8th Workshop on Radiation Monitoring for the International Space Station

3-5 September 2003, LBNL, Berkeley, USA

Chairman	**Guenther Reitz, DLR**
Co-Chairs	**Jack Miller** **Eric Benton**

Workshop on Radiation Monitoring for the International Space Station (WRMISS)

Preliminary Program

Wednesday 3rd Sept

9.00 - 10.30	Scientific Session
10.30 - 11.00	Coffee Break
11.00 - 12.30	Scientific Session
12.30 - 14.00	Lunch
14.00 - 15.30	Scientific Session
15.30 - 16.30	Coffee/Tea Break
16.30 - 17.30	Scientific Session

Jack Miller/E. Benton	Welcome
Guenther Reitz	Introduction/Actions of last meeting

Session CALIBRATION

Hisashi Kitamura	Characterization of Heavy Ion Beams used for the ICCHIBAN Experiments
Michael Hajek/Thomas Berger	Results From The Passive ICCHIBAN Irradiation Campaigns
David Bartlett	ICCHIBAN-4: NRPB Results
Ramona Gaza	The Optically Stimulated Luminescence of Al2O3:C to Heavy Charged Particles - Preliminary Results from 4th ICCHIBAN
Eric Benton	Results from Passive Detector Intercomparisons made during the ICCHIBAN-2 Experiment and Current Status of the ICCHIBAN-4 and Proton ICCHIBAN Experiments
Soenke Burmeister	Postflight Calibration of DOSTEL with Heavy Ions During the First and Third ICCHIBAN Run at HIMAC, Chiba
Yukio Uchihori	Comparison of results from the 1st ICCHIBAN experiment and current status of the 3rd ICCHIBAN Experiment
Brent Lewis	Bubble Detector Characterization for Space Radiation.

Note: Presentation time shall not exceed 30 minutes

Thursday 4th Sept

9.00 - 10.30	Scientific Session
10.30 - 11.15	Coffee Break
11.15 - 12.30	Scientific Session
12.30 - 14.00	Lunch
14.00 - 15.30	Scientific Session
15.30 - 16.30	Coffee/Tea Break
16.30 - 17.30	Scientific Session

Time to be announced during meeting: Conference diner at "Skate's" restaurant in the Berkeley Marina

Session Calibrations (continued)

Kazuhiro. Terasawa	Measurement of LET distributions at CERF facility with RRMD-III
Thomas Borak	Comparison of the Response of the LET Spectrometer RRMD-III and a TEPC to Protons from 60-200 MeV
Tadayoshi Doke	Mean LET response of RRMD-III measured for protons from the NIRS cyclotron
ALL	Round Table Discussion

Session Flight Results

Edward Semones	CR-39 Measurement Results from STS-112
Joe Palfalvi	Evaluation of SSNTD stacks exposed on the ISS
Aiko Nagamatsu	Dosimetry and tracking for space radiation in a ISS Russian segment using PADLES
David Bartlett	The use of passive personal neutron dosemeters to determine the neutron component of cosmic radiation fields in spacecraft
Mark Weyland/A.S. Johnson	A Comparison of ISS TEPC Measurements and SRAG SPE Model for the November 8, 2000 Solar Proton Event
Livio Narici	ALTEA and Alteino: studying the ISS radiation environment and its effects on the Central Nervous System

Note: Presentation time shall not exceed 30 minutes

Friday 5th Sept

9.00 - 10.30	Scientific Session
10.30 - 11.00	Coffee Break
11.00 - 12.30	Scientific Session
12.30 - 14.00	Lunch
14.00 - 15.30	Scientific Session
15.30 - 16.30	Coffee/Tea Break
16.30 - 17.00	Scientific Session

Session Flight Results (continued)

Mark Weyland/M. Golightly	ISS Operational Radiation Exposure Monitoring—Status and Results
Harry Ing	"Status of Canadian Research on Neutrons In Space".
Carry Zeitlin	Update on the status of MARIE
All	Round Table Discussion

Session New Instrument and Model Development/ Future Activities

Tamás Pázmándi	Dose conversion factors in case of different detector materials
Neal Zapp	A Report on the Validation of Space Radiation Shield Models Derived from Actual Construction and Stowage Data
Mark Christl	A Deep Space Test-bed for Radiation Shielding Studies
Thomas Berger	Overview of Active and Passive Dosimetry for the MATROSHKA experiment
Tatsuto Komiyama	New Passive Personal Dosimeter for Japanese ISS Crew Members - Concept and Development Status
All	Round table discussion
All	Recommendations/Conclusions

ABSTRACTS

Characterization of Heavy Ion Beams used for the ICCHIBAN Experiments

H. Kitamura(1), Y. Uchihori(1), N. Yasuda(1), E. R. Benton(2),
J. Millar(3), C. Zeitlin(3), and L. Heilbronn(3)

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(2) Eril Research Inc., California, USA
(3) Lawrence Berkeley National Institute, Berkeley, California, USA

Since February 2002, four heavy ion beam experiments to intercompare the response of detectors used for space radiation dosimetry have been carried out at the NIRS-HIMAC under the framework of the ICCHIBAN Project. In these experiments we have used He, C, Ne, Si, and Fe beams with energies ranging from 150 to 500 MeV/u. The ICCHIBAN-1 and ICCHIBAN-3 experiments were dedicated to intercomparing the response of active detectors and used pencil beams of about 1 cm diameter in the HIMAC Physics Experiment Room. The ICCHIBAN-2 and ICCHIBAN-4 experiments were dedicated to intercomparing the response of passive space radiation dosimeters and used beams of about 10 cm diameter in the HIMAC Biology Experiment Room. We used a number of different detectors to characterize and measure the HIMAC heavy ion beams. A Position Sensitive Si Detector (PSD) and CR-39 plastic nuclear track detector were used to measure the position distributions and dE/dx. The range of the beam was measured by generating a Bragg curve using a binary filter consisting of multiple PMMA plates of different thickness. In the HIMAC Physics Experiment Room, we also used the LBNL Si spectrometer to precisely measure the beam. In this presentation, we discuss the setup of the instruments for the experiments and the conditions of the beams measured by the detectors.

Results From The Passive ICCHIBAN Irradiation Campaigns

Michael Hajek, Thomas Berger, Peter Hofmann, Norbert Vana
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A brief summary of the results obtained during the 2nd and the 4th ICCHIBAN irradiation campaign at the Heavy Ion Medical Accelerator in Chiba (HIMAC) in the years 2002 and 2003 will be presented. A combination of passive dosemeter devices was applied in order to assess the absorbed dose and LET, consisting of TLD-600 and TLD-700 thermoluminescent (TL) dosemeters as well as CR-39 nuclear track etch detectors (HARZLAS TD-1). The discussion will be focused on the evaluation of the "blind" exposures in which the experimenters were given no information about the particle composition and dose distribution. The data from the 4th ICCHIBAN run are still preliminary. The efficiencies of TLD-600 and TLD-700 for heavy-ion exposure were estimated utilizing the high-temperature emission (HTE) in the LiF glow curve. With this information, the absorbed dose values for the "blind" irradiations were corrected. Data from TL detectors will be compared with CR-39 nuclear-track-etch-detector results.

ICCHIBAN-4: NRPB RESULTS

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Personal neutron dosemeters of simple design, and processed using simple techniques developed for personal dosimetry may be used to estimate the neutron component of the radiation field in spacecraft. Electrochemically etched pits in poly allyl diglycol carbonate (PADC or CR-39®) etched track detectors are identified and counted using fully automated read-out procedures. The tracks observed will be produced not only by secondary charged particles from interactions of the neutron component of the radiation field, but also in part by the proton and energetic heavy charged particle components of the radiation field at the location of the dosemeter, leading to an over-estimate of the neutron component. The efficiency of the etch and read procedures is very dependent on particle type, energy and angle of incidence. The ICCHIBAN-4 irradiations enable an estimate to be made of the correction necessary and also enable development of techniques to identify the HZE tracks to allow discrimination.

The Optically Stimulated Luminescence of Al2O3:C to Heavy Charged Particles - Preliminary Results from 4th ICCHIBAN

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The Optically Stimulated Luminescence (OSL) response of Al_2O_3:C and the Thermoluminescence (TL) response of LiF:Mg,Ti to relativistic heavy charged particles (HCP) were investigated using the HIMAC accelerator in Chiba, Japan as part of the 4th ICCHIBAN. The detectors used were Al_2O_3:C single crystal chips (similar to TLD-500), Al_2O_3:C powder in plastic (Luxel™) from Landauer Inc. and LiF:Mg,Ti (TLD-100). The detectors were exposed to ^{4}He (150 MeV/n), ^{12}C (400 MeV/n), ^{20}Ne (400MeV/n) and ^{56}Fe (500MeV/n) ions and they received a dose of 10 mGy to simulate the dose ranges encountered in a space environment. The linear energy transfer (LET) for the considered ions was between 2.2 and 186 keV/µm in water. Also different materials were used as a shield between the beam and the detector (namely, 5g/cm^2 Al, 10g/cm^2 Al and 5g/cm^2 PMMA). For the Al_2O_3 detectors the CW-OSL measurements were performed using green light stimulation at 525 nm. The TL measurements for LiF were performed at 1°C/sec using a commercial RISØ reader.

The efficiency of producing luminescence (OSL or TL) by a HCP was defined as the relative sensitivity of the detector to HCP with respect to gamma. The efficiencies were determined and represented as function of the LET in water. The results were compared to the 2nd ICCHIBAN results and they were found to be in excellent agreement. Previously, it was observed that there is a change in the shape of the OSL decay curves for different HCP, leading to a dependence of the efficiency on the method used to determine the OSL signal. The changes in the decay curve shape were examined in several ways, including fitting the curves to two and three exponentials of form $I = I_{0i}\exp(-t/t_i)$. Several empirical parameters describing the curve shapes were examined for their dependence upon the LET of the HCP. The results of these and related analyses will be presented.

Results from Passive Detector Intercomparisons made during the ICCHIBAN-2 Experiment and Current Status of the ICCHIBAN-4 and Proton ICCHIBAN Experiments

Eric Benton, Yukio Uchihori, Hisashi Kitamura and Nakahiro Yasuda on behalf of the ICCHIBAN Working Group and ICCHIBAN Participants

The ICCHIBAN-2 and ICCHIBAN-4 experiments were dedicated to intercomparing the response of passive detectors used for space radiation dosimetry. The ICCHIBAN-2 experiment (May 2002) consisted of exposing passive dosimeters from 11 laboratories in 9 countries to heavy ion beams at the NIRS HIMAC. The detectors were of largely two types: CR-39 plastic nuclear track detector (PNTD) to measure radiation of $LET_{\infty}H_2O$ >5 keV/μm, and thermoluminescence/optically stimulated luminescence detector (TL/OSLD) to measure total dose. No single detector was able to adequately measure the dose from all the heavy ion beams. CR-39 PNTD was unable to measure the low LET component from 150 MeV He, while TL/OSLD measured the dose from high LET heavy ions (400 MeV/n C, 490 MeV/n Si, and 500 MeV/n Fe) with reduced efficiency. Only a combination of both CR-39 PNTD and TL/OSLD yielded an adequate measure of total dose, as well as measurements of dose equivalent and average quality factor.

The ICCHIBAN-4 experiment was recently carried out (May 2003) and the irradiated detectors are currently being processed and analyzed. This experiment emphasized dosimetric measurement of heavy ion beams behind Al and tissue equivalent shielding. The Proton ICCHIBAN experiment will be conducted at the Loma Linda University Medical Center immediately following the conclusion of the 8^{th} WRMISS and will consist of a solar particle event simulation, as well as exposures to monoenergetic protons of 70, 155 and 230 MeV.

Postflight Calibration of DOSTEL with Heavy Ions During the First and Third ICCHIBAN Run at HIMAC, Chiba

S. Burmeister[1] , R. Beaujean[1] , F. Petersen[1] , G. Reitz[2]

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After the return of the two DOSimetry TELescopes (DOSTELs) from the DOSMAP mission they were irradiated with heavy ions at the Heavy Ion Medical Accelerator in Chiba (HIMAC), Japan. During the first ICCHIBAN run the HIMAC provided 400 MeV/n C and 400MeV/nuc Fe. For the third ICCHIBAN run 500 MeV/n Fe, 800MeV/n Si and 400 MeV/n Ne were provided. These ion beams were used to verify the pre flight calibration of the two DOSTEL. The first ICCHIBAN calibration confirmed the preflight calibration of DOSTEL.

In the third ICCHIBAN one DOSTEL was combined with a position sensitive silicon detector to verify the homogeneity over the sensitive area of the used Canberra PIPS detectors. No inhomogeneity were observed.

Comparison of results from the 1st ICCHIBAN experiment and current status of the 3rd ICCHIBAN Experiment

Yukio Uchihori, Hisashi Kitamura, Nakahiro Yasuda, Eric Benton on behalf of ICCHIBAN working group and participants

In the 1st and 3rd ICCHIBAN (InterComparison for Cosmic-ray with Heavy Ion Beams At NIRS) experiments, we performed an intercomparison of the response of active detectors used in space radiation dosimetry to heavy ion beams at the NIRS HIMAC. Detectors which were irradiated during these experiments included the NASDA RRMD-III, the IV-CPDS, ISS-TEPC and Shuttle-TEPC from NASA-JSC, the U. of Kiel DOSTELs, the Liulin-4J of STIL-BAS and NIRS and a number of passive detectors. Since several of these detectors had not been previously irradiated to high energy heavy ion beams, the ICCHIBAN-1 & 3 exposures were the first attempts to systematically investigate their response in the high LET region. These experiments are significant for space radiation dosimetry because not only silicon detectors but also two tissue equivalent proportional counters were included. Based on the participants' reports for the ICCHIBAN-1 experiment, we have compared the results from the different instruments. This comparison, together with initial results from the ICCHIBAN-3 experiment, will be presented. In addition, information regarding the 5th ICCHIBAN experiment will be announced.

Bubble Detector Characterization for Space Radiation

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1. Introduction

With the advent of the International Space Station (ISS), which makes imminent a long-term human presence in space, there has been increased activity in the investigation of the near-Earth radiation environment. The monitoring of the radiation exposure of the Canadian astronauts who will be involved in long-term missions has become an important issue. Prior to the early 1990's, the dose equivalent received by space workers due to neutrons was generally considered to be of much less importance than that due to galactic cosmic rays, although no systematic study had been carried out. With the publication of ICRP-60, which recommended an increased quality factor for fast neutrons, the neutron dose equivalent is now an important consideration. In fact, it has been estimated that the fraction of dose equivalent from neutrons for the ISS may lie between ~30 to 50%.

In light of the importance of the neutron contribution in space, there is an increasing need for a personal dosimeter that is passive in nature and able to respond to this neutron field. Ideally, for more versatile applications in space, it would be advantageous if this detector could be read in real time. Recent Canadian technology has led to the development of a bubble detector that meets these requirements, i.e., this detector is sensitive to neutrons, but insensitive to low linear energy transfer (LET) radiation. This detector has already found wide use in both terrestrial and airline applications for neutron measurement. It has been used to measure the neutron spectrum inside the space shuttle and on the Russian MIR space station. The response of these detectors can be adjusted by varying the droplet composition or "superheat," which is a function of the critical point and boiling point of the detector fluid.

By changing the composition of the bubble detector fluid, the detectors can therefore be fabricated to respond to different types of radiation.

2. Experimental Work

This paper describes a ground-based research effort to better characterize the bubble detectors of different compositions at various charged-particle accelerator facilities, which are capable of simulating the space radiation field. In particular, the detector response was investigated in a ~77 MeV proton beam at the Tri-University Meson Facility (TRIUMF) in Vancouver, and in heavy ion beams (180 MeV/u N and 500 MeV/u Ar) at the Heavy Ion Medical Accelerator in Chiba (HIMAC), Japan. In order to vary the superheat of the detectors, the pressure and temperature was changed in a controlled manner. The position of the beam range in the detector fluid yielded the LET value for the onset of detector sensitivity. The LET was then correlated to the detector superheat and compared to an earlier curve previously proposed by d'Errico [[i]]. With a better characterization of the response function of the bubble detector to LET, this work may have direct application in the use of the bubble detector as an LET spectrometer in space.

The total dose equivalent of the given particle beam was also determined based on a measurement of the microdosimetric spectrum using a tissue equivalent proportional counter (TEPC). Since the TEPC is the standard instrument for estimation of the total dose equivalent on the ISS, this work provides an insight into whether the bubble detector results can be suitably scaled to the high-LET component of the microdosimetric spectrum. This work is particularly important since it provides underlying research in support of the use of the bubble detector as a personal dosimeter in space (i.e., the bubble detector is both passive and direct reading and is specific to high-LET radiation measurement).

As mentioned above, the bubble detector technology has already been used for preliminary measurement of the space neutron spectrum. The bubble detectors that were used in this previous measurement had varying threshold energies up to a maximum of 10 MeV. However, for space-based experiments, a higher-threshold detector (e.g., at 100 MeV) is needed since a large contribution of the neutron dose equivalent arises from high-energy neutrons. With the goal of the development of an improved spectrometer set for future use on the shuttle or the ISS, 20-MeV threshold and 100-MeV threshold detectors were fabricated by loading the detectors with a bismuth salt. This extended-range spectrometer set was tested in an integral (mixed) field at the CERN/European Commission high-energy reference field (CERF) facility in Geneva. The high-energy neutron field at this facility resembles the high-energy neutron component of the radiation field created by cosmic rays at jet altitudes and in space.

The Nuclear Fragmentation Separation Experiment (NFSE), which is capable of discriminating neutrons from charged particles (i.e., protons and HZE particles) in a mixed radiation field was further tested at the CERF facility. This device consists of a bubble detector that is surrounded by a plastic scintillator. Here a high-energy charged particle will trigger both a light flash in the scintillator and a coincident bubble event in the bubble detector, whereas a neutron will only produce a bubble. Thus, the neutron contribution can be distinguished based on an anti-coincidence counting technique. This instrument would be very useful for ISS missions where there is an interest to discriminate between neutrons and charged particles for dosimetric monitoring requirements.

These accelerator studies provided a unique opportunity to investigate the response of the bubble detector in a mixed-radiation field. In particular, with this current investigation, the response of the detector was studied in terms of the LET, which may be more attractive from the aspect of biological risk. This study is of particular importance in assessing the application of bubble detectors for use in space dosimetry and spectrometry.

i. d'Errico, F., Fundamental Properties of Superheated Drop (Bubble) Detectors. *Radiation Protection Dosimetry*, 1999, **84**, 55-62.

Measurement of LET distributions at CERF facility with RRMD-III

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The LET distributions in front of the 80 cm-thick concrete side shield at the CERF facility were measured with a Si detector telescope (RRMD-III) covered with and without a 1 cm-thick acrylic plate. In these measurements, a slight difference between both LET distributions was observed as a result of recoil protons and/or carbon particles by neutrons. The LET distribution obtained by RRMD-III without 1 cm-thick acrylic plate is compared with lineal energy distributions obtained by DOSTEL detector under the same condition and, also, these dose equivalents are compared with that obtained by HANDI TEPC which are used as the standard in the CERF facility.

Comparison of the Response of the LET Spectrometer RRMD-III and a TEPC to Protons from 60-200 MeV

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Protons were accelerated by the synchrotron at the Loma Linda University Medical Center and extracted at 200 MeV. They were then degraded using polycarbonate absorbers to provide beams ranging in energy from 60 to 180 MeV. This energy range corresponds to about 70% of the trapped protons greater than 40 MeV in the South Atlantic Anomaly. This presentation will discuss the properties of energy-degraded beams as well as show the measured spectra obtained with a spherical tissue equivalent proportional counter (TEPC) and the silicon detector based LET spectrometer (RRMD-III). Mean values of lineal energy from the TEPC and RRMD-III were similar to the LET of incident protons from 70-180 MeV but there were divergences at lower energies. Reasons for these results will be discussed.

Mean LET response of RRMD-III measured for protons from the NIRS cyclotron

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In 2001, mean LET response of RRMD-III was measured for protons of 40 to 200 MeV which were obtained by using organic absorbers for the protons from the synchrotron at the Medical Center, Loma Linda University. The result showed a large deviation from the calculated curve in the low energy region below 70 MeV. To confirm the deviation, we have measured the mean LET response of RRMD-III using protons of 40 and 70 MeV from the NIRS cyclotron. Using some organic absorbers, protons with several energies were produced and the mean LET distributions for them were measured as well as two monochromatic protons. The result of this experiment will be reported and compared with them obtained at Loma Linda.

CR-39 Measurement Results from STS-112

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The current US passive detectors used for crew and area monitor on the Shuttle and ISS include four separate types of thermoluminescent dosimeters (TLD). NASA-JSC is currently pursuing adding CR-39 detectors back into the passive dosimeters used for both Shuttle and ISS missions. Discussions during the 2002 WRMISS indicated potential differences in the results obtained by different groups utilizing CR-39 detector systems for spaceflight measurements. To better understand these possible differences, an intercomparison was conducted between the following groups:

- Dublin Institute for Advanced Studies (DIAS), Ireland;
- Eril Research Inc., California (ERC), USA;
- National Radiological Protection Board (NRPB), UK
- Nuclear Physics Institute (NPI) of the Czech Academy of Sciences, Czech Republic

Detectors from each group were flown inside the area passive dosimeter located in the middeck of the Shuttle. Information obtained during the intercomparison can be used to identify potential causes of the differences in results and to give supporting information to help in the selection of measurement techniques that will be utilized by NASA-JSC. Results from this intercomparison will be presented in the context of these goals.

EVALUATION OF SSNTD STACKS EXPOSED ON THE ISS

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The aim of the study was to investigate the contribution of secondary neutrons to the dose inside the ISS.

A stack of SSNTDs was developed, it consists of 3 CR-39 sheets (TASTRAK, ~6 keV/μm threshold),1 mm thick, 1000 mm^2. The 1st and 2nd sheets were separated by a Ti foil (50 μm), the 2nd and 3rd sheets sandwiched a Lexan foil (350 μm). The stack was wrapped in an Al foil (30 μm) and sealed in a polyethylene bag (40 μm).

The neutron and proton responses of each sheet were studied by MC calculations and experimentally, utilizing monoenergetic protons. 7 stacks were exposed for 249 days at different locations of the Russian segment 'Zvezda'. The orbit apogee was from 400 to 420 km, the perigee was between 370 and 395 km. the orbit inclination was 51.8 ^{o}. Another 8 stacks were exposed at the CERF high energy calibration field.

The CR-39 detectors were evaluated in four steps: after 2, 6, 12 and 20 hours etching in 6N NaOH at 70 ^{o}C (V_B=1.34 μm/h). The VIRGINIA image analyzer investigated and recorded all the individual tracks.

Based on the CERF calibration, the stack provided the neutron ambient dose equivalent (H*) between 200 keV and 20 MeV, the values varied from 39 to 73 μSv/d, depending on the location. Since the CERF calibration spectrum is somewhat different from the spectra inside the ISS, the uncertainty of the dose rate has been estimated to be around ± 30 %.

Utilizing the track parameter distributions obtained by the VIRGINIA image analyzer the LET spectra were deduced.

Based on the results, the original stack was modified and the four ones of the new version were sent to the ISS early this year.

Dosimetry and tracking for space radiation in a ISS Russian segment using PADLES

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*1: National Space Development Agency of Japan
*2: High Energy Accelerator Organization
*3: Advanced Engineering Service, Inc.
*4: National Institute of Radiation Laboratory

A PADLES developed in Space utilization research center of NASDA is a passive and an integrating type dosimeter to be utilized principally for biological experiments aboard the Japanese Experiment Module Kibo of the International Space Station. Because the PADLES is compact and battery-less, it has the advantage of no necessity of crew times and we can install it extremely close to biological samples. As of now, the PADLES is to be used for three ISS biological researches proposed in the international announcements of opportunity and the First KIBO utilization solicitation. In those researches, the PADLES along with the samples of Silkworm, human culture cell and so on will be exposed to space radiation at various temperatures from –80 C^{o} to 37C^{o}. The basic characteristics of the PADLES as a dosimeter for ISS experiments has been established by intensive ground tests□ using HIMAC heavy ion accelerator in NIRS Japan.

The PADLES measures the following dosimetric quantities for investigating the biological effects for space radiation in the micro-gravity environment of ISS:

(a) an absorbed dose which is primarily measured by TLD-MSOs,

(b) LET distributions of heavy-charged particles in the LET region exceeding 10 keV/μm-water which are measured using CR-39 PNTDs,

(c) a dose equivalent which is estimated from combination of the TLD-MSO and CR-39 data,

(d) the positions and LET of HZE particles incident to the biological samples by tracking the HZE particles using CR-39 stacks.

The PADLES can be applied for personal dosimetry of astronauts and for radiation damage research of electronic devises. From June, 2001 to November, 2002, the PADLES was loaded on an ISS Russian segment for investigating white defects of HDTV CCD elements in the ISS space radiation environment. While the PADLES measured the radiation doses of the CCD elements, stacks consisting of two types of CR-39 plastic were placed at the top and bottom of CCD elements in order to measure the position and LET of HZE particles incident to an image pickup device area. We will briefly report the results from the HZE particle tracking, the radiation doses and the LET distributions including nuclear fragments in the higher LET region.

□Research project with heavy Ions at NIRS-HIMAC

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THE USE OF PASSIVE PERSONAL NEUTRON DOSEMETERS TO DETERMINE THE NEUTRON COMPONENT OF COSMIC RADIATION FIELDS IN SPACECRAFT

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For the altitude range and inclination of the International Space Station (ISS), secondary neutrons can be a major contributor to dose equivalent inside a spacecraft. The exact proportion is very dependent on the amount of shielding of the primary galactic cosmic radiation and trapped particles, but is likely to lie in the range of 10% to 50%. Personal neutron dosemeters of simple design, and processed using simple techniques developed for personal dosimetry may be used to estimate this neutron component.

For the etch regime employed, the combination of high LET threshold (there is little response below a restricted LET_{200} in PADC of about 40 keV μm^{-1}), and poor angle dependence of response to high-energy charged particles (HZE), results in a much reduced overall response of the neutron dosimeter to the HZE component of the field in spacecraft and no response to protons of energy greater than about 2 MeV. Preliminary measurements indicate that for examples of the HZE component of the radiation fields in spacecraft, a correction of 5 to 10% is necessary to account for the detector HZE response. Alternatively, an additional chemical etch can be carried out which allows discrimination.

Recent results for exposures in low Earth orbit are reported.

"A Comparison of ISS TEPC Measurements and SRAG SPE Model for the November 8, 2000 Solar Proton Event "

Steve Johnson [1], Mike Golightly[2], Mark Weyland[1], Tom Lin[1]

[1] Lockheed Martin, Houston, Texas
[2] NASA, Johnson Space Center, Houston Texas

Within two weeks of arrival of the first International Space Station (ISS) crew, one of the largest solar proton events (SPE) of this solar cycle occurred. Approximately midway through the event the crew activated the ISS tissue equivalent proportional counter (TEPC). The ISS TEPC created a time-resolved record of the accumulated dose and dose rate during the course of the event. In addition to measurements from the TEPC, the Space Radiation Analysis Group uses a ground-based code called SPERT (Solar Particle Event – Real Time) to estimate the progress of on-board exposures during an SPE. The on-board TEPC measurements and results from the SPERT code results are compared for this event.

ALTEA and Alteino: studying the ISS radiation environment and its effects on the Central Nervous System

Livio Narici for the ALTEA collaboration

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ALTEA and Alteino are two experiments aimed at investigating the radiation environment on board the ISS and the possible, transient and long term, functional effects of particles traveling through the cortex and the retina of the astronauts. The first realization of this investigation, Alteino, is on board the ISS since April 2002, and it has been in operation for one week last year. We are at present trying to power on Alteino again to increase statistics of data. ALTEA will fly on the ISS with 13A.1 Shuttle flight, which will be probably scheduled in the first part of 2005.

Alteino, based on our experience with the SilEye experiments on the MIR Station, is composed by i) one particle detector, based on silicon-striped sensors and able to discriminate nuclear species and to measure energies and trajectories of the impinging particles, and by ii) an Electroencephalographer, nedded to study the dynamics of the electrophyiological cortical activity of the Astronauts and its possible correlation with particle flux.

ALTEA is composed by six silicon detectors, assembled in a helmet-shaped structure around the astronaut's head, by a visual stimulator, an Electroenchephalographer and a triple pushbutton. Several ground based experiments support the ALTEA experiment in space.

Characteristics of the two instrumentations and first results from Alteino will be presented.

"ISS Operational Radiation Exposure Monitoring—Status and Results"

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International Space Station (ISS) operational radiation exposure monitoring has continued during the past year, although monitoring capability has been degraded due to instrument failures and severe logistics constraints created by the grounding of the U.S. Space Shuttle fleet. Two additional passive dosimetry monitoring periods were completed—05 Jun—07 Dec 2002, and 24 Nov 2002—24 May 2003—each comprised of 16 TLD packages located throughout the ISS's habitable volume. Continuation of the monitoring was not possible because of the severely constrained launch mass allowance provided by the Soyuz spacecraft. Replacement passive dosimeters must be provided via Soyuz launches due to the grounding of the U.S. Space Shuttle fleet following the catastrophic loss of the Columbia vehicle during the STS-107 mission re-entry. Current flight manifests will return passive dosimeters to the ISS with the next Soyuz launch, now scheduled for late Oct 2003. ISS Tissue Equivalent Proportional Counter (TEPC) monitoring resumed in Oct 2002 with the launch of a

replacement TEPC unit. This instrument began to exhibit anomalous behavior (significant decrease in measured dose rate) a month later, and was returned to Earth for evaluation in early December. Launch of the repaired and refurbished prime TEPC, planned for the second or third quarter of 2003, was delayed due to the lack of available payload mass on subsequent Soyuz launches—it is currently manifested for launch with the next Progress re-supply mission (Jan 2004). The Intra-Vehicular Charged Particle Directional Spectrometer (IV-CPDS) underwent a final software upgrade and operating parameter adjustment in Oct 2002 and has since been continuously monitoring in the U.S. Lab. The Extra-Vehicular Charged Particle Directional Spectrometers (EV-CPDS) were brought into an operational status in Feb 2003, but have only been operated intermittently due to operating system file corruption caused by unplanned power disruption to the instruments while in "data acquisition mode." EV-CPDS 2 and 3, oriented towards zenith and anti-velocity vector direction respectively, are now routinely acquiring data.

During the period 05 Jun 2002—24 May 2003, dose rates measured with TLD-100 dosimeters have ranged from 126-174 μGy/d in Node 1, 126-192 μGy/d in the Service Module, 120-226 μGy/d in the U.S. Lab, and 175-191 μGy/d in the Joint Airlock. Highest daily dose rates remain near the window in the U.S. Lab, inside the Joint Airlock, and the sleep stations inside the Service Module. The lowest daily dose rates remain inside the polyethylene-lined Temporary Sleep Station (TeSS) in the U.S. Lab, adjacent to the port "arm" of Node 1 (an area filled with large containers of water and other supplies), and the aft end of the Service Module. The ratio of the minimum to maximum dose rate inside the ISS's habitable volume is ~ 1.75. Since 01 Aug 2002, dose rates measured by the IV-CPDS, estimated from the count rate in first detector of the telescope's stack, ranged from 189-246 μGy/d.

A compilation of ISS and Shuttle passive dosimeter, IV-CPDS, ISS and Mir R-16, and Shuttle TEPC measurements reveals the daily dose rate in the ISS orbit reached a minimum value in approximately Mar-Apr 2002, followed by a gradually increasing trend. Between Aug 2002 and Aug 2003 the average daily dose rate, based on IV-CPDS measurements, has steadily increased by 12%. This point marks the ISS radiation environment's "solar maximum" point. By comparison, solar activity as measured by coronal radio emissions (F10.7) and local interplanetary magnetic field properties (Ap) transitioned from a solar maximum pattern to a declining phase pattern in Dec and Oct 2002, respectively.

Status of Canadian Research on Neutrons In Space

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Abstract

Bubble Technology Industries (BTI) has been involved in the study of neutron radiation in space under the sponsorship of the Canadian Space Agency (CSA) since 1988. The primary thrust of these studies is to understand the biological detriment to humans exposed to space radiation. These studies encompass numerous measurements in various space missions as well as ground-based experiments done in collation with the Russian Space Agency (RSA), NASA and the National Institute of Radiological Science (NIRS). Experiments have also been done using the accelerators in Dubna, CERN and TRIUMF. Many of these studies have already been reported in the literature.

Currently, our activities are concentrated in 3 main areas: a) Analysis of Bubble Detector Data from the "Phantom Experiment" in MIR; b) Construction of a high-resolution neutron spectrometer (called CHENSS) based on proton-recoil to be flown on the cargo bay of the NASA shuttle and c) Construction of a "Mini-Reader" for bubble detectors to be used in the Matroshka-R experiment in the ISS.

a) Data from the Phantom Experiment

The Phantom Experiment was co-ordinated by the Institute of Biomedical Problems (IBMP) and involved many groups from several countries. The objective of the project was to assess the degree of agreement among different dosimeters that are used to assess biological detriment in space. Over the period 1997 to 1999, various dosimeters were deployed for measurements inside and outside a spherical phantom on MIR. BTI provided bubble detectors for neutron measurements as part of this project. Over 100 measurements with bubble detectors were made by Russian cosmonauts and images of the irradiated bubble detectors were recorded with a special video camera. We have now almost completed the analysis of the video images on the tapes that were brought to Canada on the last visit of scientists from the IBMP. The preliminary results obtained so far support neutron dose-rates that we have measured earlier on MIR. There were significant differences between different sites on MIR, but the results were surprisingly consistent between bubble detectors inside and outside the phantom. We are attempting to compare our results with other available data made with other dosimetric devices.

b) Construction of CHENSS

CHENSS is intended to provide an accurate measurement of the neutron spectrum in space over the energy range of a few MeV to approximately 100 MeV. Early measurements made with the bubble detector spectrometer indicate the presence of a large number of neutrons above 10 MeV. However, these measurements could not define the shape of the high-energy component, which is expected to be resolved by CHENSS. CHENSS is based on a 5″ x 5″

gelled scintillation detector specially manufactured by BTI. It is a larger version of the detector used in the standard BTI commercial probe for spectral neutron dosimetry. This detector has good pulse-shape discrimination properties and can separate low and high LET radiations (such as neutrons and gamma rays). To separate the charged-particle events from neutron events, this detector in CHENSS is completely surrounded by thin plastic detector panels to allow for the "vetoing" of signals that are in coincidence. During a mission, all the signals will be recorded on a hard-drive under the control of an embedded computer and the data will be analyzed subsequent to the flight. CHENSS has been exposed to the CERF neutron beam in CERN and analysis is almost finished to yield the measured spectrum for comparison with the currently accepted CERF reference spectrum.

c) Mini-Reader for Matroshka-R.

The Matroshka-R project is championed by the IBMP with the objective of establishing as accurate dosimetry as possible for the ISS. Various groups will be performing dosimetric measurements with a variety of different devices involving a spherical phantom, inside the ISS. Bubble detectors will be provided by BTI for these experiments. In order to facilitate these measurements, a special Mini-Reader is being constructed that will meet space equipment specifications for "reading" the bubble detectors in the ISS. Currently, the Mini-Reader is nearly complete. This reader uses a low-power, compact, embedded computer controlling a special digital camera under appropriate lighting. The bubble counts along with detector ID are recorded on a flash card, which will be brought down to earth by cosmonauts upon change of shift. The images on the cards will be subsequently analyzed to yield the experimental results. At this point, all the components of the Mini-Reader are being assembled to yield the final physical unit. All the operational software has been written. The Mini-Rader will be delivered by fall to the IBMP for evaluation. Space qualification tests have yet to be done by the CSA prior to shipment to the ISS.

Results From The Martian Radiation Environment Experiment MARIE

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MARIE has been in operation at Mars since March 2002, detecting Galactic Cosmic Rays and Solar Particle Events. MARIE consists of a stack of silicon detectors with a limited dynamic range, which only allows for the measurement of a small portion of the GCR heavy ion flux. Relatively high-energy (above 500 MeV/nucleon) GCR ions out to neon have been identified, but more highly-ionizing (higher-charge and/or lower-energy) particles cause saturation of the electronics. However, MARIE is well-suited to measuring protons and helium ions from solar events. For purposes of both GCR and SPE flux or dose calculations, there are still fairly large uncertainties in the geometry factor and other corrections needed to convert from observed counts to the physically meaningful quantity. Also, the trigger threshold is not known, having been set in flight by trial-and-error until an acceptable event rate was obtained; the data show protons with energy up to 1-2 GeV, so it appears that most of the GCR proton spectrum is being recorded, although the trigger efficiency as a function of proton energy is presently unknown. With some assumptions about efficiency and acceptance, we have determined that for the time period from March 2002 to June 2003, the dose equivalent in Mars orbit averaged 0.39 ± 0.14 Sv/yr, more than double that on ISS over the same period. This result is in good agreement with a model calculation using HZETRN that predicted a surface dose equivalent of 0.20 to 0.30 Sv/yr., varying with altitude due to the shielding effect of the thin Martian atmosphere. This shielding probably accounts for the difference between the predicted values and the result from MARIE, which has very little shielding (< 0.6 g cm^{-2}) in the forward direction.

Accelerator-based testing of the backup unit is planned for late fall 2003 and is expected to resolve some of the normalization and data quality issues. Also, a detailed model of the mass distribution of the 2001 Mars Odyssey spacecraft is needed to determine the contribution from particles entering MARIE from the bottom of the silicon stack; this work involves the transfer of proprietary data from the spacecraft contractor and consequently has been delayed, however it is expected to get underway in the fall of 2003. With the additional information gained from the next few months of study, we expect to be able to report dose and flux rates with improved accuracy and precision in the near future. The nominal science mission of the 2001 Mars Odyssey spacecraft ends in August 2004, but the spacecraft is performing superbly and an extended mission is being proposed. If approved, the spacecraft is expected to continue to operate at least through 2006 and possibly beyond. For the extended mission, a revised software package will be uploaded to MARIE that will substantially improve some aspects of its performance.

Dose conversion factors in case of different detector materials

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One of the many risks of long duration space flights is the dose burden from cosmic radiation, especially during periods of intensive solar activity. Since the space radiation mainly consists of charged heavy particles (protons, alpha and heavier particles), the equivalent dose significantly differs from the absorbed dose.

The recently used measuring equipment is not fully suitable to measure both quantities simultaneously. A new combined device is under development, which consists of an on board thermoluminescent (TL) dosimeter reader (PILLE) and a three axis silicon linear energy transfer (LET) spectrometer.

The efficiency of the TL dosemeter is a function of the LET, therefore the value of the measured dose should be corrected for the efficiency. LET spectra should be used for the determination of the radiation weighting factor (w_R) and for the evaluation of the equivalent dose as well. Since the radiation weighting factor defined as a function of LET_{water}, LET_{Si} or LET_{TL} should be converted to LET_{water} for this purpose.

During the measuring process TL materials and silicon spectrometers are used and the energy absorbed in their sensitive volume is measured. Since we are interested in the equivalent dose in tissue, the results of the TL measurements and the LET spectra also have to be corrected. We need correction for the comparison of the different measurements as well.

Recently an average value has been used for the correction of the dose and LET spectra measured in different materials, despite the fact that the value of the correction factor depends on the energy of the concerning radiation. In order to gain correct results we should take into account that the correction factor is dependent on the energy spectrum. The mathematical method of the calculation and examples for low earth orbit space stations will be presented.

Construction and Stowage Data

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In the past, the development and validation of shielding models for use in space radiation exposure analyses has been by definition a long, tedious process involving tools with little or no user interface structure, and requiring extensive user training. Recent advances in technologies associated with shield model construction and implementation have yielded tools, which are by comparison extremely intuitive in their use and very precise in their geometric evaluation. One critical question that is always present in the simulation of virtually any space radiation exposure scenario can be simply stated as "how much detail is enough?" The fact that it is now possible to model vehicles on the level of actual nuts and bolts does not on its own justify the effort and computing time implicit in their use. In an effort to elucidate the state of this development effort, and hopefully to elicit input and interchange with other groups in the community working towards the same goal, we present comparisons of calculation with actual ISS measurements using models at various stages of complexity. While a pure quantification of the change is impractical due to subjectivity in the simplification process, in general we find that a significant simplification of the actual construction geometry is possible without a serious sacrifice in accuracy or precision.

A Deep Space Test-bed for Radiation Shielding Studies

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The comparison of radiation transport code calculations with experimental data obtained in a realistic deep space environment is an important element in the validation process of the transport codes. A high-altitude, high-latitude balloon-borne test-bed can provide access to the deep-space cosmic ray flux for these comparisons. This test-bed strategy would allow relatively easy, low cost and frequent access to the deep space environment for validation of transport code predictions, testing shielding materials and new radiation monitoring instrumentation. This paper discusses characteristics of a balloon-borne test-bed for radiation shielding studies.

Overview of Active and Passive Dosimetry for the MATROSHKA experiment

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The MATROSHKA facility is designed to study the dose values encountered by astro – and cosmonauts during extra vehicular acitivities (EVAs). This study is very important due to the high construction work including various EVAs carried out in the framework of the ISS assembling. The phantom torso of the MATROSHKA is equipped with a number of active and passive dosemeter devices enabling the measurement of radiation field parameters like absorbed dose, LET distribution and dose equivalent. Further on the facility enables the determination of the depth dose distribution and the precise measurement of organ doses. The phantom is built up by 33 slices composed of natural bones, embedded in tissue equivalent plastics of different density for tissue and the lungs. The active dosemeters consist of a DOSTEL, five silicon detectors embedded at organ positions within the phantom and it is also equipped with a tissue equivalent proportional counter (TEPC). Besides the active dosemeters the MATROSHKA experiment is outfitted with thermoluminescent-dosemeters (TLDs) and CR–39 track etch detectors. Within the 33 slices the TLDs are arranged in an one inch grid. A total number of 1634 dosemeter positions are available in the 33 slices. These positions will be occupied by more than 5300 TLDs. Five passive dosemeter boxes for organ dose measurement including TLDs and CR–39 track etch detectors will be put in the slices close to the active silicon detectors. The phantom is equipped with a poncho and a hood to allow skin dose measurements. Plastic stripes carrying in total 800 TLDs will be sewed in the poncho and the hood. The poncho is also equipped with six passive dosemeter boxes – and additional personal dosimeters working with CR–39 track etch detectors. At the outside as part of the upper MLI five passive dosemeter boxes will be provided for depth dose measurements behind very low shielding thickness.

New Passive Personal Dosimeter for Japanese ISS Crew Members
- Concept and Development Status -

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In a few years, Japanese astronauts will begin staying in the International Space Station (ISS) for long durations. The ISS Medical Operation Requirements Document (ISS MORD) states that each individual agency or organization will have the responsibility for arranging their crew dosimetry. Therefore, the National Space Development Agency of Japan (NASDA) began studying a new passive personal dosimeter for Japanese ISS crew members.

We seek a new passive personal dosimeter that will be able to measure skin dose equivalent and blood forming organ (BFO) dose equivalent, including neutron contribution. We recognize that there are some questions to attain this goal.

- Is there an appropriate material for the crew personal dosimeter to simulate shielding of BFO in a space radiation environment?
- Is there an appropriate method for the crew personal dosimeter to measure the contribution of neutrons in the space radiation environment?
- How much does the reading of the Thermo-Luminescent Dosimeter (TLD) decrease (fade) after charged particle irradiation?
- How much does the sensitivity of the Plastic Nuclear Track Detector (PNTD) decrease (age) during room-temperature storage after irradiation?
- How much does the sensitivity of the PNTD decrease after long-duration storage in a refrigerator?
- How different is the sensitivity of the PNTD between two given production lots? How different is the sensitivity of the PNTD between two given sheets of the same production lot?

We are conducting simulation tests and ground experiments to answer these questions. I would like to briefly present the constitution of our new passive personal dosimeter and some results of the simulation tests and ground experiments.