Intercomparison of Radiation Instruments for Cosmic-ray with Heavy Ion Beams at NIRS (ICCHIBAN Project)

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Intercomparison/ Radiation / Monitor / Dosimetry / Heavy ion beam

The first InterComparison for Cosmic-ray with Heavy Ion Beams At NIRS (ICCHIBAN) project is an ongoing, international collaboration organized at the National Institute of Radiological Sciences (NIRS), Japan, for the purpose of characterizing and comparing at a controlled, ground-based heavy ion facility the radiation response of instruments used aboard piloted spacecraft for crew and area dosimetry. We present preliminary results from the first set of ICCHIBAN exposures made at HIMAC heavy ion accelerator in February 2002. The initial series of exposures (1st ICCHIBAN run) was designed to establish the response of active detectors to two well-characterized heavy ion beams; 400 MeV/nucleon $^{12}$C and 400 MeV/nucleon $^{56}$Fe. These beams are representative in charge and energy of two of the most significant heavy ion components present in the galactic cosmic radiation spectrum. The properties of the incident beam, including intensity, profile, charge and total energy, were characterized using several different detector systems, including silicon detectors, CR-39 plastic nuclear track detectors and plastic scintillation counters. Once the response of each detector to heavy ion beams of known composition has been measured, results from on-orbit measurements made by the different instruments can be more meaningfully compared. We conclude by discussing plans for future ICCHIBAN runs, including next 2nd ICCHIBAN run for passive detectors in early summer 2002.

INTRODUCTION

The objectives of radiation dosimetry aboard piloted spacecraft are to accurately measure the radiation exposure of individual crew and to characterize the radiation field on the interior of the spacecraft to aid in modeling the environment for purposes of dosimetric assessment and mission planning. Space radiation dosimetry is currently focused on the ISS which, in the coming years, will host large numbers of astronauts and cosmonauts for extended periods of time$^{1}$. To date, a relatively large number of space radiation detectors, both active and passive, have been exposed aboard a number of different spacecraft including the NASA Space Shuttles, the Russian Salyut and Mir orbital stations, and on recoverable satellites$^{2-13}$. These instruments were developed and tested by individual research groups in a number of different countries and each detector was calibrated “in-house” by the research group responsible for developing it and using their own calibration methods. For this reason, and due to inherent differences in the operational principles of different types of radiation detector, results of measurements in space made by these different instruments are often inconsistent$^{14-16}$. The space radiation dosimetry community has long recognized the need to intercompare different spaceflight dosimeters and the Workshops on Radiation Monitoring for the International Space Station (WRMISS) has recommended that radiation instruments used aboard the ISS should be intercompared using well-known radiation fields on the ground. Following this recommendation, we have started an intercomparison program with heavy ion beams from HIMAC heavy ion accelerator, NIRS. Because heavy ion beams can simulate the galactic cosmic-ray heavy

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ions, we can compare the results of the instruments for one of most important radiation in space environment. In addition, the discrepancy between results from different instruments is, perhaps, most conspicuous in the high LET region ($\geq 100$ keV/µm). The HIMAC which has been constructed in order to investigate the application to cancer therapy of various species of accelerated heavy ion from protons to krypton and at energies up to 800 MeV/nucleon, making it well-suited for this type of intercomparison\textsuperscript{17}. In this paper, we report on the first intercomparison run, held in February 2002. This run (1st ICCHIBAN run) concentrated on comparing active instruments aboard spacecraft for radiation dosimetry.

**EXPERIMENTS**

The 1st ICCHIBAN intercomparison exposures were performed from Feb. 11 to Feb. 14, 2002 at the PH2 beam port at the HIMAC using 400 MeV/nucleon $^{12}$C and 400 MeV/nucleon $^{56}$Fe ion beams. Total accelerator time, including time for beam tuning, was approximately 40 hours. The participants in the 1st ICCHIBAN run included about 25 investigators from seven research groups. The participants and their instruments are listed in Table 1.

Prior to exposure of the participants’ instrument, each heavy ion beam was characterized using a reference ground-based detector system which included position sensitive silicon detectors, thick silicon detectors, time of flight scintillation counters and a sodium iodide detector. This detector system, belonging to the group of Miller, Zeitlin and Heilbronn\textsuperscript{18}, is routinely used for heavy-ion projectile fragmentation studies at the HIMAC. The reference detector system measured the beam profile, deposited energy in the silicon detector, velocity of ions and total energy. In addition, the range of the beam was measured by a pair of scintillation counters on either side of a binary filter system capable of providing a variable thickness of acrylic absorber and resulting in a measurement of the Bragg curve. Each participant’s instrument was mounted on a combination X-Y stage/rotating table which could be controlled via a networked computer. Because of these tables, the position and angle of the incident beam relative to the instrument could be controlled remotely. A scintillation counter (SC) and a position sensitive silicon detector (PSD) were positioned in the beam line directly in front of the space radiation instrument being exposed. The PSD was mounted on the same X-Y/rotating stage as the space instrument. The SC was fixed in front of the stage and used both to count the number of ions and to produce a trigger signal for the data acquisition system. The PSD was used to monitor the beam profile with time. Both the PSD and SC were operated during each space instrument exposure. The exposure configuration is shown in Fig. 1 and Fig. 2. Each participant’s instrument was exposed to the same beam condition in order to permit direct comparison.

The beam intensity was tuned to ~500 particles per spill and the beam profile was tuned to a 20 mm diameter circle. The beam intensity fluctuated within $\pm 50\%$ and fluctuation in the beam profile was found to be negligible. Several instruments could not be exposed to such a high event rate and they did not count a significant fraction of the incident particles because of their slow data acquisition systems. They were not required to measure all incident particles in space environment but sampled particles. However they could be operated without problem during exposures to measure deposited energy and absorbed dose.

| Participant | Institution | Country | Detectors | Detector Type |
|-------------|-------------|---------|-----------|---------------|
| C. Zeitlin, J. Miller, L. Heilbronn | LBNL | USA | Reference Detector System | Silicon Stack Detector, ToF SC, NaI SC |
| E. R. Benton | Eril Res. Inc. | USA | Passive Detector | CR-39 + TLD |
| H. Tawara, M. Masukawa, A. Nagamatsu, H. Kumagai | KEK, NASA | Japan | Passive Detector | CR-39 + TLD |
| R. Beaujean, S. Burmeister | Kiel Univ. | German | DOSTEL (I+HI+D) | Silicon Stack Detector |
| Y. Uchihori, T. Dachev | NIRS, STIL BAS | Japan, Bulgaria | Liulin-4J | Mobile Silicon Detector |
| T. Doke, K. Terasawa | Waseda Univ. | Japan | RRMD-III | Silicon Stack Detector |
| T. Sheler, E. Semones, N. Zapp | NASA-JSC | USA | ISS-TEPC, Shuttle-TEPC, IV-CPDS | TEPC, TEPC, Silicon Stack |
All of the active space radiation instruments operated without trouble and were able to collect important data. (Fig. 3) The working group of ICCHIBAN run has required the following information from each participating instrument:

1. LET or y distribution
2. Dose (in H$_2$O) per a particle
3. Dose Equivalent (in H$_2$O) per a particle

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**Fig. 1.** Exposure configuration of LBNL Ground Base Detector, ToF (Time of Flight), SC (Scintillation Counter), NIRS-PSD (Position Sensitive Detector) and Binary Filter System for reference measurement.

**Fig. 2.** Exposure configuration of Space Radiation Detector and reference detectors with XY and Rotating (Theta) table.

**Fig. 3.** A photograph on experiment in 1st ICCHIBAN run. The golden instrument is the IV-CPDS detector from NASA JSC and it is on beam line.

**Fig. 4.** Result of measurements by the Liulin-4J for carbon 400 MeV/nucleon beam. The distributions show deposited energies in silicon detector inside the Liulin-4J instrument. The beams were injected from various angles. The vertical lines show deposited energies estimated from the incident ion energies.
CONCLUSIONS

In February, 2002, we conducted the 1st ICCHIBAN run dedicated to active detectors. The experiment is the first attempt to intercompare instruments used to measure the space radiation for dosimetric purposes. The exposures were successfully performed and were able to obtain useful data from each participant’s instrument. We will conduct the 2nd ICCHIBAN run, dedicated to passive instruments, in May 2002. The intercomparison project will be continued for three years in an effort to reduce the discrepancy between different radiation instruments and to improve our understanding of how each type of instrument responds to the radiation environment encountered in space.

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