to neutral as well as charged particles. The E detector is the main neutron detector, and F is an anticoincidence shield for charged particle rejection. On Mars, the signature of an albedo neutron from the surface will be a signal in E and possibly D (if the recoil proton is sufficiently energetic), with no signal in F or any of the other detectors. For neutron energies above 100 MeV, the recoil protons are likely to be energetic enough to escape D and hit the anticoincidence so these events will be rejected. At the lower end of the neutron spectrum, RAD will see a continuous flux due to the Radioisotope Power System (RPS) that provides the power for the rover, so that the measurement energy range is 10-100 MeV.

A calibration campaign has been conducted using the two flight model RAD Sensor Heads (FM RSH's) and an early prototype RSH, along with engineering model RAD Electronics Boxes (EM REB's). Various combinations of RSH's and REB's have been used in particle beams at the Brookhaven National Laboratory's NSRL (protons, ^{12}C at 290 MeV/nuc, and ^{56}Fe at 1 GeV/nuc), PTB (5, 14, and 19 MeV neutrons), and iThemba Labs (100 MeV neutrons). Data from these runs will be presented, and will be used to demonstrate that RAD meets the design requirements. Additional calibration runs are planned using the final flight model RAD in a proton beam at Loma Linda University, and using the flight spare RSH in heavy ion beams at HIMAC in early 2009.

The calibration data show that the performance of all detectors and electronics is nominal. The calibration of the silicon detectors (A, B, and C) is straightforward. Calibration of D and E is more involved due to quenching effects, which are well-known in both organic and inorganic scintillators. With areal density of about 12.6 g cm^{-2}, the D detector is by far the most massive in the stack, and it will stop many low-energy charged particles, whether they are incident from above, or recoil protons produced by neutrons in the E detector below. An example of quenching in D is shown in Fig. 2 for 1 GeV/nuc ^{56}Fe beam on a 3 g cm^{-2} CH_2 target at the NSRL. The CsI(Tl) response deviates only slightly from linearity for these high-energy particles. In general, the quenching behavior in CsI depends on the charge and energy of the particle, so a full characterization of the response requires a variety of beams and energies. The NSRL data obtained so far cover much of the LET range of interest, and lower-energy heavy ion beams that will be used at HIMAC (^{56}Fe at 500 MeV/nuc and ^{28}Si at 400 MeV/nuc) will cover the rest. The response of D and especially E to neutrons, and the statistical separation of gamma rays, will also be discussed.

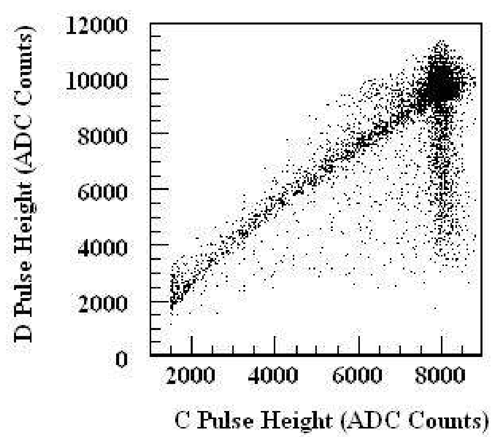

Figure 2. Scatter plot of pulse height in D, the CsI(Tl)detector, vs. pulse height in the C silicon detector, for 1 GeV/nuc ^{56}Fe incident on a 3 g cm^{-2} polyethylene target.

Development of Tissue Equivalent Detectors for Space Crew Dosimetry
and Characterization of the Space Radiation Environment

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The Radiation Physics Laboratory at Oklahoma State University (OSU) is beginning its second year of a three-year grant from the NASA Experimental Program to Stimulate Competitive Research (EPSCoR) to develop, fabricate, and test a progressively sophisticated and capable series of compact, self-contained tissue-equivalent ionization chambers and proportional counters in order to investigate alternative tissue equivalent and tissue-like materials, anode designs, spectrometer circuitry, and approaches to neutron/charged particle discrimination for real-time space radiation dosimetry. During the first year of the project, we developed several low current, low noise electrometer circuits for use in portable ionization chambers and tested a number of charge-sensitive preamplifiers and amplifiers for use in both ionization chambers and proportional counters. We also designed, fabricated, calibrated, and tested the Balloon-Borne Ionization Chamber (BBIC). This 8 liter plastic ionization chamber is capable of measuring dose rates from 0.1 to 10 μGy/hr and was successfully tested during a ~2 hour balloon flight up to an altitude of ~32 km conducted by the OSU ASTRO program over central Oklahoma. The BBIC will serve as the centerpiece of a Near Space Standard Science Platform (NS^3P) for use by high school and college students conducting experiments with high altitude balloons in order to promote Science, Technology, Engineering, and Mathematics (STEM) education and interest in NASA's mission throughout the USA. We are currently developing a 2" diameter spherical acrylic proportional counter which we plan to calibrate and test in early 2009.

A Possible New Generation Personal Dosimeter TEPSC (Tissue Equivalent Plastic Scintillator Counter)

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The JSC (Johnson Space Center) - SRAG (Space Radiation Analysis Group) has been using the combined passive dosimeters - CR-39 plastic nuclear track detectors (PNTDs) sensitive to high LET (≥ 10 keV/µm water) + thermoluminescence dosimeters (TLDs)/optically stimulated luminescence dosimeters (OSLDs) sensitive to low LET (≤ 10 keV/µm water) to measure the space radiation experienced by astronauts and for the different monitored areas inside spacecraft. However the approach of TLD/OSLD + CR-39 cannot be used for on-site radiation monitoring which is necessary for future human space flights to the Moon and Mars.

A possible new generation active dosimeter which may satisfy NASA requirements for future human flights to the Moon and beyond is the TEPSC (Tissue Equivalent Plastic Scintillator Counter). This dosimeter is being developed by Radiation Monitoring Devices Inc. (RMD) with NASA's support. The new dosimeter is composed of a small area of tissue equivalent plastic scintillator (TEPS) and a solid-state photomultiplier (SSPM).

The light response of the plastic scintillator to relativistic nuclei (Z = 1- 26, E = 0.1 - 10 GeV/n) is the most important aspect of the TEPSC. The most recent and relevant research work in this area was carried out in the 1980s by researchers at the University of Chicago (UC) using their abundant experimental data obtained from high energy cosmic ray physics. UC researchers proved that the BTV (Birks-Tarle-Voltz) core-halo model for the light response of plastic scintillator to relativistic nuclei is the most successful and determined all the physical parameters in the BTV model.

A very important part of data analysis work for TEPSC is to look for a function to convert the light energy measured to the total energy loss in the plastic scintillator. This work was completed recently in SRAG through systematic calculation and research using the BTV core-halo model and the related parameters in the response formula.

This paper discusses the requirements for the new generation active dosimeters and the physical principles for the TEPSC and presents the conversion function to determine the total energy loss in the plastic scintillator using the light energy measured.

Next Generation Radiation Monitoring for the ISS

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NASA has recently initiated development of replacement active radiation monitoring hardware to meet the monitoring needs of NASA for the remaining life of the International Space Station. Three active instruments are under development: 1) A Tissue Equivalent Proportional Counter for IVA use, 2) A Tissue Equivalent Proportional Counter for EVA environmental monitoring, and 3) an adaptation of the Mars Science Laboratory Radiation Assessment Detector for use on ISS. These instruments will replace the existing suite of ISS monitoring instruments upon completion of development. Instrument performance details, timeline for instrument transition, and monitoring approach prior to and following replacement hardware delivery will be presented.

European Crew Personal Active Dosimeters (EuCPAD)
Part1: Review on existing devices (M. Luszik-Bhadra)
Part2: Numerical simulations (S. Rollet)
Part3: Draft design (G. Reitz)

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A feasibility study was set up by ESA to select an appropriate radiation detector system which could serve as “European Crew Personal Active Dosimeters” (EuCPAD). The study comprises reviews and analysis on commercial and scientific radiation systems already in use on Earth and in space. In course of this review, data on existing active personal dosemeters as used on earth are updated to include newest information on high energy responses and experience with their performance at workplaces. Some new technologies which are still under research are presented as well. Further on the numerical simulation of radiation effects is carried out for selected active detector systems. Particle, energy and incidence response are calculated for different particles using Monte Carlo transport codes such as FLUKA, GEANT4 and PHITS. These investigations have provided the conceptual bases for the selection of the most appropriate detector system. A preliminary concept of the EuCPAD finalizes the presentation.

Comments and Suggestions for Space Radiation Research

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One of the main purposes of radiation measurements in space is to determine the radiation risk for astronauts and it is useful from time to time to look at the present status of the work and consider any new strategies that may improve results.

Research conducted previously indicates that the biological impact and the radiation risk is dominated by high LET ($\geq$ 5 keV/μm water) and that to determine radiation risk the LET spectrum with high LET should be measured. So far the LET spectra with high LET for astronauts can only be measured with CR-39 plastic nuclear track detectors (PNTDs).

In addition to the traditional simulation approach to obtain radiation risk for astronauts, radiation risk can also be calculated using an experimental method based on the risk cross section determined by radiobiology and the LET spectra measured with CR-39 PNTDs. Both the simulation method and the experimental method have their own advantages and disadvantages. Therefore to determine the radiation risk as accurate as possible the two methods should be combined.

This paper will present some comments and suggestions for future work in space radiation research, especially for the radiation risk estimation and the LET spectrum method using CR-39 detectors.

A possible new generation personal dosimeter TEPSC (Tissue Equivalent Plastic Scintillator Counter) which may satisfy NASA requirements for the future human flights to the Moon and to Mars will also be discussed.

LATE ABSTRACT

CHARACTERISING PASSIVE DOSEMETERS FOR DOSIMETRY OF BIOLOGICAL EXPERIMENTS IN SPACE (DOBIES)

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Introduction:

The DOBIES (Dosimetry of biological experiments in space) project focusses on the use of a standard dosimetric method (as a combination of different passive techniques) to measure accurately the absorbed doses and equivalent doses in biological samples. Dose measurements on biological samples are of high interest in the fields of radiobiology and exobiology. Radiation doses absorbed by biological samples must be quantified to be able to determine the relationship between observed biological effects and the radiation dose.

The radiation field in space is very complex, consisting of protons, neutrons, electrons and high-energy heavy charged particles. It is not straightforward to measure doses in this radiation field, certainly not with only small and light passive dosemeters. The properties of the passive detectors must be tested in radiation fields that are representative of the space radiation.

We will report on the characterisation of different type of passive detectors at high energy fields. The results from such characterisation measurements will be applied to recent exposures of detectors on the International Space Station.

Material and methods:

Following passive detectors are used:

- thermoluminescent detectors (TLD)
- optically stimulated luminescence detectors (OSLD)
- track etch detectors (TED)

The different groups have participated in the past to the ICCHIBAN series of irradiations. Here protons and other particles of high energy were used to determine the LET-dependency of the passive detectors. The last few months, new irradiations have been done at the iThemba labs (100-200 MeV protons), Dubna (145 MeV protons) and the JRC-IRMM (quasi mono energetic neutrons up to 19 MeV). All these detectors were also exposed to a simulated space radiation field at CERN (CERF-field).

Discussion:

The interpretation of the TLD and OSLD results is done using the measured LET spectrum (TED) and the LET-dependency curves of ths TLD and OSLDs. These LET-dependency curves are determined based on the different irradiations listed above. We will report on the results of the different detectors in these fields.

Further information on the LET of the space irradiation can be deduced from the ratio of the different peaks of the TLDs after glow curve deconvolution, and from the shape of the decay curve of the OSLDs.

The results in the CERF field can on the other hand directly being used as a calibration for space radiation fields.

Conclusion:

Combining different passive detectors will lead to improved information on the radiation field, and thus to a better estimation of the absorbed dose to the biological samples. We use the characterisations on high energy accelerators to improve the estimation of some recent space doses.