SPACE SCIENCE
Interim Report of Cosmic Ray Doses in Airplanes Measured by a Pocket Dosimeter

Kazunobu Fujitaka

Key words: airplane, dose estimation, solar activity

Neutron doses in airplanes still remain ambiguous. From the viewpoint of health physics, however, it is not a bad idea to measure the dose with a small pocket dosimeter (1” x 1” silicon ionization chamber: Aloka PDM-101) with a proper conversion factor to the total dose (neutrons involved).

Dose values obtained on board airplanes are summarized in Fig.38. Data include uncertainty which originates from the latitudinal and the flight directional dependences. Solar activity is another source of variation. However, it is most probable that the general public wants to know only how much they receive during an airplane flight to a specific destination. Reasons of variation are not their concern.

Data were collected for 77 flight ranging from domestic flights to long distance flights. About 50 were intercontinental flight. Data collection and analyses were done by the same person. Values were obtained using the same instrument with a few exceptions, so it would be possible to make systematic adjustments for better values later. The total dose shown here was estimated as 2.7 times the indicated value of PDM-101. The measurements were started in 1997, and have been done over 5 years which is almost equal to half the period of solar activity variation. Actually, the dose increases with flight hours wherever the airplane goes, and the maximum dose of a one-way flight would be below 50 Sv. In this figure, the dose is limited to flights only from/to Narita.
Fig. 38  Estimated dose when an airplane flies from/to Narita. Abscissa represents time length in unit of minute.
91. The Effect of High LET Radiation Is Compromised in NHEJ Deficient Human and Rodent Cells

Shiori Saito and Ryuichi Okayasu

Key words: high LET radiation, non homologous end Joining (NHEJ), cell survival, repair, premature chromosome condensation (PCC)

We have measured radiation cell survival in various human and rodent cell lines exposed to high LET (LET=80keV/m) carbon ion particles (290MeV/u), and the results were compared with those for cell lines irradiated with X-rays. Non homologous end joining (NHEJ) deficient human fibroblast (180 BR: Ligase IV mutant) irradiated with carbon ions (LRT=80keV/m) showed a survival level which was identical to the survival obtained with X-rays. On the other hand, normal human fibroblast showed a significantly higher cell survival when X-rays were used as compared with the survival with high LET carbon ions. Likewise, NHEJ repair deficient hamstar xrs6 cells (Ku80 mutant) showed 180BR-like survival response while wild-type Chinese hamstar ovary (CHO) cells showed a normal human cell-like response. These results may suggest that the initial damage induced by high LET radiation is different from that induced by X-rays, and the regular DSB repair process is not properly functioning in cells irradiated with high LET. Our preliminary results using the premature chromosome condensation (PCC) assay seem to indicate the difficulty in repairing the damage produced by high LET irradiation in normal cells.

No figure
92. Pion-Emission Cross Section in Finite Nuclei at Cosmic Ray Proton Energy

Susumu Kinpara

Key words: pion-emission cross section, effective pion-nucleon coupling model, galactic cosmic ray proton

Cosmic ray experiments on the earth play a decisive role to determine an abundance of the elementary particles and their energy spectrum. Above all, the pion-emission cross section determines branching ratio that the projectile energy is assigned to the secondary and which dominates the distribution of the radiation field. In the present work we investigate the high energy limiting behavior of the elementary particle reaction for the use of the transport equation.

One of the successful treatments on the hadronic phenomena is the meson-nucleon effective field model in the framework of the relativistic nuclear many-body problem. In the effective pion-nucleon coupling model the interaction is represented by either pseudoscalar(PS) or pseudovector(PV) type. In the case of the real pion external line the suppression mechanism is not necessarily applicable so that the PS one is anticipated to make a contribution compared with the PV one exceedingly.

For calculation of the many-body system the Green’s function formulation is employed systematically. Incorporating the emitting phenomenon, the external pion is assigned a definite energy and charge in the final state with restriction of their conservation law respectively. It is assumed in this work that the final state momentum distribution of the target nucleus is changed by the uniform displacement in the momentum space. Therefore, the backward scattering of the neutron gets rid of the suppression resulting from the nuclear finite size effect.

It is instructive to derive the high energy limit of the total cross section. Approaching a constant value over TeV region, it gives a remarkable result suitable for the ultra relativistic energy. Because the calculated cross section depends on the range parameter the nuclear density distribution is responsible for the resultant high energy limit to be appropriate definitely. The angular distribution of the neutron spreads with the peak at the backward hemisphere accompanying the oscillatory behavior, in contrary to the pion momentum which is emitted forwards without the modulation by the exclusion effect and serves as the secondary particle.

In summary, we have calculated the pion-emission cross section in the framework of the effective meson-nucleon coupling model. It has been shown that the precise calculation of the pion emitting process is significant for the understanding of the galactic cosmic rays. The high-energy limiting behavior is improved considerably by taking into account the nuclear translational motion. The physical meaning and the role for the cascade process is in current investigation.
93. Resonance Model for Radiation Action

H. Yamaguchi, H. Ohara and A. J. Waker

Key words: biophysical model, radiation action, radiation protection

It is widely recognized that RBE is a multiple-valued function of LET, for both physical reasons (inadequateness of LET alone as a microscopic description of radiation quality) and biological reasons (different biological systems and conditions). Attempts are being made continuously to seek more physically meaningful and practically descriptive radiation quality in microscopic dimension and also to reassess the numerical values of radiation weighing factors related to the radiation protection.

LET has been used as a quantitative parameter of radiation quality in a number of the attempts to construct a biophysical model of subcellular mechanism of radiation action. No general parameter on radiation quality, however, has yet been fully identified despite much effort in the field of microdosimetry.

Bearing these facts in mind, we propose a biophysical model in which two processes are assumed for radiation action including damage production and damage repair. The ionization mean free path is proposed as the parameter to describe the damage production process, and LET is ascertained as the parameter of the repair process. Assumptions are as follows: (1) There are two targets in microscopic and macroscopic to explain the radiation action. (2) The entity of initial damage in the microscopic target is DSB (Double Strand Break) of DNA. (3) The microscopic target has structures potentially leading to DSB. (4) As a measure of such structures, there are three distributions of distances between atoms, those within DNA, DNA and water, and in pair of water molecules. (5) The yield of initial DSB in the microscopic target can be described by the extent of the ionizing mean free path arising closer to the distance of the target structures leading to DSB (resonance nature). (6) The yield of initial DSB in the macroscopic target is related to biological response observed and the macroscopic target is specified by its mean chord length. (7) The non-repaired or miss-repaired DSB is relevantly expressed to the observable biological endpoint in the cell that has repair ability.

The potential structure leading to DBS was obtained by a model system of B-DNA 5′-TCGCGTTGCGCT-3′, 24 Na+ and 7973 water molecules in the box. The first possible distribution of distance(s) is associated with direct radiation action and the other two distributions, with indirect radiation action. Yields of water radicals and their diffusions are involved to estimate occurrences of DSB. Based on the differential cross section of an electron as a function of its kinetic energy, we calculate the integral cross section of the electrons and the total cross section of heavy charged particle of track segment type. The microscopic cross section to produce DSB may associate to form the macroscopic cross sections, suggesting the presence of two sizes of the target. The present model is done with four parameters, i.e. the geometrical cross section of the microscopic target and the mean chord length of the macroscopic target, for each electron and heavy charged particle. Optimization of the initial (DSB production) cross section has been made by fitting the model to the cell killing data with a repair deficient cell line of AT-cells.

The values of the parameter, the geometrical cross section, are $\Sigma_0=2.4 \times 10^{-7}$ $\mu$m$^2$ ($r_0=2.8$ Å) for electrons (X-rays) and heavy charged particles, where $r_0$ is effective radius of the geometrical cross section, and the mean free paths are 1.31 $\mu$m for electrons and 9.4 $\mu$m for heavy charged particles. The value $r_0$ suggests one water molecule as the common microscopic target for electron
and heavy charged particle. The value of the mean chord length suggests different size of the macroscopic target, i.e. the size like chromosome for electron and that like cell nucleus for heavy charged particle.

The probability of repair from the initial cross section may be described with either of three variables, i.e. mean free path, $Z^2/\bar{\sigma}$ and LET. We found LET as the proper variables to describe the repair probability. Introducing an empirical expression for the repair probability as a function of LET, inactivation cross sections for T1-cell (repair efficient cell line) can be systematically explained and expressed as a function of such measurable variable as the energy of particles (Fig.39). This expression may be important for radiation protection if the scheme of the radiation protection includes that of fluence-based.

Fig. 39. Inactivation cross section ($\bar{\sigma}$ m$^2$) for T1 cells as a function of particle energy for fluence-based radiation protection.
In order to compare response and sensitivity of various space radiation monitoring instruments for heavy ion and reconcile differences in measurements made during space flights, the intercomparison program, ICCHIBAN (InterComparison for Cosmic-ray with Heavy Ion Beams At NIRS) project, have been carried out in HIMAC. In total 70 investigators (including 27 foreign investigators) participated to 4 ICCHIBAN runs during two years. In this fiscal year, 2nd and 3rd ICCHIBAN runs were performed. The former was for passive detectors (TLD, OSL, CR-39 and so on) and the latter was for active detectors (Si Stack detector, Si portable detector and Tissue Equivalent Proportional Counter). The results from the detectors have been analyzed by the working group.

Publication:
Real Time Radiation Measurement by Liulin-4J Spectrometer at High Altitude

Yukio Uchihori

Keywords: high altitude, airplane, space radiation, real time monitor

Radiation environment in an aircraft at high altitudes above 20 km has been measured with Liulin-4J portable silicon spectrometer. The aircraft (Fig. 40) was operated by NASA Dryden Flight Research Center in California, USA for scientific research on high altitude environment. The data from the spectrometer show that the dose rate depends on altitude and geomagnetic latitude. This investigation will help to confirm calculated results by a simulation code for the high altitude environment in which a future supersonic airplane will fly.

Publication List:

Fig. 40. ER-2 high altitude aircraft and dose rate dependency for altitude. Horizontal axis shows local time and the histogram shows the dose rate. The solid line shows the altitude of the ER-2 at each local time.
96. Preventive Effects of Running Exercise on Bones in Heavy Ion Particle Irradiated Rats

Satoshi Fukuda, Haruzo Iida, and Xueming Yan

Keywords: heavy ion particle, rat, bone mineral, histomorphometry

We examined the effects of running exercise on preventing decreases in bone mineral and tissue volume after heavy ion particle irradiation in rats. Male Wistar rats underwent whole-body irradiation by heavy ion particle beam (C-290MeV) at doses of 0.5, 1.0, and 5.0 Gy and then were divided into voluntary running groups and control groups. Rats in the running groups ran on the treadmill 15 m/min, 90 min/day for 35 days after exposure. At the end of the experiment, a tibia was obtained from each rat for measurement of bone mineral density (BMD) and cross-sectional area, strength strain index, and bone histomorphometric analysis. The weights of muscles and concentration of serum calcium were measured. Total BMD and trabecular BMD in the metaphysis and cortical BMD of the diaphysis of tibia in the running groups increased. Bone volume and trabecular thickness increased while trabecular separation decreased in the running groups compared to those in the control groups at respective doses. However, the osteoid surface and eroded surface varied in the running groups compared to those of the respective corresponding groups. The dynamic parameters such as mineralizing surface, mineral apposition rate, and bone formation rate in the running groups were varied, probably due to the differences in radiation-induced sensitivities of bones following radiation exposure. The overall results suggest that running exercise might have a beneficial effect on preventing bone mineral loss and changes in bone structure induced by space radiation, but it is necessary to examine the optimal conditions of running exercise response to doses.

Publication:
97. Genomic Instability in Mutation Induction on Normal Human Cells Exposed to Chronic Low-dose Radiation in Heavy Ion Radiation Field

Masao Suzuki, Chizuru Yamaguchi, Yukio Uchihori, Hiroshi Yasuda and Kazunobu Fujitaka

Keywords: genomic instability, hprt locus, scattered low-dose (rate) radiation, heavy ion radiation field

We have been studying cellular responses in normal human fibroblasts exposed to scattered low-dose radiation in a heavy ion radiation field. This year we focused on the induction of genomic instability in mutation induction detected with a 6-thioguanine resistant clone targeted on hprt locus. Cells were cultured in a CO₂ incubator, which was placed in the irradiation room for biological study of heavy ions in the HIMAC and exposed to low-dose radiation produced with scattered radiation from heavy-ion beams throughout the life span of the cell population. Genomic instability in cellular response was examined to measure mutation induction in low-dose accumulated cell populations after exposing to X-ray challenging doses as a function of accumulated doses. The mutation frequency of the low-dose accumulated cell population was 2-5 times higher than that of unaccumulated cell population up to 15 days after being exposed to low-dose radiation (Fig.41). The results indicate that very low-dose accumulation of scattered radiation from heavy-ion beams induced genomic instability in mutagenesis.
98. LET and Ion Species Dependence of Cell Killing, Mutation Induction and Chromosome Damage on Normal Human Fibroblasts

Chizuru Yamaguchi, Masao Suzuki and Kazunobu Fujitaka

Keywords: LET & ion species dependence, HZE particles, hprt locus, chromatin breaks, premature chromosome condensation (PCC)

This year, we focused on both cell killing and mutation induction, depending upon both ion species and LETs.

First, we studied both LET and ion species dependence of RBE values for cell killing effect. Normal human fibroblasts were irradiated with heavy ion beams, such as carbon, neon, silicon and iron ions with various LETs ranging from 13 to 400keV/µm. Cell killing effect was detected as a reproductive death using a colony-formation assay. The results clearly indicated that the peak position of RBE at 10% survival level shifted to higher LET region with increasing atomic number of ion sources (Fig.42).

Second, to identify the difference in mutation induction at the cellular level between carbon and neon ions, we examined the induction of 6-thioguanine-resistant clones, concentrated on the hprt locus as the target gene of mutation. The cells were irradiated with either carbon or neon ions at various LETs ranging from 13 to 335keV/µm. The dose-response curves for both carbon and neon ions increased steeply up to 0.5Gy and leveled off or decreased above 1Gy, compared to the response to $^{137}$Cs rays. However, we observed a large difference in the frequency at the plateau between neon- and carbon-ion-induced mutations. For example, the frequency for carbon-ion-induced mutation at 110keV/µm was around 30 times higher than that for neon-ion-induced mutation at 105keV/µm when compared to a similar LET value. There is circumstantial evidence that the different ion species, such as carbon and neon, led to quantitatively different mutation frequencies even when the LET value was similar.

Publication:

![Fig.42. RBE for cell killing as a function of LET](image_url)
99. Influence of the Shielding on the Space Radiation Radiobiological Effectiveness. II. Chromosomal Aberrations

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Keywords: high-LET radiation, chromosome aberration, telomere, unrejoined breaks

Reported studies of DNA breakage induced by radiation of various qualities have generally shown a higher fraction of unrejoined residual breaks after high-LET exposure. This observation is supported by the argument that high-LET radiation induced DNA breaks that are more complex in nature and, thus, less likely to be repaired. In most cases the doses used in these studies were very high. We have studied unrejoined chromosome breaks by analyzing chromosome aberrations using a fluorescence in situ hybridization (FISH) technique with a combination of whole chromosome specific probes and probes specific for the telomere region of the chromosomes. Confluent human fibroblast cells (AG1522) were irradiated with rays, 490 MeV/nucleon Si, or with Fe ions at either 200 and 500 MeV/nucleon, and were allowed to repair at 37 °C for 24 hours after exposure. A chemically induced premature chromosome condensation (PCC) technique was used to condense chromosomes in the G2 phase of the cell cycle. Results showed that the frequency of unrejoined chromosome breaks was higher after high-LET radiation, and the ratio of unrejoined to misrejoined chromosome breaks increased steadily with LET up a peak value at 440 keVµm.

Publication:
Simultaneous Exposure of Mammalian Cells to Heavy Ions and X-rays

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Keywords: High-LET radiation, synergistic effect, Cell survival, Chromosome aberration

Crews of space missions are exposed to a mixed radiation field, including sparsely and densely ionizing radiation. To determine the biological effectiveness of mixed high-/low-LET radiation fields, mammalian cells were exposed in vitro simultaneously to X-rays and heavy ions, accelerated at the HIMAC accelerator. X-ray doses ranged from 1 to 11 Gy. At the same time, cells were exposed to either $^{40}$Ar (5.5 MeV/n, 86 keV/µm), $^{28}$Si (100 MeV/n, 150 keV/µm), or $^{56}$Fe (115 MeV/n, 442 keV/µm) ions. Survival was measured in hamster V79 fibroblasts. Structural aberrations in chromosome 2 were measured by chemical-induced premature chromosome condensation combined with fluorescence in situ hybridization in isolated human lymphocytes. For argon and silicon experiments, measured damage in the mixed radiation field was consistent with the value expected using an additive function for low- and high-LET separated data. A small deviation from a simple additive function was observed with very high-LET iron ions combined with X-rays.

Publication: