Wednesday, June 11

S31-72
074326

Session WP4
Room 4
2:30 - 5:30 p.m.

Radiation: Physical Characterization and Environmental Measurements

PRODUCTION OF NEUTRONS FROM INTERACTIONS OF GCR-LIKE PARTICLES

L. Heilbronn
Lawrence Berkeley National Laboratory, Berkeley, CA 94720

In order to accurately determine the radiation risk to astronauts from galactic cosmic radiation (GCR), the nature of the secondary radiation field produced by the interactions of the GCR in shielding materials and tissue must be understood. Neutrons are an important component of the secondary radiation field, especially behind the thick shielding anticipated for lunar or Martian bases[1,2] (Fig. 1). The predominant source of these neutrons is nuclear interactions of GCR protons and heavier nuclei in shielding. Some studies have been conducted at ground-based accelerator facilities on the production of neutrons from interactions of GCR-like particles, but because accelerator resources are limited and because neutron experiments require a large amount of time at those accelerators, the best approach to the problem of determining the amount of neutron radiation behind shielding is through calculations such as the ones reported in references 1-3. From the viewpoint of the experimentalist, the key questions are (1) What are the critical data needed by theorists for the development and verification of their calculations, and (2) What data sets already exist that can be applied to the problem?

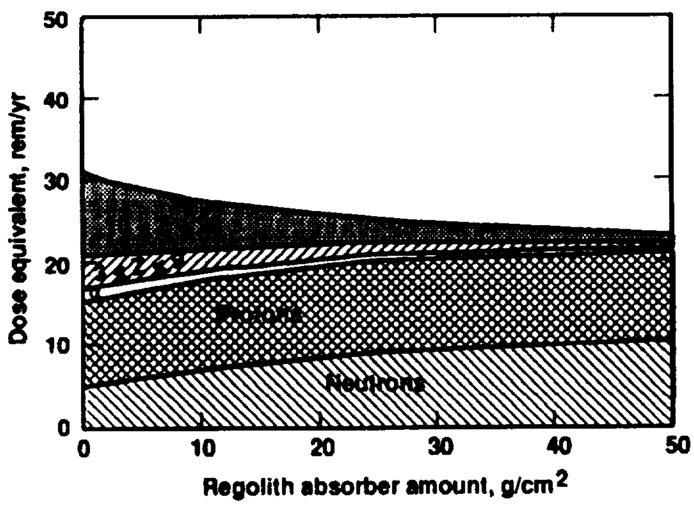

Figure 1. Calculated contributions to the annual dose equivalent to the blood-forming organs from neutrons, protons and heavier nuclei as a function of depth in Martian regolith, for the GCR flux at solar minimum after transport through the Martian atmosphere (16 g/cm^2 CO_2). (From reference 2.)

In answer to question (1), data are needed on total neutron production, angular distributions, and energy distributions. Details on the systematics of neutron production as a function of projectile mass and energy and target mass will be needed. The projectiles include protons, helium, and heavy ions with atomic number as large as 26 (iron). The projectile energies should span the range of energies from 100 MeV/nucleon to 2 GeV/nucleon. Targets should include possible shielding materials such as aluminum, water, and regolith components, as well as tissue components such as water, carbon, and nitrogen.

The production of neutrons by GCR nuclei (Z=2 and greater) is important. One calculation[3] predicts that about 15% of the neutron flux behind 50 g/cm^2 of water comes from helium interactions, and another 16% comes from interactions of heavier nuclei. However, the heavy ion neutron data base has a scant amount of applicable data. To our knowledge, there is only one reference on neutron production from heavy ion GCR-like particles stopping in shielding materials. (177.5 MeV/nucleon and 160 MeV/nucleon helium particles stopping in C, Pb, steel, and water.[4]) There is little thin target neutron cross section data that is relevant to GCR-like interactions.

In order to fill in some of the gaps in the heavy ion neutron data base we have done two sets of accelerator-based experiments that have measured neutrons from heavy ion interactions. One experiment measured the yield of neutrons resulting from 272 and 435 MeV/nucleon Nb ions stopping in Nb and Al targets. The other experiment has measured the yield of neutrons from 155 MeV/nucleon C and He ions stopping in Al targets. Figure 2 shows neutron energy spectra at 3°, 9°, 16°, 28°, 48° and 80° for the 435 MeV/nucleon Nb + Nb system. The solid lines are BUU (Boltzmann-Uehling-Uhlenbeck) model calculations of the data.

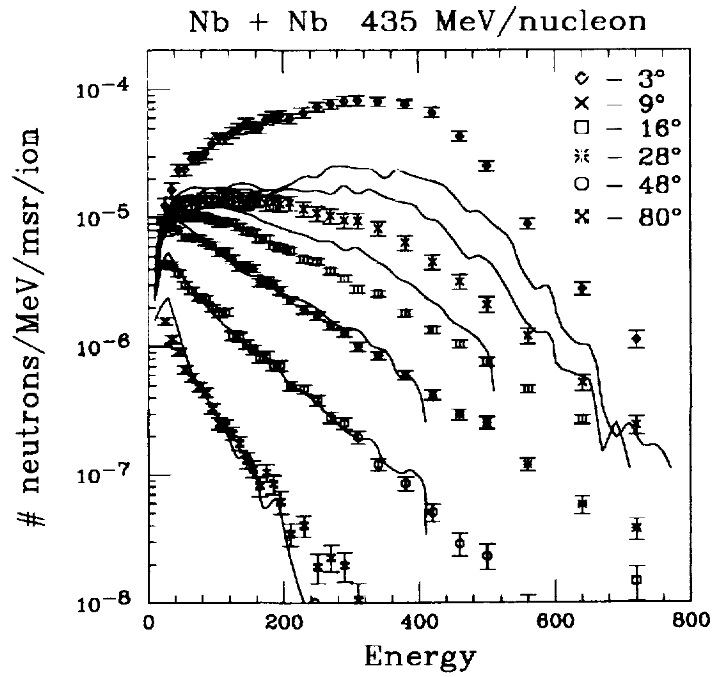

Figure 2. Neutron production as a function of angle and energy in 435 MeV/nucleon Nb + Nb collisions. The solid line is the result of a BUU model calculation.

As can be seen, BUU is unable to fit the entire range of data (nor can other current models), indicating that more work is needed on the development of models that predict neutron production in heavy ion interactions. The experimental data presently available are insufficient to resolve the discrepancies between data and model calculations. For the data set above, acquiring cross section data for the same system and other projectile energies would aid the model development. Additional thick-target and cross section data from a wide range of systems is also needed.

REFERENCES

1. L. C. Simonsen and J.E. Nealy, Radiation Protection for Human Missions to the Moon and Mars, *NASA TP 3079*, 1991.

2. L. C. Simonsen, J. E. Nealy, L. W. Townsend and J. W. Wilson, Space Radiation Shielding for a Martian Habitat, *SAE Technical Paper 901346*, 1990.

3. F.A. Cucinotta, Calculations of Cosmic-Ray Helium Transport in Shielding Materials, *NASA TP 3354*, 1993.

4. R. A. Cecil, B. D. Anderson, A. R. Baldwin, R. Madey, A. Galonsky, P. Miller, L. Young, and F. M. Waterman, Neutron angular and energy distributions from 710-MeV alphas stopping in water, carbon, steel, and lead, and 640-MeV alphas stopping in lead, *Phys. Rev. C* 21, 2471-2484 (1980).

SOLAR PARTICLE EVENT DOSE DISTRIBUTIONS: PARAMETERIZATION OF DOSE-TIME PROFILES

E. N. Zapp[1], C. R. Ramsey[1], L. W. Townsend[1], and G.D. Badhwar[2]
[1]Department of Nuclear Engineering, The University of Tennessee, Knoxville, TN 37996-2300, [2]Space Radiation Analysis Group, NASA Johnson Space Center, Houston, TX 77058

INTRODUCTION

In order to provide adequate warning to deep space astronauts to terminate extravehicular activities or surface operations and to seek protective shelter, methods of accurately predicting the time development of dose buildup from measurements of doses in the early stays of a large solar particle event (SPE) must be provided. We have developed an inventory of dose-time profile calculations for all major SPEs that occurred from January 1986 through April 1994. This inventory of SPE dose-time profiles provides a database for further model development focused on predicting the future buildup of radiation doses from a limited number of observations of absorbed dose spread over time relatively early in a large solar particle event.

METHODS

A typical SPE dose-time profile is displayed in Figure 1. The shapes of the curves are typical for a major event and can be represented by a Weibull function of the form

$$D(t) = D_{\infty} \left\{ - \exp\left[- \alpha \left(t - t_0 \right)^{\gamma} \right] \right. \tag{1}$$

where D_{∞}, α, γ are fitting parameters and t-t_0 is the time since protons began arriving. The procedure is to determine these fitting parameters for the inventory of SPE dose-time profiles using least squares regression analysis methods.

RESULTS

Weibull function fits for the fifteen SPEs in the inventory have been made. The fitting parameters for each event will be available at presentation. A typical fit to a dose-time profile is displayed in the figure for the large SPE which began on September 29, 1989.

CONCLUSIONS

A parameterization of dose buildup over time, based upon a Weibull function, appears promising as a computer model for predicting cumulative doses and times to reach various dose limits from a limited number of measurements of absorbed dose spread in time.

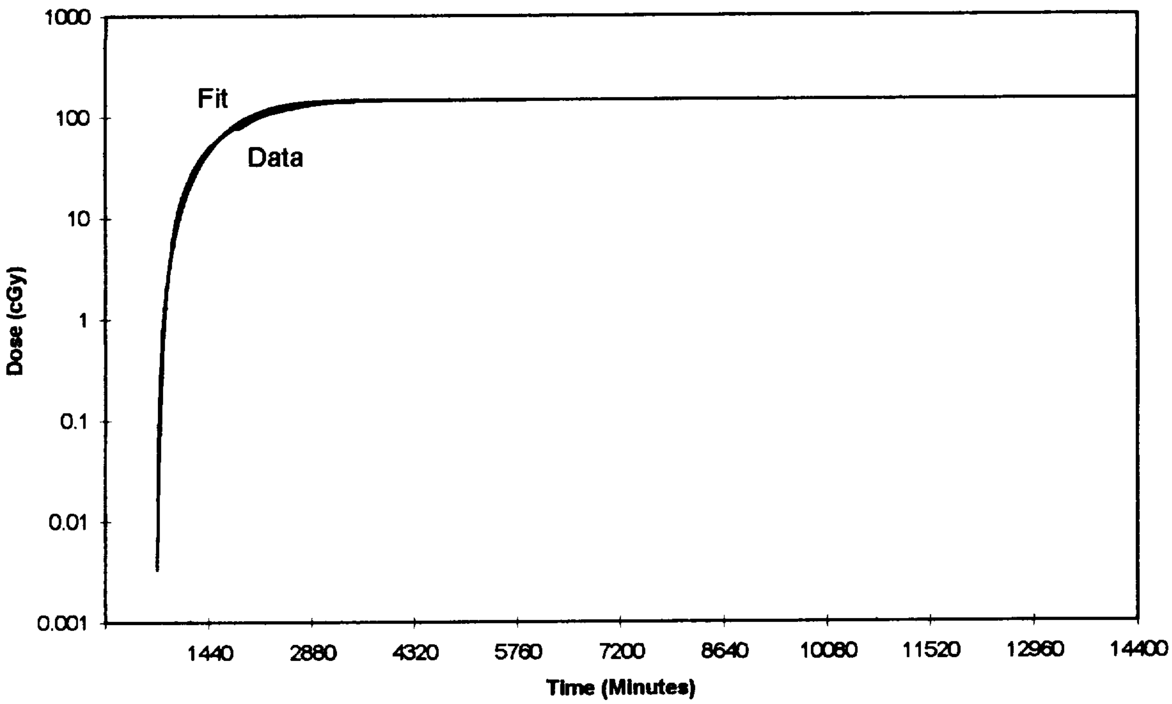

Figure 1. Fit for Skin Doses from the solar particle event on 9/29/89 to 10/9/89 located at S26/W90.

ASSESSMENT OF NUCLEAR EVENTS IN THE BODY PRODUCED BY NEUTRONS AND HIGH-ENERGY CHARGED PARTICLES

R. A. Noulty,[1] H. Ing,[1] E. T. H. Clifford,[1] B. Selkirk,[1] J. Gamero,[1] and A. Mortimer[2]
[1]Bubble Technology Industries, Chalk River, Ontario, [2]Space Life Sciences, Canadian Space Agency, Ottawa, Ontario

SUMMARY

Nuclear fragmentation, which is of concern for radiation protection of astronauts, can be produced by neutrons and high-energy charged particles in space. An experiment is being planned to determine the relative importance of the two modes of interactions. The experiment is based on coincidence counting between a bubble detector and a plastic scintillator which is used as a coincidence shield. This information is needed to interpret properly past measurements of space radiation with various detectors, including the bubble detector, and will lead to a better understanding of the source of the radiation with the potential of reducing the biological risk from such radiation effects. The experimental equipment which is being built for this measurement will be useful for other studies involving active detectors.

INTRODUCTION

The neutron bubble detector[1] is a popular personal dosimeter which provides a good assessment of biological detriment from neutrons found in various radiation environments on earth.[2,3,4] There are reasons to believe[5] that such a detector may also be a good indicator of biological detriment for high-energy particles in space.

In our previous measurements of neutron spectra in biosatellites[6] and the space station Mir, we have interpreted[7] the readings of bubble detectors as being caused by high-energy neutrons. This interpretation was based on data from an earlier experiment where high-energy protons from the Orsay cyclotron were used to irradiate bubble detectors and produced negligible response.

Charged particles interact with matter predominantly via the Coulomb force with the electron cloud surrounding the nucleus, rather than with the nucleus itself. In fact, the interaction of charged particles with the nucleus is so rare that it is usually neglected in the computation of charged particle behaviour in a medium to derive characteristic parameters such as penetrating depth, stopping powers, etc. For radiation dosimetry on earth, the calculations of those and biological effect treat charged particles very differently from those for neutrons and photons because of their vastly different interaction modes with matter.

SIMILARITY OF CHARGED PARTICLES AND NEUTRONS AT HIGH ENERGY

However, as charged particles increase in energy, they can interact with the nucleus more readily and can create nuclear fragmentations similar to high energy neutrons. Despite the rarity of such events compared to electron interactions, nuclear fragmentation by charged particles may play a crucial role in producing biological damage in a space environment. Since the target nucleus – whether it be a radiation detector or tissue – usually cannot distinguish the nature of the impinging projectile and the net effect is similar, there is reasonable justification to consider lumping high-energy charged particles and neutrons together from the viewpoint of biological effect associated with the nuclear fragmentation process.

SEPARATION OF NUCLEAR EVENTS

Despite the apparent capability of the bubble detector to respond to neutrons and high-energy charged particles on an equal basis, it is nevertheless scientifically interesting to determine the relative importance of these two different interaction processes in the bubble detector. This information would allow us to confirm our earlier interpretation of bubble detector data from space. Also the information has other implications such as the possibility of allowing certain procedures to be implemented to reduce radiation exposure to the crew.

For example, since neutrons are not a direct component of cosmic rays in space, their presence is due to secondary sources of radiation production which can be modified by judicious choice of environmental materials such as those used in the construction of the space vehicle. Also, if a significant fraction of nuclear fragmentation events are caused by high-energy charged particles, it may be possible to consider shielding the crew from radiation hazard – especially in the event of anomalously high radiation activity.

EXPERIMENT TO SEPARATE NEUTRONS AND CHARGED PARTICLES

Equipment is being built for an experiment to assess the relative contribution to nuclear fragmentation processes due to neutrons and charged particles in space. The equipment is intended to be flown in the Mir space station in late 1997.

The apparatus consists essentially of a bubble detector surrounded by a plastic scintillator coincidence counter. The bubble detector is fitted with an acoustic detection system to register electronically the formation of bubbles induced by space particles. The plastic scintillators are housed in a light-tight assembly and viewed with two photomultipliers.

When a bubble formed in the bubble detector is created by a high-energy charged particle, its formation would be accompanied by a signal in the plastic scintillator since the particle would have traversed the outer scintillator giving off light in order to reach the central bubble detector. However, if the bubble is formed by a neutron, so signal would be expected from the scintillator since neutrons would normally penetrate the outer scintillator without interaction. Thus, comparison of the total number of bubbles and the fraction of these which are accompanied by coincidence signals in the plastic scintillator will yield the desired information.

EQUIPMENT DETAILS

The design of the equipment has taken into account the space environment in the performance of the experiment. The size of the scintillator was kept to a minimum, consistent with producing adequate light signal for minimum ionizing radiation. Since high counting rates are anticipated in traversing the South Atlantic Anomaly, the timing circuits have been designed to achieve acceptable randoms to reals ratio over this region. Special boards are made to provide high voltage to the photomultipliers and bubble acoustic sensors and to process the digitized signals. A programmable microprocessor (Intel 8031) is used to control the signals and handle data display and storage. The instrument is designed to be low weight, resistant to noise and powered by the 28 volt supply of the space station.

After completion of this experiment, the equipment would be available for other experiments of scientific interest. The plastic scintillator "coincidence shield" could be used with other types of active radiation sensors that fit within the cavity, designed to house the bubble detector for this experiment.

REFERENCES

[1]H. Ing and H. C. Birnboim, "A Bubble-Damage Polymer Detector for Neutrons," Nucl. Tracks Rad. Meas. 8 (1984) 285-288.

[2]P. Broussard and L. B. Pascale, "Radiological Protection at PWR Plants in Service," RGN International Edition Vol. A. (1993) p. 55-56.

[3]J. Shulze, R. Rosenstock, and H. L. Kronholz, "Measurements of Fast Neutrons by Bubble Detectors," Radiat. Prot. Dosim. 44 (1992) 351-354.

[4]B. J. Lewis, R. Kosierb, T. Cousins, D. Hudson, and G. Guery, "Measurement of Neutron Radiation Exposure of Commercial Airline Pilots Using Bubble Detectors," Proc. Intern. Nuclear Congress (INC93), Toronto, Canada, 3-6 October 1993, Cl. 3, 1-9.

[5]H. Ing, T. D. McLean, R. A. Noulty, and A. Mortimer, "Bubble Detectors and the Assessment of Biological Risk from Space Radiation," Radiat. Prot. Dosim. (in press).

[6]H. Ing and A. Mortimer, "Space Radiation Dosimetry Using Bubble Detectors," Adv. Space Res. 14 (1999) (10)73-(10)76.

[7]H. Ing, T. D. McLean, R. A. Noulty, and A. Mortimer, "Measurements of Space Radiation Using Bubble Detectors," Proc. Spacebound/93, May 16-18, Ottawa, Ontario (1993) 9-10.

GROUND-BASED SIMULATIONS OF COSMIC RAY HEAVY ION INTERACTIONS IN SPACECRAFT AND PLANETARY HABITAT SHIELDING MATERIALS

J. Miller[1], C. Zeitlin[1], L. Heilbronn[1], T. Borak[2], T. Carter[3], K. A. Frankel[1], S. E. Rademacher[2] and C. Stronach[3]
[1]Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA
[2]Colorado State University, Fort Collins, CO 80523, USA
[3]Virginia State University, Petersburg, VA 23806, USA

INTRODUCTION

One of the constraints on the design of spacecraft and future planetary habitats is the effect of the structural materials on the radiation environment inside the spacecraft. High energy heavy charged particles are relatively small in number in space, but because of their highly ionizing character they may have significant biological effects, and the fact that they can fragment in matter complicates the problem. It will obviously be impractical to verify the shielding and transport properties of every candidate material and configuration under actual space flight conditions, and for this reason shielding designers will need accurate models of radiation transport in matter. These models require experimental data for their development and verification. The data needed are of two general types: (1) cross sections, which are probabilities that an ion with a given charge, mass and energy incident on a given target nucleus will produce a fragment with a particular set of properties (charge, mass, energy, angle); (2) fluences, which are numbers of fragments produced at depth in shielding. Cross sections more directly reflect the dynamics of the high energy nucleus-nucleus interactions, and are fundamental information which must be incorporated in heavy ion transport models. Fluence measurements are used to test the ability of a given model to account for the many different interactions which can occur in a thick target such as a spacecraft wall or the human body. We have made a series of measurements at particle accelerators with heavy ion projectiles incident on shielding and tissue-equivalent materials, including aluminum, polyethylene, water, graphite and composite materials.

EXPERIMENTAL METHODS

Charge and energy spectra were obtained using a particle spectrometer (Figure 1), the major components of which are solid state (silicon) detectors of several different thicknesses. The number and type of detectors is adjusted according to the beam ion and energy. Position sensitive detectors (PSD's) provide position information.

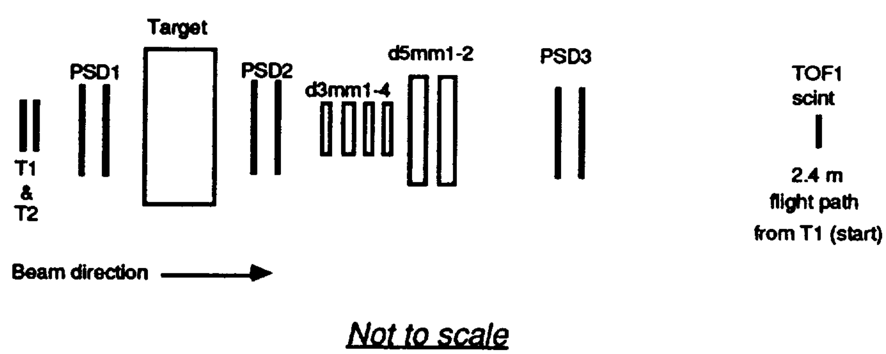

Fig. 1. Charged particle spectrometer used for beam characterization at the BNL AGS.

RESULTS AND DISCUSSION

Figure 2 shows a sample of data taken at the Brookhaven National Laboratory Alternating Gradient Synchrotron (BNL AGS) for fragment fluence spectra produced by 1 GeV/nucleon ^{56}Fe in aluminum and two different thicknesses of graphite-epoxy, one possible shielding material. The primary iron beam produces the large peak at the right in each spectrum, and discrete energy loss peaks for charges from the primary (Z=26) down to at least Z=4 can be identified by eye. This simple example shows the similarity in the fragmentation properties of 2.54 cm aluminum and 5 cm graphite-epoxy, and the effects of doubling the thickness of graphite-epoxy from 5 to 10 cm: note the slightly increased energy loss at 10 cm (due to the slowing of the beam) and the increased fragmentation—evidenced in the increased height of the fragment peaks relative to the primary iron. The data can be readily converted into separate energy spectra for each fragment, and analytical techniques using the information from additional detectors have extended the range to Z=2 and in some cases 1.

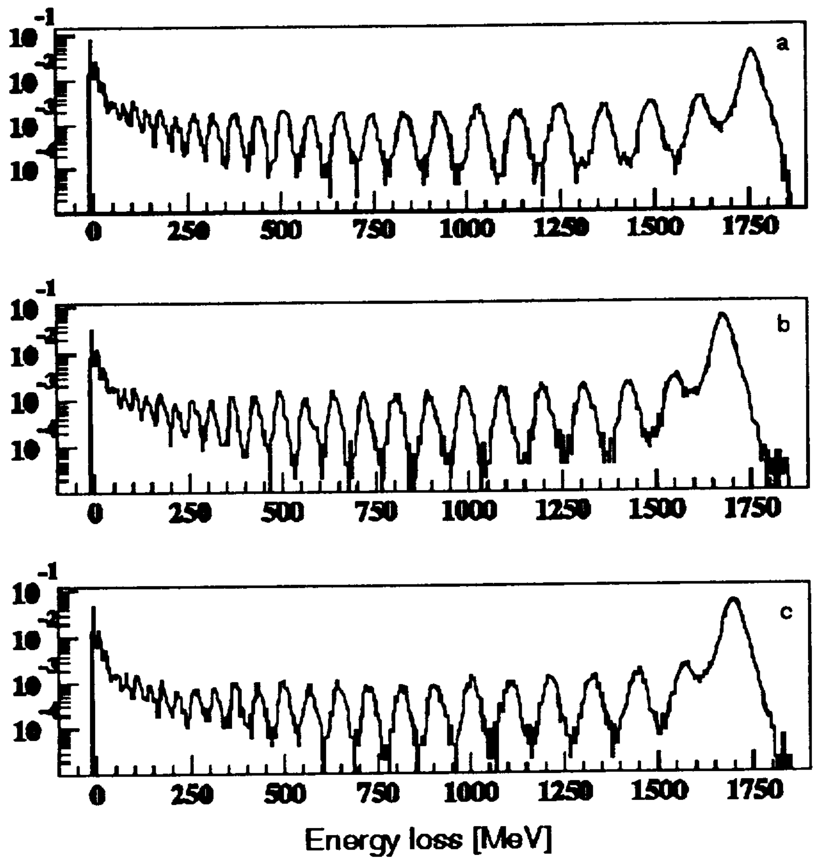

Fig. 2. Energy loss spectra from 1 GeV/nucleon ^{56}Fe fragmenting in three different shielding material targets. a) 10 cm graphite-epoxy; b) 5 cm graphite-epoxy; c) 2.54 cm aluminum. The ordinate is number of counts (unnormalized). The abscissa is the summed energy loss (in MeV) in two 3 mm thick silicon detectors.

CONCLUSIONS

Accelerator experiments generate high statistics data in a controlled setting with well-defined beams. While they cannot simulate the complex radiation fields found in space, they can be used to test model performance for selected critical sets of parameters, *e.g.* for particular incident particle charges, masses and energies and target compositions and thicknesses. They can also be used at various stages of the shielding design process to test the response of candidate materials to a representative subset of space radiation components.

This work was supported in part by the NASA Space Radiation Health Program under Contract No. L14230C through the U.S. Department of Energy under Contract No. DE-AC03076SF00098.

RADIATION MEASUREMENTS IN SPACE MISSIONS

G. Reitz,[1] I. Apathy,[2] R. Beaujean,[3] S. Deme,[2] C. Heilmann,[4] J. Kopp,[3] M. Leicher,[3] and K. Strauch[1]
[1]DLR, Institut für Luft-und Raumfahrtmedizin, Abteilung Strahlenbiologie, D-51140 Köln, [2]KFKI Atomic Energy Research Institute, Health Physics Dept., H-1525 Budapest, [3]Universität Kiel, Institut für Reine und Angewandte Kemphysik, D-24118 Kiel, [4]CRN, GADVI, F-67037 Strasbourg Cedex 02

Detector packages consisting of plastic nuclear track detectors, nuclear emulsions, and thermoluminescence detectors were exposed at different locations inside the Shuttle and at the astronauts' body and in different sections of the Mir space station. Total dose measurements, particle fluence rate and linear energy transfer (LET) spectra of heavy ions, number of nuclear disintegrations and fast neutron fluence rate from these exposures were obtained. Additionally, results from a particle telescope with two silicon detectors, first used inside Biorack on STS-76 and absorbed doses from TLD readings obtained with an onboard TLD-Reader during Euro-Mir 95 will be discussed. The dose equivalent received by the astronauts was calculated from the measurements.

RADIATION MEASUREMENTS IN CIVIL AIRCRAFT

R. Beaujean,[1] J. Kopp,[1] F. Roos,[1] G. Reitz[2]
[1]Universität Kiel, Institut für Reine und Angewandte Kemphysik, D-24118 Kiel
[2]DLR, Institut für Luft-und Raumfahrtmedizin, Abteilung Strahlenbiologie, D-51140 Köln

The instrument DOSTEL, which was developed for dosimetry measurements in manned space flights and contains two planar silicon detectors for the registration of charged particles, was used to monitor the level of the ionizing radiation aboard German airline aircraft.

Results from recent flights in 1996 and 1997 will be presented. Data include count rates, dose rates and LET spectra from different altitudes and latitudes. Deduced radiation quality factors and dose equivalent values will be discussed.

ANALYSIS OF THE PRE-FLIGHT AND POST-FLIGHT CALIBRATION PROCEDURES PERFORMED ON THE LIULIN SPACE RADIATION DOSIMETER

Ts. Dachev*, J. Semkova*, V. Petrov#, V. Redko#, V. Bengin#,
T. Kostereva#, J. Miller+, L. Heilbronn+, C. Zeitlin+

* Solar-Terrestrial Influences Laboratory, 1113 Sofia, Bulgaria
# Institute of Biomedical Problems, 123007 Moscow, Russia
+ Lawrence Berkeley National Laboratory, Berkeley, CA 94720

ABSTRACT

LIULIN, a dosimetry-radiometry system, was developed to satisfy the requirements for active flux and dose rate measurements for the flight of the second Bulgarian cosmonaut in 1988. The system consists of a compact battery-operated detector unit and a read/write microcomputer and telemetry unit. The detector unit contains a silicon solid state detector (SSD), with an active area of 200 mm and thickness of 306 μm. The instrument worked successfully on board the Mir space station from 1988 through 1994 and was returned to Earth in 1995. After pre-flight electronics tests the instrument was calibrated using radioactive sources and accelerated 170 MeV/nucleon proton and alpha particles at the Dubna, Russia accelerator. Analysis of the results obtained at Dubna showed that the instrument sensitivity was overestimated by factor of 2 during the electronics tests. A comparison with data obtained on MIR with the French-built tissue equivalent LET spectrometer NAUSICAA shows that at high latitudes the tissue-equivalent absorbed dose measurements are typically two times greater than the doses measured by Liulin. The NAUSICAA flux data are usually underestimated in comparison with LIULIN SSD data and in comparison with theoretical predictions of the number of protons required to produce the observed absorbed dose. Differences up to a factor of two can be explained by differences in the shielding of the instruments on board the MIR station. In order to study the response of the detector to heavier charged particles post-flight calibrations were recently performed with 1 GeV/nucleon ^{56}Fe ions at the Brookhaven National Laboratory AGS accelerator. At the AGS, the instrument was mounted in tandem with several thin position-sensitive silicon detectors behind a stopping target of lead and graphite-epoxy. Since the LET of the primary beam exceeded the upper limit of LIULIN's sensitive range, the calibration was performed using the lower LET charged fragments produced by nuclear interactions of the primary ^{56}Fe in the aluminum. The silicon detectors provided charge and energy identification for the surviving charged nuclear fragments for which the flux and absorbed dose were recorded by LIULIN.

RADIATION ENVIRONMENT MONITORING FOR ASTRONAUTS

G. Mackay [1], I. Thomson [1], N. Sultan [2], Alfred Ng [2], and Pat Sullivan[2]
[1] Thomson & Nielsen Electronics Ltd., 25E Northside Rd., Nepean, Ontario, Canada K2H 8S1.
[2] Canadian Space Agency, St-Hubert, Quebec, Canada J3Y 8Y9.

INTRODUCTION

The radiation environment in space, particularly Low Earth Orbit (LEO), can be hazardous to the well being of the mission crew. Radiation doses measured inside MIR and STS are considerably higher than those found in occupational situations on earth. Computer simulations also indicate that astronauts in Extra Vehicle Activity (EVA) can be exposed to even higher dose levels, especially to their skin, and eyes where cataract formation is of concern. On-board radiation monitoring for future crew safety, especially during EVA is of extreme importance. This paper discuses the results of two passive experiments, flown on MIR and BION-10, and the resulting development of a real time astronaut monitor developed for the Canadian Space Agency.

METHODS

Computer simulations of the radiation environment were carried out to determine the dose, not only to crew members in shielded areas, but also to crew involved in Extra Vehicle Activity (EVA). The need for radiation measurements on-board the spacecraft has been demonstrated by these simulations. This is especially true of crew involved in EVA. As a result, prototype radiation monitoring instruments based on semiconductor MOSFET dosimeters were developed. The simulations also showed the need to measure three types of dose to humans, viz. skin, ocular and blood-forming organs (BFO). These doses are defined at different depths in the human body.

Instruments which measured the radiation dose both inside and outside a spacecraft were flown on MIR space station as well as the Russian recoverable satellite BION-10. A further experiment was designed and built for a flight on BION-11 which is expected to be recovered early in 1997. As a result of these flight experiences, an astronaut dosimetry system has been developed which can be used for on-board measurements of crew radiation dose.

RESULTS

Simulations of radiation inside MIR show that the environment inside the spacecraft is dominated by high energy protons and the dose to crew members is about 0.3 mSv/day (110 mSv/yr). This calculation was confirmed in experiments using integrating electronic dosimeters on missions of 96 days, 268 days and 430 days durations. This result should be compared with radiation workers in terrestrial occupations who are allowed a maximum dose of 20 mSv/yr.

Computer simulations also predict that higher radiation doses will be received by astronauts in EVA and the organs at greatest risk are the skin and eye lens. Daily skin doses of up to 100 mSv could be encountered in EVA in the Space Station Alpha orbit. In contrast with the doses inside the spacecraft, EVA doses are dominated by high energy electrons.

Figure 1 shows the recently developed Astronaut Radiation Monitor (ARM), which has sensor technology based on the two passive models flown on MIR, BION-10 and BION-11. The ARM is a battery powered real time monitor capable of measuring dose to an astronaut skin, eye and BFO. Such doses are measured using appropriate shielding which surround three MOSFET dosimeters. In addition to measuring dose to the skin, eye and BFO, the ARM has a semiconductor dose rate monitor capable of detecting radiation at rates as low as 0.01 mSv/hr. The latter feature is designed to warn astronauts when high radiation levels are encountered, thereby giving them time to take protective measures. All measurements are time stamped and stored in electronic memory, which can be downloaded later for detailed analysis. The ARM makes dose measurements (skin, eye and BFO) once per hour and dose rate measurements once per minute, with a storage capability of 40 days. In the future, personal dosimeter badges may be interfaced with the ARM, providing a dose record for the individual astronaut during his mission. Monitor parameters are listed in table 1.

Table 1 Astronaut Radiation Monitor Specifications.

PARAMETER	
size	21 cm x12 cm x 5 cm (L x W x H)
mass	2.1 kg
power	10.8 V (0.3 W)
type of dose measurement	skin, eye and blood forming organ
maximum dose measurement	2.0 Sv
minimum dose measurement	0.40 mSv
dose rate detection limit	0.01 mSv/hr
output	RS232

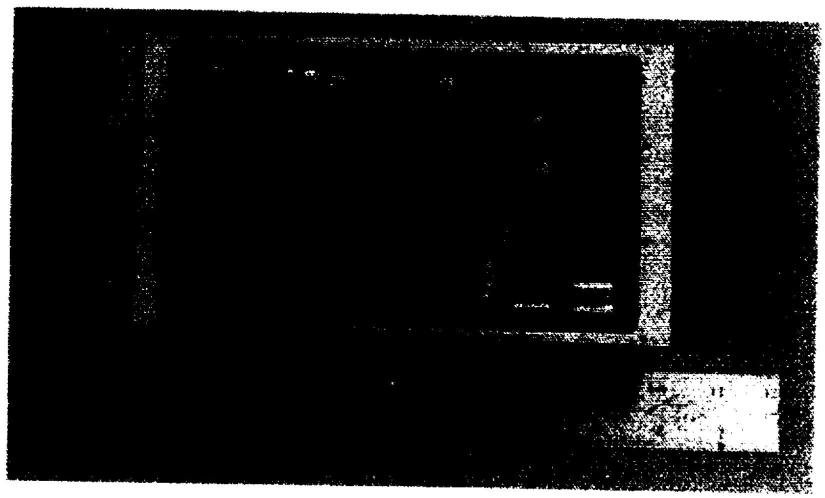

Figure 1 Astronaut Radiation Monitor.

CONCLUSIONS

It has been demonstrated by simulation and experiment that the dose to crew members in long duration missions can be considerably higher than for terrestrial radiation workers and the need for on-board radiation dosimeters has been demonstrated. The need for differentiating measurements, especially in EVA, for skin and eye doses as well as whole body doses has been demonstrated. In addition, the feasibility of using integrating electronic dosimeters on-board the spacecraft has been demonstrated. A dosimetry system which will measure doses to organs at risk (skin, eye, BFO) has been developed as a result of this work and will be tested in future missions.

The ultimate goal is for each astronaut to have his/ her own radiation protection badge which can be interfaced with the ARM. In this manner each astronaut can record his/ her eye, skin and BFO dose during the entire mission, including EVA, thereby giving ample time for protective measures to be taken by the crew members if dose levels become dangerous.