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Fragmentation Measurements for GCR Transport

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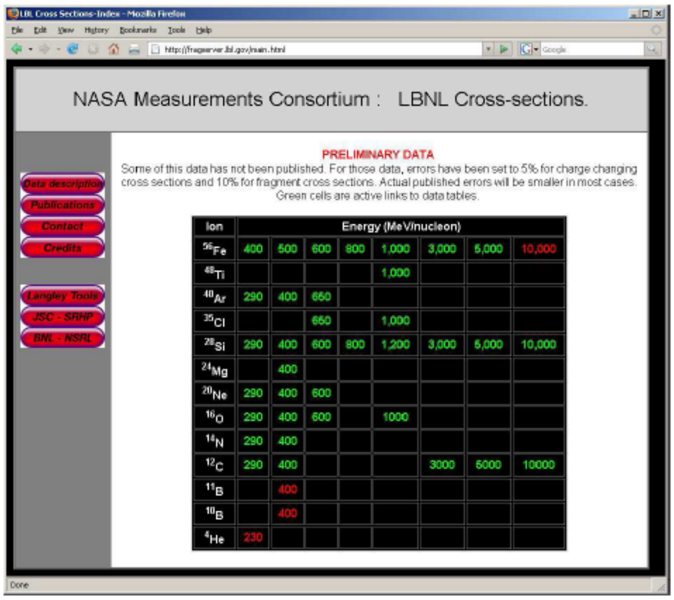
The LBNL group is concluding a series of accelerator experiments in which we have measured fragmentation cross sections of GCR-like ions. A large database of cross sections is available on the web, and many results have been published recently, with more to come in the near future. The data come from two accelerators at the Brookhaven National Laboratory, the AGS and NSRL, and from the HIMAC accelerator at the National Institute of Radiological Science in Chiba, Japan. The ions measured and their energies are shown in Figure 1 below, which is a screenshot of the front page of our web site, http://fragserver.lbl.gov/main.html . Entries in green indicate that the data have been partly or entirely analyzed, and visitors to the web site can click on these links to see tables of cross sections. Cells with red font correspond to data sets that have not yet been analyzed; only a few remain. The measured ion species range from He to Fe, and energies range from 230 MeV/nuc at the low end to 10 GeV/nuc at the high end.

The measured cross sections are of two types, "total" charge-changing, and fragment production, which are partials. Several groups have previously reported measurements for many of the ions and energies studied by our group, but our database has some unique features. First, data have been obtained for targets spanning the periodic chart from hydrogen to lead., as our standard list of targets includes C, CH_2, Al, Cu, Sn, and Pb. The large data sets that were previously reported were focused on H targets, since those cross sections are essential for understanding the propagation of Galactic Cosmic Rays through interstellar space. Second, we deploy detectors far from the target, subtending small acceptance angles. Typical fragmentation experiments report cross sections for fragments with charges Z greater than about half the beam Z, i.e., $Z_f \geq Z_{beam}/2$. The reason for this is demonstrated in Figure 2, which shows both a large-acceptance fragment spectrum (left) and a small-acceptance spectrum (right) obtained with a 650 MeV/nuc ^{40}Ar beam on a CH_2 target. Most previous experiments were performed with large-acceptance detectors, and this example – which is typical – shows that fragment peaks cannot be resolved below about $Z_{beam}/2$ in large acceptance spectra. This is due to combinatorics when there are only relatively light fragments in the event. At small acceptance, the average multiplicity is lower, so that peaks for all fragment species (and a couple of interesting combinations) can be seen and cross sections can be extracted, with the caveat that corrections for angular acceptance are needed. The third and final unique feature of the LBNL database is its sheer size: When complete, the database will contain over 200 charge-changing cross sections and over 2000 fragment production cross sections, most of which have not been measured before.

In addition to analyzing the data for cross sections, it is also possible to study the shielding properties of various materials. Using both data and Monte Carlo calculations, we have verified theoretical work by Wilson et al. showing that hydrogen provides the most effective shielding against GCR ions per g cm^{-2} of shield. Many targets placed in the 1 GeV/nuc iron beam at the AGS have been compared for their shielding effectiveness, and the results are shown in Figure 3. Looking at the problem from another angle, we have studied the effectiveness of a particular depth of polyethylene with many beams. We find that virtually any species of heavy ion can serve as a good proxy for the GCR, provided the beam energy is 1 GeV/nuc or preferably higher.



Ion	Energy (MeV/nucleon)							
^{56}Fe	400	500	600	800	1,000	3,000	5,000	10,000
^{48}Ti					1,000			
^{40}Ar	290	400	650					
^{35}Cl			650		1,000			
^{28}Si	290	400	600	800	1,200	3,000	5,000	10,000
^{24}Mg		400						
^{20}Ne	290	400	600					
^{16}O	290	400	600		1000			
^{14}N	290	400						
^{12}C	290	400				3000	5000	10000
^{11}B		400						
^{10}B		400						
^{4}He	230							

Figure 1. The front page of the LBL group's fragmentation data web server.

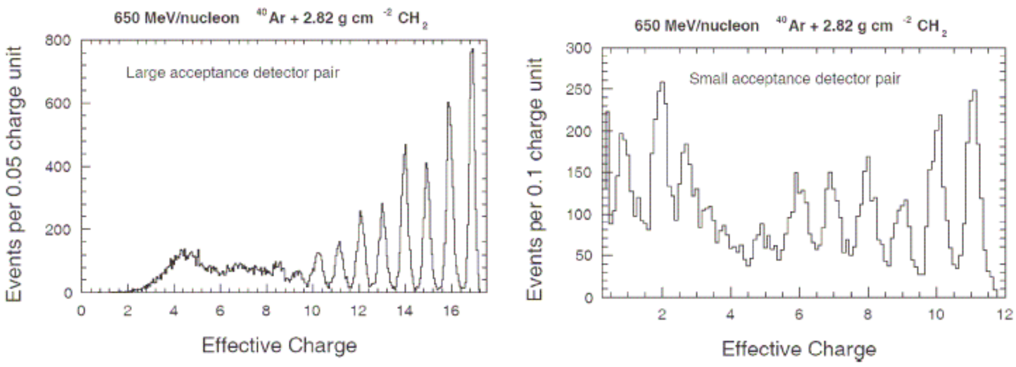


Figure 2, Charge distributions obtained at large acceptance (left) and small acceptance (right) for the same beam and target.

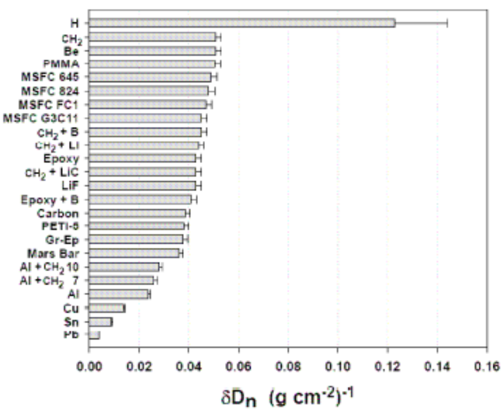


Figure 3. Dose reduction per g cm^{-2} of shield mass (δD_n) for a variety of materials placed in the 1 GeV/nuc ^{56}Fe beam at the Brookhaen AGS. A larger value of δD_n indicates more effective shielding. The higher the mass number of the material, the less effective it is, in accordance with calculations for the full GCR by Wilson et al. Hydrogen data were extracted from C and CH_2 data using a method similar to that used for cross section analysis, with the result that H is found to be far and away the best material for this application. Several composite materials give results comparable to, but not quite as good as, polyethylene. In general, the more hydrogenous the shielding material, the better.

Environmental Models and Validation of Engineering Designs

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Abstract

Constellation Program development schedules place the first uncrewed flight of the Crew Exploration Vehicle (CEV) in 2010 giving the first opportunity to validate this new shield design. Prior to this test, an improved understanding of the Low-Earth Orbit (LEO) environment is required for an adequate evaluation of the CEV shield prior to Lunar operations. Unfortunately, even preliminary environmental models under development in the Living With a Star (LWS) Program (AP9 beta version) will not be available until 2010 and a modified set of AP8-based models (modulated and drifted with anisotropies) will still play an important role over the next few years. The International Space Station (ISS) is an important test bed for the LEO models prior to CEV testing. Still the best long term dataset consists of measurements with a Tissue Equivalent Proportional Counter (TEPC) aboard the Mir spacecraft extending over several years (1994-1999) of near continuous operation. A combined study of TEPC data aboard Mir and Shuttle allows representation of one complete solar cycle (Solar Cycle 22/23) to better establish the corresponding modulation factor within the context of the AP8 models. Still the dynamic range covered by the Mir/Shuttle data is disappointingly similar to Solar Cycle 20 (Sunspot Numbers of 10-120). Other variables such as distribution in latitude and longitude as well as anisotropies can be tested but modulation during high Sunspot Numbers 200 and over as observed in the past is not possible with the present datasets.

Radiation Protection Strategy for the Orion/CEV Program: A Contractor's Perspective

Razvan Gaza, Tim Cooper, Hesham Hussein, Kandy Jarvis, Anna Mytyk, Chirag Patel, Brandon Reddell, and Tad Shelfer

Lockheed Martin is the prime contractor chosen to design and build the next generation of manned spacecraft. It is projected that Orion, as an integral part of NASA's Constellation program, will be the vehicle carrying humans to the Moon and onward to Mars. Such long-term missions carry increased risk for acute and long-term detrimental health effects to the crew due to extended exposure to the space radiation environment outside Earth's magnetosphere. To mitigate this risk, a model-integrated analysis of crew exposure is performed as early as the design phase, and radiation protection considerations derived from this analysis are iteratively incorporated in the design of the vehicle.

This presentation provides an overview of the radiation analysis performed by the contractor in the context of implementing ALARA, and includes descriptions of the crew radiation exposure requirements, analysis approach, input data – vehicle and human models and environment definitions, radiation transport and dose estimation tools.

Preliminary results indicate that in contingency situations (i.e., during a Solar Particle Event) the Orion crew must take shelter under a deployable radiation shield in order to maintain their exposure below the limit specified in the requirements.

Active and passive radiation monitoring on board the Orion vehicle are also discussed, with an emphasis on requirements and the current approach to the development of active dosimetry instrumentation.

Minimizing Astronauts' Risk from Space Radiation during Future Lunar Missions

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In the design of lunar exploration missions, assessments of radiation risk and optimization studies are required in support of resource management decisions, operational planning, and go/no-go decisions. To fulfill such requirements, the future space radiation environments must be estimated accurately. The galactic cosmic radiation (GCR) flux for the next solar cycle was estimated as a function of interplanetary deceleration potential, which was coupled with the estimated neutron rate of the Climax monitor using a statistical model. A probability distribution function for solar particle event (SPE) occurrence was formed from the combined database of proton fluence measurements of SPEs that have occurred during the past 5 solar cycles (19-23) and those of large proton SPEs that were identified from impulsive nitrate enhancements in polar ice. The probability with which any given proton fluence level of a SPE will be exceeded during a space mission of defined duration was then calculated using a Poisson process model. Analytic energy spectra of SPEs at different ranks of the integral fluences were constructed over broad energy ranges extending to GeV, and representative exposure levels at those fluences were analyzed. For the development of an integrated strategy of optimizing radiation protection on lunar exploration missions, radiation risks at various points inside a spacecraft and a rover were calculated with detailed geometry models that represent proposed transfer vehicle and rover concepts.

Recent Shuttle and ISS radiation measurements: STS-121, STS-115, STS-116, STS-117 and ISS Expedition 13

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Monitoring space radiation is of vital importance for risk reduction strategies of current (Space Shuttle and International Space Station) and future (Lunar and Mars) human space exploration missions. The radiation environment in space consists of a complex variety of highly energetic particles such as protons, electrons and heavy charged particles with a wide distribution of linear energy transfer (LET) values. Maintaining the ALARA principle that governs the radiation protection program for astronauts in Low-Earth Orbit involves following the National Council on Radiation Protection recommendation for passive radiation dosimetry monitoring, namely to use a combination of thermally/optically stimulated luminescence dosimeters (TLDs/OSLDs) for the low-LET region (LET<10 $keV/\mu m$ water) of the space radiation spectrum and plastic nuclear track detectors (PNTDs) for the LET>10 $keV/\mu m$ (water) region (NCRP, 2004). This combination of radiation detectors has been successfully implemented at NASA Johnson Space Center for routine monitoring of crewmembers and area monitoring at different locations throughout the Space Shuttle and International Space Station starting July 2005. A summary of the absorbed dose and dose equivalent results for the most recent Shuttle and ISS flights (STS-121, STS-115, STS-116, STS-117, and Expedition 13) will be presented.

Dosimetry oF Biological Experiments in SPACE (DOBIES) with LUMINESCENCE (OSL and TL) AT THE SCK-CEN

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Abstract:

The effects of the complex radiation field in space, consisting of protons, neutrons, electrons and high-energy heavy charged particles, 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. For radiation protection purposes the effective doses to astronauts need to be assessed, while in dosimetry for biological experiments the absorbed dose and the equivalent doses to the samples need to be known. Special techniques and correction methods combining luminescence detectors and track etched detectors are required due to the presence of particles with a wide range of LET (Linear Energy Transfer) values. The DOBIES (Dosimetry of biological experiments in space) project focusses on the development of a standard dosimetric method (as a combination of different techniques) to measure accurately the absorbed doses and equivalent doses in biological samples.

We will report on the first efforts in this project, where different types of passive detectors have been exposed on the International Space Station during one mission in 2006. Different types of thermoluminescent detectors (TLD) were sent with the experiment: MTS-100, MTS-600, MTS-700, MCP-N, MCP-600, MCP-700. and Al_2O_3:C have been exposed during BASE A flight. At the same time different types of CR 39 have been exposed. The detectors were sent as radiation sensors on a microbiological experiments: BASE A. The BASE A experiment took place from 18/09/2006 to 29/09/2006 as part of the ISS Soyuz mission 13S. All these detectors were also exposed to a simulated space radiation field at CERN (CERF-field), and to standard high LET irradiation fields (ICCHIBAN-series).

The TLD and results from BASE-A are discussed, and compared to earlier flights. The interpretation of the TLD and OSLD results is done using the LET-dependency curves. These are taken from the literature and irradiations in standard high energy particle fields on earth.

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. For biological experiments a small, passive and convenient detector is necessary. A combination of only TL and OSL detectors can give a good estimation of the absorbed dose.

Space radiation dosimetry by PADLES in the ISS Russian segment to evaluate the effect of crew-cabin shielding (ALTCRISS Project Phase 1 and 2)

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The ALTCRISS project has been conducted by the National Institute of Nuclear Physics (INFN) in Italy in order to evaluate the effect of the crew-cabin shielding by using an active detector (sileye/alteino cosmic ray detectors) and three kinds of passive dosimeter packages (DLR, Napoli and JAXA) in International Space Station Russian segment. The duration of ALTCRISS Phase 1 experiments was 108 days from December 2005 to April 2006, Phase 2 was 158 days from April to September 2006, phase 3 was 215 days Sep 2006 to April 2007, and Phase 4 will be conducted from Sep 2007.

The passive dosimeters were installed in three conditions: between polyethylene blocks, in a zip bag without the polyethylene blocks and at ground (Baikonur Cosmodrome). The polyethylene blocks (thickness of $5g/cm^2$) was equivalent to the crew-cabin shielding of a US module. With relocating the active detector, the passive dosimeters between polyethylene block and in zip bag without the polyethylene were also relocated in PIRS and ZVEZDA module.

We report the results of space radiation measurements of the ALTCRISS project Phase 1and Phase 2 using the PADLES system.

The PADLES package consists of two types of passive and integrating dosimeters, a CR-39 plastic nuclear track detector (HARLTZLAS TD-1: Fukivi Chemical Industry) and a thermoluminescence dosimeter (TLD-MSO-S: Kasei Optonics, LTD.). Tissue-equivalent material~~s~~ (NAN-JAERI) were also enclosed in PADLES packages as a radiator for CR-39 to precisely measure a personal exposed dose. We compared the doses obtained by PADLESs with or without the polyethylene blocks, and with or without the tissue-equivalent material. The results indicated that the polyethylene blocks and the radiator of the tissue-equivalent material for CR-39 did not affect the measured doses and LET distributions.

TL dose measurements on board the Russian segment of the ISS by the "Pille" system during Expedition-13 and -14

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The most advanced version of a thermoluminescent (TL) dosimeter system ("Pille-MKS") consisting of ten $CaSO_4$:Dy bulb dosimeters and a compact reader, developed by the KFKI Atomic Energy Research Institute (KFKI AEKI) for application in space is continuously in use on board the ISS since October, 2003. The Pille-MKS dosimeter system is applied for the routine and EVA individual dosimetry of astronauts as part of the service system as well as for onboard experiments and operated by the Institute for Biomedical Problems (IBMP). It is unique providing accurate and high resolution TL dose data already on board the space station which became increasingly important during the suspension of the Space Shuttle flights.

Seven dosimeters are located at several places of the Russian segment of the ISS and read out once a month, two dosimeters are dedicated for EVAs and one dosimeter is kept in the reader and read out automatically every 90 minutes providing high resolution in time. During particular events, like coronal mass ejections, hitting Earth, incidental measuring campaigns are intercalated with frequent readouts.

In this paper we report results of dosimetric measurements made aboard the International Space Station during Expedition-13 and -14 using the "Pille" portable TLD system and compare them with our previous measurements on the ISS and previous space stations.

During his 12-day stay onboard the International Space Station (ISS) in April 2007, spaceflight participant Charles Simonyi performed the scientific research program "Pille-Simonyi" on behalf of the Hungarian Space Office in co-operation with the Federal Space Agency of the Russian Federation.

The goal of the program was to measure Ch. Simonyi's personal dose with a high (daily) time resolution as well as the dose at his sleeping place; to supplement the radiation map of the Zvezda module and to update some parameters of the Pille dosimeters characteristic to their aging as these dosimeters are permanently in use on board since 2003. Results of the measurements are also detailed in this paper.

High LET Radiation Measured for STS-116 with CR-39 PNTDs

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Abstract

Radiation research indicates that the impact to human tissues from radiation exposure is strongly related to the LET (Linear Energy Transfer) of the particles and particles with high LET (≥ 5 KeV/μm water) dominate the damage. High LET radiation in LEO (Low Earth Orbit) is composed mainly of GCR (Galactic Cosmic Rays), SEPs (Solar Energetic Particles) and particles trapped in the SAA (South Atlantic Anomaly) and should be emphasized and measured for all the space missions. At present stage, the active personal dosimeters are not available and the best passive personal dosimeters for measuring radiation with high LET are CR-39 PNTDs (Plastic Nuclear Track Detectors). Radiation LET spectra (differential and integral fluence, dose and dose equivalent) for STS-116 space mission were measured with CR-39 PNTDs for both astronauts and different locations inside the spacecraft. The radiation impact for astronauts can then be estimated using the differential fluences measured with CR-39 detectors. This paper introduces the method of measuring the LET spectrum using CR-39 detectors, presents the experimental results measured by CR-39 for different locations inside the spacecraft and compares the results with high LET measured with active dosimeter TEPC (Tissue Equivalent Proportional Counter) and passive CR-39 PNTDs attached to TEPC.

Tissue Equivalent Proportional Counter Measurements During Recent Shuttle flights and ISS Expedition 15

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The low-Earth orbit (LEO) radiation environment was measured with the Shuttle tissue equivalent proportional counter (TEPC) during three recent shuttle missions: STS-121, STS-116, and STS-118. The TEPC on-board ISS failed in July 2006 and was replaced with a backup unit launched on STS-117. The backup ISS TEPC began operation on 6/15/2007 and will begin serving as the primary reference instrument after the completion of a short term checkout period. We report on the measurements made by the Shuttle and ISS TEPCs and present dose, dose equivalent, and average quality factor for the trapped, galactic cosmic ray (GCR), and solar proton components of the radiation field.

Charged Particle Directional Spectrometer CPDS
Measurements of the December 2006 SPEs

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The low-Earth orbit (LEO) radiation environment during the December 2006 solar particle events (SPEs) was observed by the IV and EV charged particle directional spectrometers (CPDS) aboard the International Space Station (ISS). The EV instrument is mounted on the S0 truss of the ISS and consists of three separate silicon detector telescopes which are oriented in different directions. The IV instrument is a single silicon detector telescope located inside the USA Laboratory module of the ISS. We report on the measurements made by the CPDS instruments and compare them to measurements made by other instruments.

New Results for the Earth Radiation Environment

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Data obtained by Liulin type instruments on ISS, Foton M2 satellite and aircrafts since 2001 are analyzed to try to evaluate the contribution of neutron component in the spectra of energy deposited in Si-detector. The dose in Si, D(Si), was converted to obtain an apparent dose equivalent H_{app}. The conversion coefficients used were obtained during calibrations of Liulin type instruments at the CERN (CERF) and on the base of intercomparison with TEPC during common measurements in dedicated aircraft flights. Obtained data for GCR and trapped radiation components are compared with the NASA Phantom TORSO TEPC and DLR DOSTEL data. A good agreements is observed between D(Si) data obtained by Liulin and DOSTEL. Liulin MDU values of H_{app} obtained as mentioned above in general underestimate a little the neutron component obtained by TEPC. Best agreement with the values results of the comparison with TEPC are obtained at L>2.8. Worst are the results of the comparison when taking the data registered in SAA region. It could be expected because the procedure mentioned is based on D(Si) distribution typical for the regions outside of SAA. As expected the other radiation belt spectra contains very low neutron component in the spectra. Some new results recently obtained from the analysis of the ISS Liulin data are shown also. Expected new space experiments with Liulin type spectrometers on Foton M3 satellite, ISS and Indian Moon Chandrayaan-1 satellite are shortly presented.

ALTEA status and perspectives

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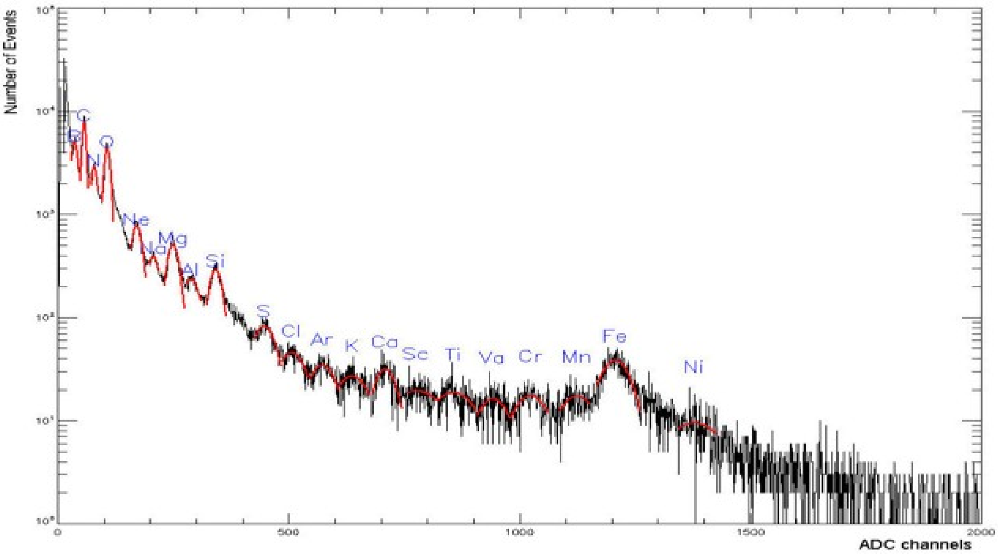
ALTEA is a program aimed at studying the radiation environment in the International Space Station (ISS) and the effects of the ionizing radiation on brain functions, proposing risk parameters and possible countermeasures. CNS effects due to prolonged exposure to ionizing radiation in space is conceivably to increase during manned voyages to the Moon and Mars, outside the geomagnetic shield.
This talk will be focused on the activity with the ALTEA hardware on the ISS. The ALTEA hardware consists in 6 active particle telescopes each with 6 *stripped* planes of silicon (8 x 16 cm^2 each). ALTEA-space experiments are aimed at investigating the radiation environment in the ISS and the changes on the



astronauts' brain dynamics in relation to the energy deposited by each particle passing through their brain; The ALTEA space hardware [1-2] started operations in the ISS, USLab, in August 2006. As an example of the results the energy spectrum measured by the ALTEA detectors in the first 3 months of operation is shown in the figure.
ALTEA was operative during the Dec 2007 solar flare and preliminary results regarding this event will be presented.
The ALTEA data stream is routed directly in our User Home Base in Rome, and at JSC, following an agreement with NASA still in draft form. Access to data through our database will be provided following submission of a very simple request form.
ALTEA has been switched off at he beginning of August 2007, in order to upgrade the NASA Rack Laptop, and we are working to have the detectors on line again as soon as possible. ALTEA-shield, a follow up experiment with the ESA sponsorship will start as soon as next spring.
Since the operation beginning we also performed 7 sessions with the astronauts measuring concurrently the ions passing through their brain and the electrophysiological brain activity. Preliminary results will be presented.
Results, status of the art and perspectives of the project will be discussed.

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Measurements of the Radiation Environment in Mars Orbit

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Stephen Guetersloh, NASA-JSC
Kerry T. Lee, Lockheed Martin Aerospace Co.

Despite many problems with the performance of the hardware, new and unique results from the MARIE experiment aboard the 2001 Mars Odyssey spacecraft have been obtained for a limited number of ions and energies. The primary problem with MARIE, which operated for 20 months in 2002 and 2003, was a severely limited dynamic range in the readout of the silicon detectors; two additional important problems were the the excessively long readout time per event, and the failure of the Čerenkov detector, which was intended to provide a signal that would distinguish between particles that entered the detector from the front vs. those that entered from the back. The rate problem necessitated higher than optimal settings of the trigger threshold, which in turn caused a low (and difficult to determine) efficiency for detection of high-energy protons. These shortcomings lead to considerable difficulty when attempting to normalize results to physically meaningful quantities like flux and dose. The limited dynamic range resulted in saturation above LET of about 33 keV/μm, so that particles heavier than Mg cannot be identified. Therefore dose equivalent cannot be calculated without model input.

A typical deposited energy (ΔE) spectrum from MARIE is shown as the black histogram in Figure 1, with minimal cuts on data quality. A χ^2 method has been developed to estimate the most probable combination of charge, energy, and direction of the incident particles based on all usable detectors in the stack. For many events, no good solution is found. The blue histogram in Figure 1 shows the events in which a reasonable solution was found, for either or both the forward-going and backward-going hypothesis. In Figure 2, a scatter plot of ΔE in B4 vs. ΔE in B1 is shown, for a small sample of events, in order to demonstrate the clear presence of relatively low-energy protons and helium ions. Low-energy particles are easily identified and their directions are obvious. There are relatively few such particles, and they are of interest for purposes of studying the effect of solar modulation on GCR fluxes, providing useful comparisons to models. (They do not, however, account for much of the dose.) The limited dynamic range, coupled with the fact that Li and Be ions are rare in the GCR, dictates that we can determine fluxes of low-energy particles only for He and C. The energy ranges are limited, at the low end, by the requirement that the particle can penetrate several detectors and not drive the readout into saturation, and at the high end by the requirement that the direction of the particle be distinguishable. For He, the energy range within these constraints is from 150 to 300 MeV/nuc; for C, 170 to 260 MeV/nuc. The results for carbon can be compared to ACE/CRIS measurements for the same time period, in the same energy range, and the two measurements are found to be in good agreement. The results for helium are, to our knowledge, the only such flight measurements for this time period. The measured fluxes are generally higher than those predicted by the Badhwar-O'Neill model by about 30-50%.

High-energy C, N, and O can also be identified in the MARIE data. The peaks are visible in Figure 1, especially in the blue histogram. Because the distributions of individual ions overlap, it is best to group them together. The ion direction cannot be determined for these events, so a larger geometry factor must be used, and we must use a Monte Carlo simulation to estimate the contamination from heavier ions that interact in the spacecraft. Since there are no other measurements of high-energy GCR in this time period, the CNO flux can only be compared to the Badhwar-O'Neill model, and again the measured fluxes are found to be higher than predicted by a factor of almost 2. Implications of this disparity will be discussed.

A brief discussion of the continuing efforts to monitor the radiation environment in Mars orbit using the Gamma-Ray Spectrometer and High Energy Neutron Detector systems aboard Odyssey will also be given.

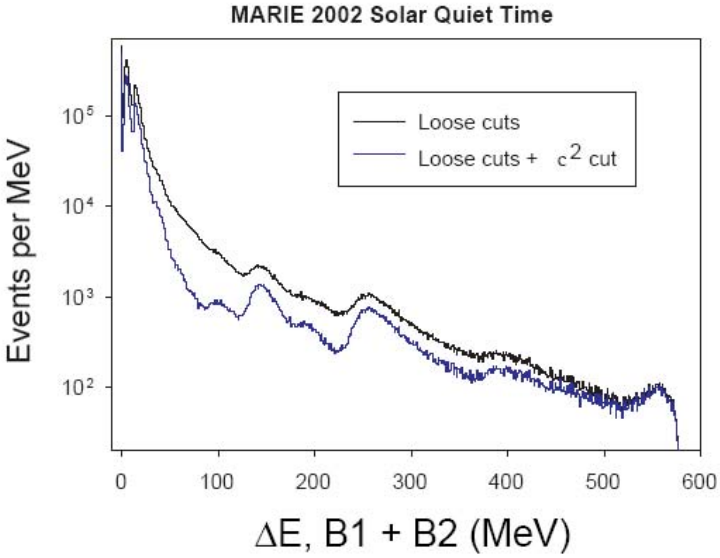

Figure 1. Spectrum of summed deposited energy in the first two 5mm thick detectors in the MARIE stack. The broad peak centered at about 100 MeV is due to boron, with peaks for C, N, and O also visible. Cuts have been made to remove events that caused saturation of either or both detectors.

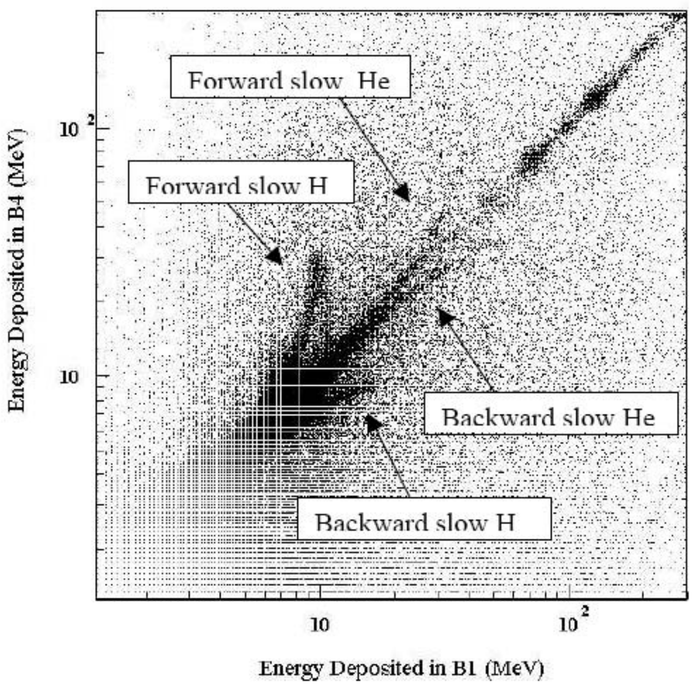

Figure 2. Scatter plot of the deposited energy in the last 5mm thick detector in the stack (B4) vs. that in the first 5mm thick detector (B1). Low-energy protons and He ions populate the indicated regions. The subset of the data shown in this plot represent about 3% of the total acquired in 2002. With the full statistics, a band of events due to low-energy carbon ions can also be seen.

MATROSHKA 2 A – Preliminary DLR Results

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The MATROSHKA 2 A experiment aimed as a successor of MATROSHKA 1 for the depth dose and skin dose determination of a simulated anthropomorphic phantom inside the International Space Station. The MATROSHKA 2 A experiment started with the launch of the new passive detector set in December 2005. After integration of the detectors into the facility in January 2006 the exposure time lasted till December 2006. Detectors were brought down with STS-.116 on the 22nd of December 2006 and distributed to the co-investigators in spring 2007. Passive detector systems from TLD, namely ^{6}LiF: Mg, Ti (TLD-600) and ^{7}LiF: Mg, Ti (TLD-700) were distributed in the NTDP boxes, the TLD tubes and mounted in polyethylene stripes directly on the poncho – acting as skin dose detectors. First preliminary results of the MATROSHKA 2 A detectors from DLR will be presented and discussed.

Preliminary TLD results of the MATROSHKA-2a experiment

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During the MATROSHKA-2a experiment an anthropomorphic phantom was exposed inside of the ISS for a period of nearly a year. The main part of this experiment consisted of dose distribution measurements 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). In each location we used four types of TLDs: MTS-7 (^{7}LiF:Mg,Ti), MTS-6 (^{6}LiF:Mg,Ti), MCP-7 (^{7}LiF:Mg,Cu,P) and MTT-7 (^{7}LiF:Mg,Ti with changed activators concentration). The same types of TLDs were also used in the organ passive boxes and in the poncho.
The TLDs returned to IFJ in 2007 and readouts were performed during Spring and Summer this year. During presentation the first results for all TL detectors will be presented.

Evaluation of the track etch detector stacks exposed inside and on the MATROSHKA phantom. Phase IIA, 2005-2006

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Two types of track etch detector stacks were constructed for the MATROSHKA IIA experiment, one for the organ dose measurements in the lung and kidney of the phantom, the other one for the skin dose measurements attached to the poncho of the phantom. In addition a reference stack was placed inside the ISS.

After a multiple etching procedure the track detectors were evaluated by an image analyzer and from the track parameter measurements the LET spectra were deduced. Based on these spectra the absorbed dose, the equivalent dose and the mean quality factor were calculated.

The configuration of the stacks, the methods of the calibration and evaluation and the preliminary results will be presented.

Radiation Measured for Matroshka-2 with Different Passive Dosimeters

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Abstract

Research in space radiation indicates that radiation in low Earth orbit (LEO) is mainly contributed by Galactic Cosmic Rays (GCR), solar energetic particles, electrons and protons in the SAA (South Atlantic Anomaly) and albedo neutrons and protons scattered from the Earth's atmosphere. On the other hand, research on radiation biology shows that the impact of radiation on astronauts depends strongly on the particles' linear energy transfer (LET) and is dominated by high LET radiation. From the perspective of radiation dosimeters often used, the preferred passive dosimeters for radiation measurement are CR-39 plastic nuclear track detectors (PNTDs) which are sensitive for high LET and thermoluminescence dosimeters (TLDs) and/or optically stimulated luminescence dosimeters (OSLDs) which are sensitive for low LET. CR-39 PNTDs, TLDs and OSLDs were used to investigate the radiation for Matroshka-2 experiment by JSC-DIAS (Dublin Institute for Advanced Studies) researchers. LET spectra and radiation quantities (differential and integral fluence, absorbed dose, dose equivalent and quality factor) were measured for Matroshka-2 with CR-39 PNTDs and TLDs. This paper introduces the LET spectrum method for radiation measurement using CR-39 detectors, presents the LET spectra measured with CR-39 PNTDs and the radiation quantities combined from the results measured with CR-39 PNTDs and TLDs.

The MATROSHKA experiment – Data intercomparison

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The talk will give a brief overview concering the current status of the MATROSHKA experiment, summing up MTR 1 and MTR 2 A as well as giving an outlook on MTR 2B. Further on a data intercomparison of TLD data for MTR 1 and MTR 2 A is foreseen. For the first time data from an anthropomorphic phantom experiment exposed outside (2004 – 2005) and inside (2006) can be compared. The comparison will focus on TLD data for MTR 1 and preliminary TLD data for MTR 2 A provided by the various coinvestigators of the experiment.

The Silicon Scintillator Devices (SSDs) inside the MATROSHKA Phantom

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The Silicon Scintillator Devices (SSDs) are designed to measure the doses of charged and neutral particles inside the MATROSHKA phantom aboard the International Space Station (ISS). The SSDs consist of tissue equivalent plastic scintillator (BC-430) with the dimensions of 10.7 mm X 10.7 mm X 20 mm and are surrounded by 6 PIN-photodiodes. Four photodiodes (10 mm X 20 mm each) are optically coupled to the scintillator for light detection and as well as for the detection of penetrating charged particles. The other two PIN-diodes (10 mm x 10 mm each) at the face sides of the scintillator are separated by black foil in order to work as anticoincidence against charged particles. Depending on the penetration of charged or neutral particles there are different signals detected in the PIN-diodes. For the data analysis a condition was found that distinguishes between charged and neutral particles. With this discrimination the dose induced by both charged and neutral particles can be obtained. Although there exist only few datasets of the SSDs the dose contribution of the SAA crossings are calculated as well as the doses induced by GCR. The results of the data analysis will be presented.

STUDY OF DOSE DISTRIBUTION IN A HUMAN BODY IN SPACE FLIGHT WITH THE SPHERICAL TISSUE-EQUIVALENT PHANTOM

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The spherical tissue-equivalent phantom is a multi-user experimental facility of the international Matroshka-R project. The phantom diameter is 35 cm, the spherical cavity of 10 cm diameter is located in the phantom center. Due to the specially chosen phantom shape and size the detector locations inside the phantom can be selected such a way that the chord length distributions of the detector locations are attributed to self-shielding properties of the critical organs in a real human body [1]. The Russian tissue equivalent prepolymer Diafor-TDI is used as a phantom material [2]. Mass of the equipped phantom is about 30 kg.

A number of specific requirements is stipulated for use of phantoms – dummies of the human body in a space experiment. The main of these requirements are the following: minimization of the mass-dimensional parameters and of time of operator maintenance. If compared with the anthropomorphic phantom Rando [3] used in space experiments inside and outside the space station [4], the spherical phantom has lower mass, size, and does not require the phantom disassembling for the detector retrieval; moreover, its tissue-equivalent properties are closer to the standard human body tissue than Rando-phantom material.

The spherical phantom having all necessary space flight qualified parameters has been installed in the starboard crew cabin of the ISS Service Module since Jan., 2004. There were two experimental sessions with the spherical phantom in the crew cabin, (1) from Jan. 29, 2004 to Apr. 30, 2004 and (2) from Aug. 11, 2004 to Oct. 10, 2005. Only passive detectors were used in the first two sessions. The detectors are placed inside the phantom along the axes of 20 containers and on the phantom outer surface in 32 pockets of the phantom jacket. After each session numerous passive detectors installed inside the phantom and on its surface were returned to the ground. The places of the detector locations inside the phantom correspond to the following human organs and systems: the gastro-intestinal tract (GIT), the central nervous system (CNS), the blood-forming system (BFO), the eye lens (EL), and skin (SK). For the spherical phantom used in the experiment, the representative points of the above mentioned organs are located at the following radial depths from the surface of the phantom (disregarding the radial direction): 9 cm – for GIT, 7 cm - for CNS, 5 cm – for BFO, 3 cm – for EL, and 0.1 cm - for SK, respectively.

The results obtained with the passive detectors returned to the ground after each session show the dose difference on the phantom surface as much as a factor of 1.9, the highest dose being observed close to the outer wall of the crew cabin, and the lowest dose being in the opposite location along the phantom diameter.

Maximum dose rate measured in the phantom (0.33 mGy/day) is obviously due to the galactic cosmic ray (GCR) and Earth' radiation belt contribution on the ISS trajectory. Minimum dose rate (0.15 mGy/day) is caused mainly by the strongly penetrating GCR particles and is observed behind more than 5 g/cm^2 tissue shielding.

The design-structure of the spherical phantom and the new tissue-equivalent material have passed the successful approbation in conditions of a real space flight at the Russian Segment of ISS. The application of the spherical tissue-equivalent phantom for the integral estimation of the ionizing radiation doses received by human during the long-term mission can be considered as a system approach of using these phantoms as a phantom-witness of the dose loading to the human organism. The spherical phantom-witness can be widely used in future space exploratory missions instead of an anthropomorphic one for the crew' radiation risk estimation and health protection.

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"Update on the Status of the Development of an Active Space Radiation Dosimeter Based on the Medipix-Technology"

L. Pinsky, J. Chancellor, D. Minthaka (University of Houston)

ABSTRACT

As reported last year, the University of Houston has been pursuing membership in the Medipix Collaboration at CERN for the purpose of developing an active space radiation dosimeter based on the technology. Recently the Medipix Collaboration's Management Board voted unanimously to admit the University of Houston group via a Research Foundation at the University, and that process is underway. The TimePix version of the Medipix2 detector is now available and will be used in the near future at accelerator runs to acquire baseline data to allow the development of pattern recognition algorithms to distinguish and identify individual particles by charge and energy. The TimePix has the capability to be programmed pixel by pixel to function in either an ADC or TDC mode. The ADC capability has been shown to be linear over several orders of magnitude. The neutron sensitivity is also being developed and the current status of these efforts will be presented along with a discussion of future development plans.

Measuring Space Radiation with the Angle Detecting Inclined Sensor (ADIS) Method

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High energy ions (> 10 MeV protons and corresponding energies for heavy ions) are a major contributor to human radiation exposure in space. No practical amount of shielding can exclude the higher energy cosmic rays and solar energetic particles. It is important to measure both protons and heavy ion fluxes: The energy deposition rate by ions increases as the charge squared, so a high energy Fe ion deposits 676 times the energy of a proton with the same beta—even leaving aside the question of relative biological effectiveness. The Angle Detecting Inclined Sensors (ADIS) technique provides single element resolution (sigma < 0.25 e) through the Fe peak for such ions. ADIS uses simple planar solid state detectors to achieve this resolution without the complexity of position sensing detectors. We will discuss how ADIS makes possible simple, low power, low mass, but highly capable instruments that are ideal for monitoring radiation conditions in space. Such ADIS based instruments have been selected as the High Energy Particle Sensor (HEPS) for NPOESS (now de-scoped) and Energetic Heavy Ion Sensor (EHIS) for GOES-R (ongoing).

Tissue Equivalent Radiation Dosimeter on a chip

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Available digital dosimeters are bulky and unable to provide real-time monitoring of dose for space radiation. The complexity of space-flight design requires reliable, fault-tolerant equipment capable of providing real-time dose readings during a mission, which is not feasible with the existing thermo-luminescent dosimeter (TLD) technology, especially during extravehicular activities (EVA). Real-time monitoring is important for low-Earth orbiting spacecraft and interplanetary space flight to alert the crew when Solar Particle Events (SPE) increase the particle flux of the spacecraft environment. A dosimeter-on-a-Chip (DoseChip) for personal dosimetry comprised of a tissue-equivalent scintillator coupled to a solid-state photomultiplier (SSPM) built using CMOS technology is being prototyped by Radiation Monitoring Devices. The ubiquitous nature of CMOS technology provides a standardized development platform, and the ability to integrate the supporting electronics into a miniature, lightweight design. The DoseChip provides a tissue-equivalent response to the relevant energies and types of radiation for low-Earth orbit and interplanetary space flight to the moon or Mars and will be sensitive to the dose rates and particle fluxes of ambient Galactic Cosmic Rays (GCR) to the higher rates of major SPE. The DoseChip will complement the existing Crew Passive Dosimeters by providing real-time dosimetry and as an alarming monitor for SPE.

We will report on the results from evaluation at RMD and the NSRL. The spectral response of our initial prototype Dosechip with low LET, 1-GeV protons and higher LET, 1-GeV/n ^{28}Si clearly shows resolved peaks proportional to the expected energy deposition. Analysis of second-generation prototypes and planned design parameters of the final dosimeter system are included.

Space Dosimetry with a 3D Silicon Detector Telescope – the ISS Versions of TriTel

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As the duration of space flights and the frequency of manned space missions leaving the near-Earth region will probably increase in the future, improving the accuracy of dose measurements and dose estimates of astronauts will be increasingly important.

Development of a 3D silicon detector telescope, called *TriTel*, began in the KFKI Atomic Energy Research Institute several years ago in order to determine the average radiation 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 – will be the dose equivalent characterizing the stochastic biological effectiveness of the cosmic radiation. Within the framework of the European SURE (ISS: a Unique Research Infrastructure) program *TriTel* (with accompanying passive detector stacks) will be operated onboard the European Columbus module of the ISS, while in cooperation with the Institute of Biomedical Problems, Moscow another version of the instrument will be installed in the Russian segment of the ISS.

In the course of the development, the measurement scenario and the data processing algorithms have been worked out. Design, manufacturing, testing and optimization of the analog and digital circuits, the manufacturing of the housing of the detector unit and development and testing of the onboard and the on-ground software are still in progress. The geometry, the mechanical construction, the principle of the measurements, the measurement ranges and the expected results of the project are presented in this paper.

COMBINED ION AND NEUTRON SPECTROMETER FOR SPACE APPLICATIONS (CINS)

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CINS CONCEPT

The basic concept is to combine a charged particle telescope and neutron spectrometer into a single unit with common electronics. The charged particle telescope will consist of seven elements: four 5mm thick lithium drifted silicon detectors, two 1mm thick plastic scintillators for rate monitoring and a 38mm thick BGO scintillator for the end of the stack. The telescope detectors are 4 cm in diameter. Guard rings in the silicon detectors reduce their active area to 3.7 cm. CINS is similar to MARIE in that the 4 thick Si detectors provide particle identification and spectra. The plastic scintillators are used as triggers and simple counters which are helpful in high-rate environments. The BGO adds mass, stops protons up to energy of 150 MeV and makes the stack asymmetric for directionality.

The instrument electronics will use the Mars Odyssey MARIE instrument design as a starting point with improvements from the JHU/APL GRNS (Gamma Ray Neutron Spectrometer) flying on the MESSENGER mission to Mercury such as fixing the MARIE dynamic range and high data rate problems.

The neutron spectrometer will use low, medium, and high-energy detectors developed under previous NSBRI grants. The low energy system employs a conventional helium-3 gas tube detector; the medium or fast neutron energy system uses a boron-loaded Eljen plastic scintillator as the detector; and the high energy neutron system utilizes a 5mm thick lithium drifted silicon detector. There is some overlap between the medium and high energy systems in the 10-20 MeV energy range. The Eljen scintillator has been procured, assembled and calibrated during 2006/07.

PROJECT GOALS

CINS will monitor the complete particle radiation environment and will be used in ground based accelerator experiments at NSRL using heavy ions to determine charged particle fragment and neutron energy spectra from collisions with 10-20 g/cm^2 targets of common spacecraft materials. Detector and telescope performance characteristics including noise, resolution and event rate will also be evaluated. During 2008 CINS energy spectra will be compared with the measured LET or equivalent dose of a TEPCs to ascertain the limitations in response of the latter device.

INTERIM RESULTS FROM NSRL

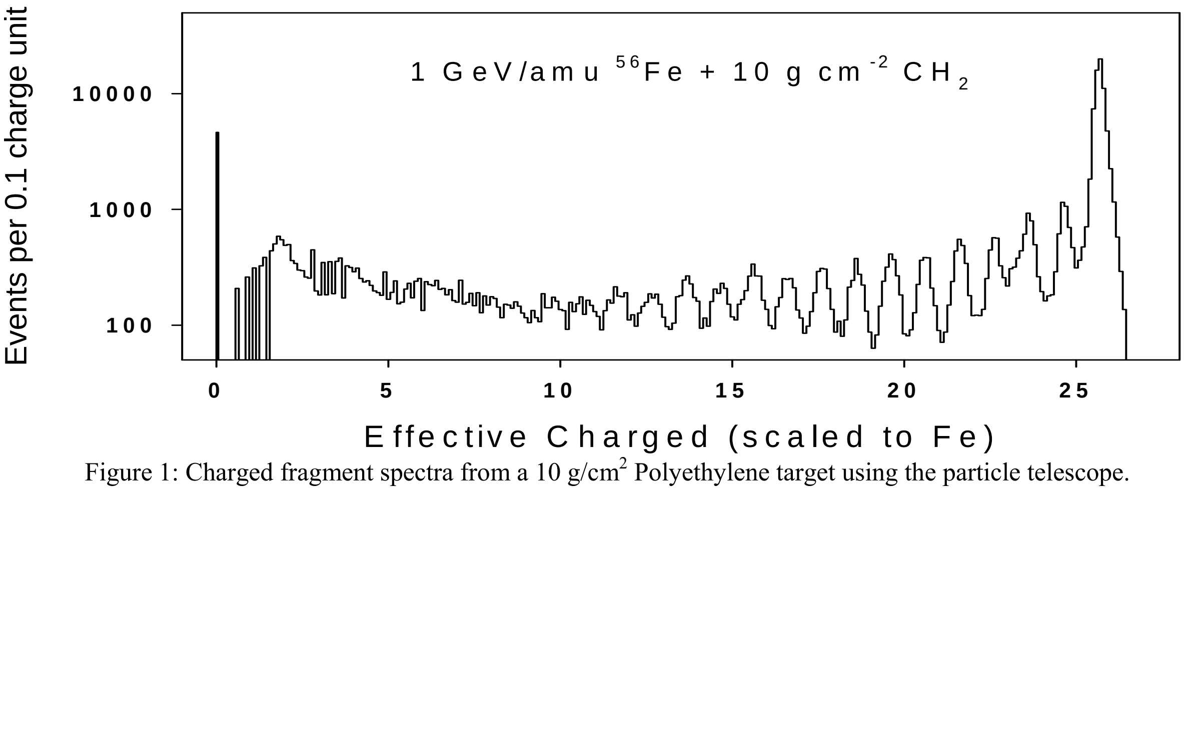

Figure 1: Charged fragment spectra from a 10 g/cm^2 Polyethylene target using the particle telescope.

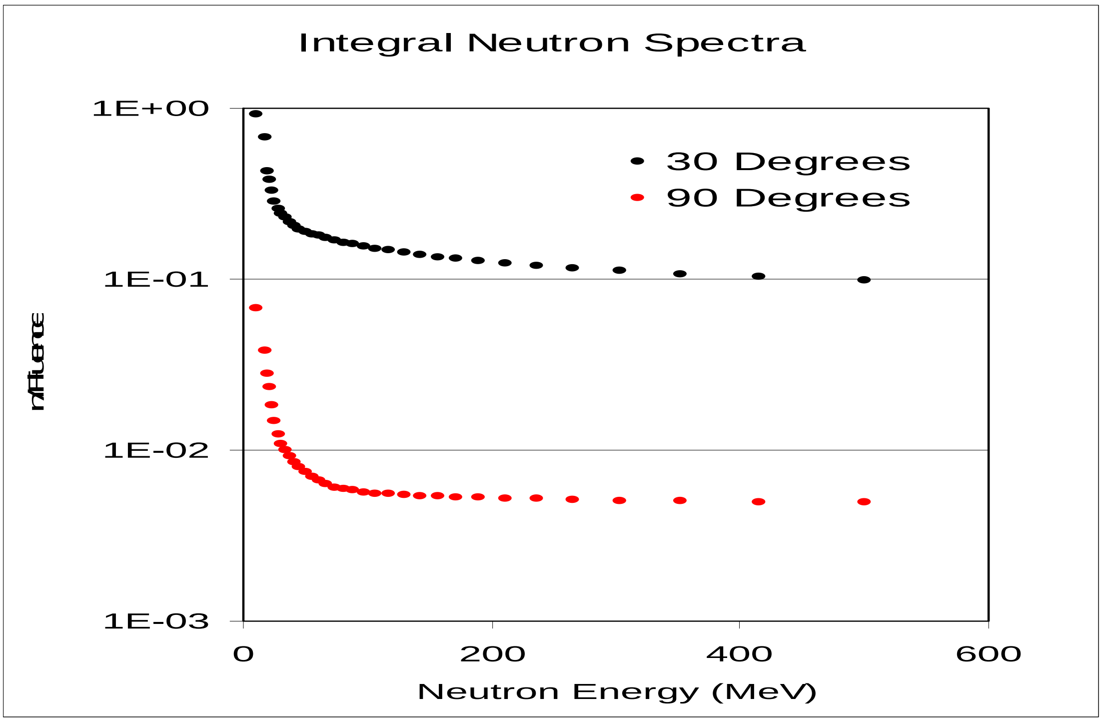

Figure 2: Integral neutron energy spectra from 5mm thick silicon detectors produced by colliding 1 GeV/amu iron ions with a 34.4 g/cm^2 aluminum target. The y-axis is in units of neutrons per incident iron ion.

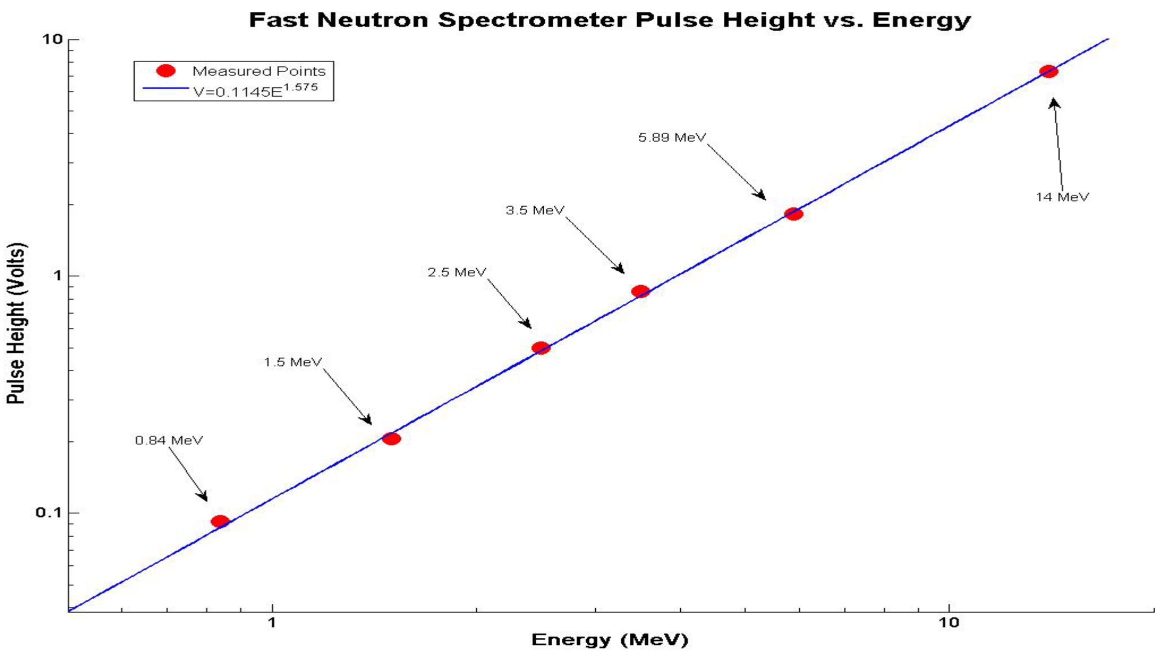

Figure 3: Eljen boron loaded plastic scintillator mono-energetic neutron calibration at Columbia University RARAF. $V = 0.1145\ E^{1.575}$ in good agreement with the $E^{1.6}$ prediction for organic scintillators.

The Radiation Assessment Detector (RAD) for the Mars Science Laboratory:

Applicability for Satisfying Current and Future Needs of NASA Space Radiation Monitoring

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The Radiation Assessment Detector (RAD) is a compact, low mass energetic particle analyzer designed to characterize the radiation environment on the surface of Mars, and scheduled to launch on MSL in 2009. Because of its small size, mass and power consumption, coupled with its capabilities, RAD has the potential to satisfy several current and future needs of NASA space radiation monitoring.

RAD's measurement capability includes:

- *Charge particles* ($1 \leq Z \leq 26$) as a function of energy and time.
- *Neutral particles* (neutrons and gamma-rays) (10-100 MeV) as a function of energy and time.
- *Absorbed Dose and Dose rate* (LET of 0.3 to 1000 keV/mm) as a function of time.
- *Dose Equivalent* (time-resolved Si LET spectra to determine LET-based quality factors)

Using the HPA PADC dosemeter for measurements of neutron dose on ISS

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The HPA have been making assessments of the neutron component of the dose equivalent in the ISS using poly allyl diglycol carbonate etched track detectors since 2004. These assessments are complicated by the presence of protons inside the ISS which are not intended to be a part of the dose equivalent assessment, because that part of the dose equivalent is determined by other means. These direct protons, within a limited energy range and critical angle, produce tracks that are indistinguishable from tracks from neutron interactions, a significant component of which are produced by secondary protons within the same energy and angle limits.

A method will be discussed for the determination of the proton contribution to the total track count. Calculated data for the proton fluence (Ersmark) in the ISS, for the energy range directly detected by the dosemeter, and assumptions of the dosemeter critical angle will be used to give an approximate proton contribution. This calculation will permit the bias in the neutron dose equivalent assessment to be quantified. If this positive bias is seen to be small relative to the existing calibration uncertainties of the dosemeter, then it may be viewed as having little significance.

Advances in the Analysis of CR-39 PNTD using Atomic Force Microscopy

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Following standard chemical etching for optical microscope read-out, CR-39 plastic nuclear track detector (PNTD) exposed in low-Earth orbit (LEO) under minimal shielding, e.g. on the exterior of the ISS Matroshka canister, is typically saturated with a high density of overlapping tracks. This makes measurement of the LET spectrum extremely difficult to impossible. The vast majority of these tracks are from low energy protons that are stopped within a fraction of a g/cm^2 of shielding. One way to avoid the saturation problem is to perform only a minimal chemical etch (bulk etch $B < 1$ μm) and to then analyze the detector using Atomic Force Microscopy (AFM). Because AFM provides what is essentially a 3-D topographical map of the post-etch PNTD surface, there is more useful information contained in an AFM image than in a standard image of the post-etch surface obtained using an optical microscope and CCD camera. We have developed a new method for analyzing CR-39 PNTD image data acquired by AFM based on topographic contour analysis and have applied this method to the measurement of LET spectra in the least shielded CR-39 PNTD layers exposed on Matroshka and to our previous low-shielding experiment on the exterior of the Mir orbital station. We are currently extending this approach in an effort to further automate the analysis of CR-39 PNTD exposed in space.

FLUORESCENT NULCEAR TRACK DETECTORS – A NEW TECHNOLOGY FOR LET SPECTROSCOPY OF HEAVY CHARGED PARTICLES IN SPACE DOSIMETRY

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Abstract

A new optical, non-destructive method of detecting and imaging individual heavy charged particle tracks using Fluorescent Nuclear Track Detectors (FNTD) is investigated as a possible spectroscopic tool for low and high LET charged particles. The technique combines new luminescent aluminum oxide single crystals having aggregate oxygen vacancy defects and doped with Mg (Al_2O_3:Mg) with a laser scanning confocal fluorescence detection [1,2].

Spectroscopic capabilities of this new method were demonstrated for linear energy transfer (LET) in water from 2.2 to 8700 keV/µm (corresponding to LET in aluminum oxide from 6.6 to 27100 keV/µm). The new tool is intended for space radiation dosimetry.

Two groups of the FNTDs were irradiated at Heavy Ion Medical Accelerator (HIMAC) of NIRS in Chiba, Japan. One set of detectors was irradiated “bare” (no absorbing medium other than the crystal itself) and another set was irradiated behind metal wedge absorbers designed for the various energies of heavy ions. Several detectors were irradiated at the NASA Space Radiation Laboratory heavy ion facility (AGS Booster) at the Brookhaven National Laboratory. Each detector was imaged and processed using an optical setup described in [2,3]. Linear dependence is obtained for fluorescence amplitude as a function of Z/β (where Z is ion charge and β is ion velocity).

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Tissue Equivalent Detectors for Space Crew Dosimetry
and Characterization of the Space Radiation Environment:
A NASA Experimental Program to Stimulate Competitive Research (EPSCoR) Project

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Oklahoma State University (OSU) recently received 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. Strategic partnerships with the Space Radiation Analysis Group at Johnson Space Center, the Cosmic Ray Research group at Marshall Space Flight Center, and the NASA Oklahoma Space Grant Consortium (OSGC), as well as with the private sector, are integral to the project. The instruments will be tested by means of high-altitude balloon flights over central Oklahoma conducted by students in the OSGC/ASTRO and OSU Radiation Physics programs, as well as at ground-based particle accelerator facilities including NSRL at Brookhaven National Laboratory, the proton therapy facility at Loma Linda University Medical Center, and the Los Alamos Neutron Science Center. By taking an evolutionary approach to the development and investigation of tissue equivalent radiation detectors, we will enhance the space radiation and aerospace engineering infrastructure at OSU to make it nationally competitive in the development of real-time radiation instrumentation. In addition, the ionization chamber developed in the early part of this project will form the core 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 country.

Future European Dosimetry Activities using Columbus

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The characterization of the space radiation field inside the new ISS Module Columbus has highest priority towards an accurate determination of the astronaut's exposure and the related health risk. Several passive and active devices were proposed by European investigators to provide the needed information as precise as possible including optimised radiation records. Some of the devices are already successful operated onboard the ISS, where they are still present, while others are ready to be launched or in a final development stage. The presentation will give an overview on the existing instruments and the planned investigations.

Future activities of PADLES dosimetry in JEM docked with ISS

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ABSTRACT

In April 2008, Japanese Experiment Module (JEM : Kibo) will be docked with International Space Station (ISS). Various science experiments in the fields of material sciences, life science, space medicine, applied research and so on will be conducted on JEM and its exposed facility.

We reported so far the development of a PADLES (Passive Dosimeter for Life-Science Experiments in Space) system used CR-39 and TLD as dosimeters in JAXA Space Utilization Research Center at the past WRMISS. A series of programs named AUTO PADLES was constructed for the fast and systematic analysis of the PADLES dosimeters. The AUTO PADLES has the following functions: 1) semi-automatic analyses of the opening mouths of etch pits on CR-39 etched surfaces with an ellipse-fitting algorism, 2) incorporation of the TLD and CR-39 responses to high-energy heavy ions obtained from the HIMAC heavy-ion accelerator. The heavy-ion exposure conditions was set so as to simulate inside ISS space radiation environments, and 3)an automatic calculation of LET distributions, absorbed doses, dose equivalents, by a combination of the TLD and CR-39 data. Consequently the PADLES system can drastically reduce the maximum analysis time down to about two weeks for each flight experiment.

In this time, we will introduce the summary of future activities and launch schedule of PADLES utilized in JEM.

At the present, the PADLES system are planning to be utilized for the following objects from 2008; area monitoring, radiation dosimetry of biological samples, astronauts personal dosimetry and other dosimetric experiments.

On the area monitoring, Area PADLESs will be installed at twelve fixed locations of JEM. These Area PADLESs are exchanged and recovered every 6 months, and then analyzed on JAXA. Such the continuous area monitoring will be conducted throughout a JEM program. The results obtained by Area PADLESs are expected to support the planning of the life science experiments on JEM, risk assessments on space flights and updates of the radiation models.

On ISS biological research experiments proposed in the international announcements of opportunities and the first JEM utilization solicitation, Bio PADLESs will be installed with biological samples of Silkworm, human culture cell and so on. The Bio PADLESs are exposed to space radiation at various temperatures from –80 C^{o} to 37C^{o}. We have already investigated the responses of CR-39 and TLD at various temperatures.

For personal radiation dose records of the Japanese crewmembers, Crew PADLESs will be provided for continuous use during their missions throughout EVA and IVE. The Crew PADLES measures the skin exposure doses and LET distributions of space radiation particles. Those records are applied to asses exposure limits defined to individual astronauts.

Observation program of ultra heavy nuclei in galactic cosmic rays

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Our galaxy is filled with relativistic nuclei and electrons, being called galactic cosmic rays (GCRs). The origin of GCRs nuclei is still unknown. The precise observation of ultra heavy (UH) CRs ($Z \geq 30$) is important to resolve the remaining problems in cosmic ray astrophysics. Observation program of UH nuclei in GCRs is proposed with the use of high performance solid-state track detector (SSTD) on board long-duration balloon and/or International Space Station (ISS). The program focuses to measure the isotopic abundance above iron-peak elements and the composition of the rare ultra heavy nuclei up to actinide elements with relativistic energy. The observation of nuclear composition covers a wide range of scientific themes including studies of nucleosynthesis of cosmic ray sources, chemical evolution of galactic material, the characteristic time of cosmic rays, heating and acceleration mechanism of cosmic ray particles. In order to achieve the objectives, long-duration balloon and/or ISS capable of carrying very large scientific payloads for long extended period is best suited. The possible approach is based on a large telescope array consisting of modularized SSTD stacks.

Polar Balloon Flights: Opportunities for Space Radiation Studies

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Scientific ballooning has enabled myriad investigations with relatively modest investments for several decades. Some of these have been competitive with space missions, while others have enabled space missions. A sea change in scientific ballooning occurred with the inauguration of 8 – 20 day flights around Antarctica in the early 1990's. These circumpolar flights have been spectacularly successful, with payloads recovered, refurbished, and reused to minimize life-cycle costs. The attainment of 25 - 32 day and 35 - 42-day flights, respectively, in two and three circumnavigations of Antarctica has increased the expectations of users. Requests for participation in the Antarctic Long-Duration Balloon (LDB) program, a NASA partnership with the U.S. National Science Foundation Office of Polar Programs, is greater than the traditional capacity of two flights per annual campaign. Realizing that polar flights in the Arctic would complement Antarctic flights, the Swedish Space Corporation / Esrange and NASA inaugurated a joint European / U.S. capability for medium-duration scientific balloon flights from Sweden to Canada in 2005. In parallel, NASA is pursuing development of a super-pressure balloon that would enable long-duration missions at non-polar latitudes. Polar LDB flights, especially, offer opportunities for Space Radiation Studies.