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Influence of the shielding on the space radiation biological effectiveness

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Abstract

A research program in space radiobiology is described in this report. The program is focused on the effect of the shielding on the biological effects of heavy ions. Both experiments and models are included in the program. Experiments aim to determine genetic effects of heavy ions with or without shielding. Mathematical models, based on Monte Carlo codes, will be used to interpret the biological results. The final goal is to get a feasible model able to predict the radiation-induced biological damage in space, given the free-space radiation field and the space vessel shielding. The grant is supported by the Italian Space Agency (ASI), and involves Italian radiation biophysics groups (Universities of Milan and Naples, National Institute of Health in Rome), in collaboration with NASA (USA), NIRS (Japan), CERN (Switzerland), Brookhaven National Laboratories (USA), and TERA (Italy).

KEYWORDS: Shielding, heavy ions, space radiation, chromosome aberrations.

1. Introduction

The exposure of astronauts to cosmic radiation poses a major risk to space flights, especially the interplanetary missions [1]. One of the major problems in estimating health risk for astronauts is the uncertainty of the actual particle distribution at the point of exposure of crew members, or at the site of specific organs inside the body.

For terrestrial radiation workers, additional protection against radiation exposure can be provided through increased shielding. However, high-energy particle radiation in space is very penetrating. A thin or moderate shielding is generally efficient in reducing the equivalent dose, but as the thickness increases, shielding effectiveness drops. This is the result of the production of a large number of secondary particles, including neutrons, caused by nuclear interactions of the galactic cosmic rays (GCR) with the shielding. These particles have generally lower energy, but can have higher quality factors than incident primary cosmic particles. Shielding is effective against trapped protons, but its efficiency is poor against GCR penetration.

Transport codes and anatomical models are valuable for health risk assessment, but not without a significant uncertainty. Transport calculations specify the physical characteristic of the radiation field inside or behind shielding. However, to estimate risk, it is necessary to calculate the properties of radiation fields, with a stochastic description of the fluences and the corresponding biological effectiveness of particles of different charge and energies. Moreover, this information has to be associated with models able to predict mixed field effects. The problem is particularly serious for the trip to Mars. In that case, crew is exposed to GCR and possibly to SPE, without the shielding of the Earth's geomagnetic fields.

Considering these uncertainties, NASA [2] and NRC [3] have pointed out that major improvements are urgently needed in a) models of biological response in monochromatic and mixed charged particle fields, and b) experiments on biological effects of heavy ions with shielding.

2. Proposed research program

The proposed research program has two interacting components:
a) development of a new biophysical models for the prediction of biological damages by shielded heavy ions;
b) to perform biological measurements to test the model.

The starting point for the new model are codes/models developed by one of the groups participating in this project: the radiation transport code FLUKA, and the biophysical model for the induction of DNA lesions and chromosomal aberrations based on a Monte Carlo code.

We propose to perform direct measurements of the biological effectiveness of unshielded and shielded heavy ion beams. The following biological endpoints will be studied:
a) Delayed clonogenic death of human diploid human skin fibroblasts
b) Chromosomal aberrations in human peripheral blood lymphocytes
c) DNA fragmentation spectra in human diploid human skin fibroblasts

Data will be used to test the biophysical models of cosmic radiation transport and action developed in the framework of this same proposal.

Few ground-based accelerator exposure facilities provide beams of HZE particles at energies within the

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range of space radiation. Italian and NASA scientists involved in the present project have elected to use two high energy accelerators: the Alternate Gradient Synchrotron (AGS) at Brookhaven National Laboratory (BNL) and the Heavy Ion Medical Accelerator Center (HIMAC) at the National Institute for Radiological Sciences (NIRS) in Chiba, Japan.

Shielding will be performed by light plastic material (PMMA), which is considered by NASA particularly efficient in shielding, being rich in hydrogen atoms, and aluminum.

3. Preliminary results

Preliminary experiments on chromosomal aberrations induced by heavy ions with shielding have been performed at GSI (Darmstadt). The 400 MeV/n ^{12}C therapeutic beam (fig. 1) was used, with or without a 148 mm PMMA absorber (172 mm water-equivalent). Isolated human peripheral blood lymphocytes were exposed in the dose range 0-6 Gy, and incubated at 37 °C for 0 or 17 h before fusion to mitotic hamster cells. PCC 2 and 4 were hybridzed *in situ* using whole-chromosome fluorescent DNA probes. Details of the combined PCC-FISH procedure are described in our previous papers [4].

The unshielded and shielded beam have similar LET, approximately 13 keV/µm. However, the spectral composition of the beam is different. Samples exposed without PMMA were hit by carbon ions. Samples exposed after 148 mm PMMA shielding were irradiated by a mixture of ions. Approximately 50% of the particles had Z = 6 (C), while the other 50% was a mixture of lighter particles (B, Be, Li, He, and H). The relative contribution in dose of the heavier C ion was approximately 75%.

No significant diferences were observed in the yield of PCC excess fragments immediately after exposure, as well as in the yield of exchanges after repair, in shielded and unshielded beams. Although the overall damage produced by the two beams is similar, interesting differences are observed in the quality of the damage. Frequency distribution of the number of fluorescent hybridized spots at 4 Gy is different in the two cases (Fig. 2), suggesting that more cells carrying multiple-damage are produced with the shielded beam. The different spectral composition of the beam should be considered in the analysis of these data.

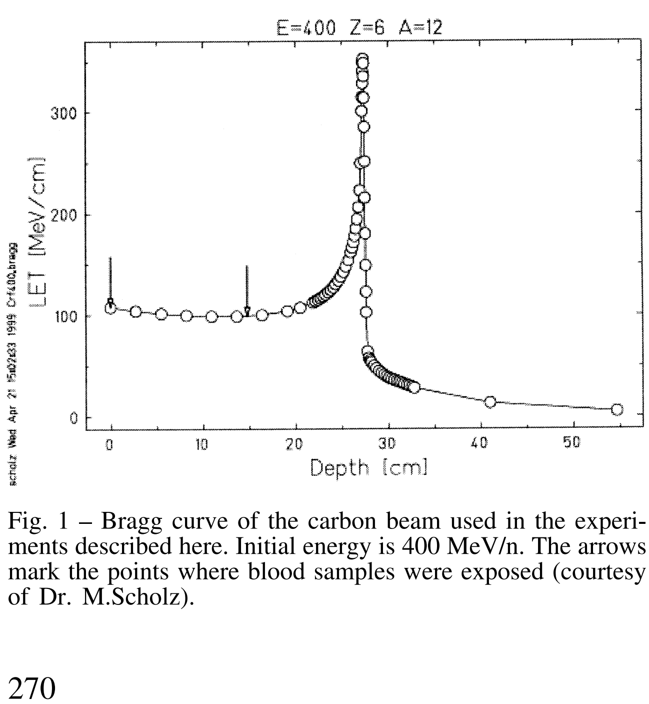

Fig. 1 – Bragg curve of the carbon beam used in the experiments described here. Initial energy is 400 MeV/n. The arrows mark the points where blood samples were exposed (courtesy of Dr. M.Scholz).

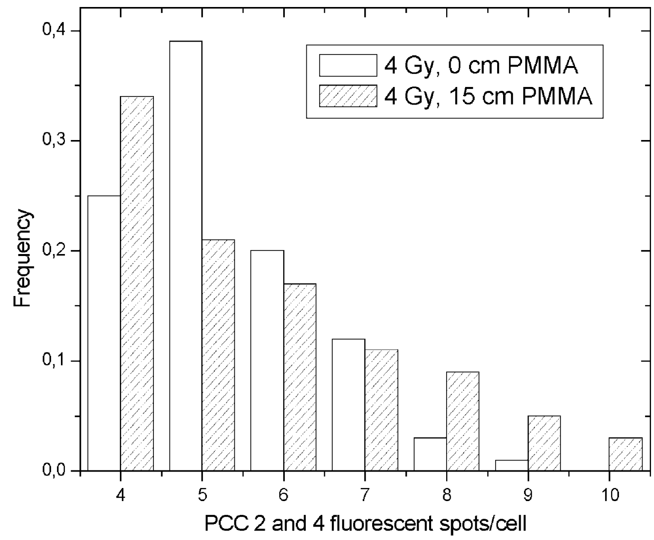

Fig. 2 – Frequency distribution of the number of fluorescent spots (PCC 2 and 4) measured after 17 h from exposure to 4 Gy of 400 MeV/n C-ions with or without shielding. Control cells displays 4 spots, corresponding to a pair of chromosomes 2 and a pair of chromosome 4. Excess spots are either rejoined (exchanges) or free (deletions). The average value is about 5.5 spots/cell for both shielding, but the distribution has a pronounced tail when 15 cm PMMA shielding is used.

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