Poster Session I

Physics, Biophysics, and Technology Development I

6:30 p.m. – 8:00 p.m.
Grand Ballroom Salon D

Chair:

Michael Dingfelder
PATTERNS OF ENERGY DEPOSITION BY HZE PARTICLES IN CELLULAR TARGETS

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INTRODUCTION
The interpretation of data from mechanistic studies on radiation biology requires detailed descriptions of the local patterns of energy deposition in the appropriate cellular or sub-cellular sites to explore the effects of radiation quality on biological response. The objective of this project is to provide Monte Carlo (MC) simulations on the local patterns of energy deposition by high-energy, highly charged (HZE) particles in the appropriate environment including effects of micro-, and macro-geometrical considerations. The focus is on HZE radiation induced leukemia which is a major concern of NASA for long term space flights because of its short latency time of 2-3 years.

The project currently performs work in the following directions: 1. develop the detailed MC track structure code to perform step-by-step HZE particle transport in the bone/bone-marrow geometry; 2. characterize energy deposition/dose to trabecular bone; 3. update and improve the HZE track structure code.

TRABECULAR SPONGIOSA
We have developed a simple, non-bone-site-specific, non-patient-specific, and computationally-efficient geometrical model using the geometry package of the general-purpose MC transport code PENELOPE. Internal dimensions are obtained from path-length distributions as measured in different human bones. Details of the model are published in J.A Gersh, M. Dingfelder, and L.H. Toburen, Modeling energy deposition in trabecular spongiosa using the Monte Carlo code PENELOPE, Health Physics 93 (2007) 47-59. We have started work to extend our geometrical model to murines. Internal dimensions of murine bones published in the literature strongly suggest that simple scaling of our human model suffice. Therefore, in a first step, our murine model, which we refer to as scaled mouse model, consists of the human model scaled by a factor of 0.1

HZE PARTICLE TRANSPORT
We have extended PARTRAC’s capabilities to transport HZE particles through liquid water. Interaction cross sections for HZE particles were obtained from proton interaction cross sections in liquid water by scaling laws within the plane wave Born approximation (PWBA). We have successfully coupled the event-by-event code PARTRAC – which supports only slab-geometries – with our trabecular spongiosa geometry model. The resulting code system HITSPAP (Heavy Ion Transport Simulation using PARTRAC And PENELOPE) transports HZE particles with PARTRAC while secondary electrons with PENELOPE.

SIMULATING THE TRANSPORT OF HZE PARTICLES THROUGH TRABECULAR SPONGIOSA
We have simulated the passage of HZE particles through both the human and the murine geometry. More details and results are displayed on the poster Simulating the transport of heavy charged particles through trabecular spongiosa presented by J.A. Gersh at this meeting.

INTERACTION CROSS SECTIONS
While liquid water serves as substitute for soft tissue and bone marrow, we will use metallic calcium, a major component of bone, as substitute for bone in PARTRAC. PENELOPE uses a sum of atomic cross sections due to the atomic constituents (ICRP recommendations) of cortical bone and bone marrow. We are currently updating inelastic proton interaction cross sections with liquid water and have started the derivation of proton interaction cross sections with calcium. We have adopted a model for the dielectric response function of calcium based on theoretical models and available experimental information. The model fulfills sum rules and reproduces other properties of the optical and dielectric functions.

This work is supported by the NASA Grant NNJ04HF39G through the Office of Biological and Physical Research. Emails: dingfelderm@ecu.edu (MD), toburenl@ecu.edu (LHT).
CINS CONCEPT
The basic concept is to combine a charged particle telescope and neutron spectrometer into a single unit with common electronics. The charged particle telescope consists of seven elements: four 5mm thick lithium drifted silicon detectors, two 1mm thick plastic scintillators for rate monitoring and a 38mm thick BGO scintillator for the end of the stack. The telescope detectors are 4 cm in diameter. Guard rings in the silicon detectors reduce their active area to 3.7 cm. In CINS the 4 thick Si detectors provide particle identification and spectra. The plastic scintillators are used as triggers and simple counters which are helpful in high-rate environments. The BGO adds mass, stops protons up to energy of 150 MeV and makes the stack asymmetric for directionality.

The instrument electronics uses the Mars Odyssey MARIE instrument design as a starting point with many improvements, such as fixing the MARIE dynamic range problem, from the JHU/APL GRNS (Gamma Ray Neutron Spectrometer) that made its first flyby of Mercury on the MESSENGER spacecraft on January 14, 2008.

The neutron spectrometer uses low, medium, and high-energy detectors developed under previous NSBRI grants. The low energy system employs a conventional helium-3 gas tube detector; the medium or fast neutron energy system uses a boron-loaded Eljen plastic scintillator as the detector; and the high energy neutron system utilizes a 5mm thick lithium drifted silicon detector. There is some overlap between the medium and high energy systems in the 10-20 MeV energy range.

PROGRESS
During the 2006-2008 time period we 1) refurbished 4cm diameter X 5mm thick silicon detectors by re-drifting and applying guard rings; 2) designed, procured and fabricated a 12cm X 12cm Eljen boron-loaded scintillator to detect up to 15 MeV neutrons; 3) Procured a 38mm X 38mm BGO detector ; 4) obtained and fabricated 1mm thick scintillators for particle telescope; 5) designed and fabricated detector boards for NSRL evaluations; and 6) designed and fabricated the charged particle telescope electronics for control, power and data acquisition. We executed experiments for detector evaluation with carbon, silicon, iron and neutron beams at NSRL in March 06, May, Sept., Oct. 07, March 08 and at RARAF in November 06.

HARDWARE

Seven Element Charged Particle Telescope and the Eljen Scintillator Fast Neutron Detectors
Potential radiation exposures represent a major hazard for personnel in space, but the doses vary widely depending upon mission scenarios. Microdosimetry is perhaps the only technique capable of directly determining in real time the radiation quality of a mixed or unknown radiation field and, therefore, the dose equivalent, gray equivalent, and/or effective dose upon which regulatory radiation limits are based.

The primary goal of this project is to carry out Earth-based research to develop a rugged; compact and portable; low power, low mass, and low voltage; solid-state microdosimeter for space flight and to verify performance by tests with ground-based radiation sources and beams of high-energy protons and heavy ions. Although not part of our original goals, we were presented with an opportunity to fly a version, MIDN-1, on the MidSTAR-I spacecraft as an educational project for (undergraduate) midshipmen in space research and engineering at the U. S. Naval Academy, provided a working version could be produced and tested within the first year of the project. Meeting the challenge, the group was able to produce a prototype, which passed vibration tests at the Naval Research Laboratory and was successfully launched into space in March, 2007. More recently, a duplicate of that prototype was successfully used at the NSRL facility of the Brookhaven National Laboratory to obtain spectra for a 1-GeV/nucleon titanium beam, and these results will be presented. In parallel with the development and testing of the space instrument, we have been carrying out extensive ground-based studies with the same versions of the solid-state sensors flown in space with radiation sources and accelerator beams at the U. S. Naval Academy and NSRL. These experimental data have been compared with calculations using transport codes. Based on the results of this research, we have redesigned the space system and are now testing a new generation prototype, which will be described.
We have developed an automated system, the Cell/Tissue Culture Radiation Exposure Facility (CTC-REF), to improve radiobiology research capabilities at NASA Space Radiation Laboratory (NSRL) at Brookhaven National Laboratory (BNL). Current radiobiology experimentation at NSRL is limited primarily by the amount of time required to manually move samples to/from the radiation target area. Additionally, the NSRL facility currently does not support immediate processing of samples after radiation exposure. Our CTC-REF system will address the above issues as follows. First, an automated sample movement system has been developed to reduce the overhead time of the current manual system of moving samples to/from the radiation target area. Second, an Online Assay System has been designed to provide immediate sample analysis, such as sample fixation, to allow a better understanding of the radiation effects on the samples. In addition, the CTC-REF system is designed with the capability to support animal experiments in the future.

The CTC-REF will be an “add-on” facility to the current setup inside the Radiation Target Room at NSRL. Investigators will have the option to use the CTC-REF to increase the throughput and efficiency of their research. When the CTC-REF is not used, it can be easily and safely moved out of the way. The CTC-REF’s two key systems, the Automated Sample Changer and the On-line assay system, can be used individually or in tandem to improve radiobiology research capabilities at NSRL.

The Automated Sample Changer system uses a robot (with an articulated arm) paired with an incubator to automatically move the samples in and out of the Radiation Target Area, therefore reducing the overhead time of the current manual system of moving samples. The robot can smoothly move the samples to/from the Radiation Target Area within one minute, with minimal sample environmental variation outside the incubator. The current Automated Sample Changer design is shown on the left in the figure below.

The On-Line Assay System uses an integrated system of fluid reservoirs, fluid loops and pumps (interfaced to investigator’s sample containers within the CTC-REF incubator) to support automatic processing of samples directly after radiation exposure. Currently at NSRL, samples must be moved from the Radiation Target Room to the nearby biological lab before beginning post radiation assays. Providing an automated on-line assay facility inside the Radiation Target Room would allow investigators to study the immediate effect of radiation on their samples. In addition, this On-Line Assay System can also be used to provide pre radiation sample processing, such as changing sample medium. The current On-Line Assay System design is shown on the right in the figure below, configured to interface to six sample containers in a carrier, as an example.

The CTC-REF functional prototype will be delivered to NSRL in December 2008 for initial trials and validation. We hope the CTC-REF will become a valuable tool which will improve radiobiology research capabilities at NSRL. This work is funded by NASA Ames Research Center (SBIR contract NNA07BA46C).
Space radiation poses a significant risk to NASA-wide activities (human spaceflight, robotic missions and launch operations). Reducing the risk is a multidiscipline challenge, involving operational forecasters, mission planners/operators, and the space physics research community. Improvements are needed in space weather forecasting capabilities to assess and predict the impact of radiation effects on astronauts and operating systems.

Traditionally, various aspects of radiation impacts across the agency have been localized, with few interactions or complex interfaces between programs, mission directorates, and functional offices. As NASA fulfills the Vision for Space Exploration and visits more extreme environments of scientific interest; high costs, unacceptable health risks, and unexpected interactions and consequences may result from the new mission content. The complex nature of the prediction, protection, interaction, mitigation, and adverse effects of/from radiation require that NASA consider what, if any, Agency-level initiatives are required to ensure that these complex interactions are understood, that requirements are properly formulated and allocated, and that the systems and concepts of operations that are developed are able to fully support NASA missions.

The NASA Office of the Chief Engineer has implemented a one-year study to look at future space weather support architectures. Elements of the study will include:

- Identify NASA Mission Directorates strategic and mission requirements
- Describe current state of space weather/climatology architecture (sensors, models, simulation facilities, and forecasting capability)
- Document current trends in space weather/climatology theory and models
- Prepare NASA operational space weather needs and constraints document

The output of the study will include three alternative architectures:

- "Status quo"
- "Modestly evolutionary"
- "Breakthrough"

Acknowledgements

This study is funded by the NASA Office of the Chief Engineer.
RADIATION EXPOSURE DURING SUBORBITAL SPACE FLIGHT

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We are all constantly exposed to radiation, in a variety of forms and to varying degrees. The crew and passengers of suborbital commercial space flight will experience enhanced exposure to cosmic radiation as they reach altitudes up to 100 km above the Earth. However, because of the short duration of suborbital missions, they will likely get a lower dose than the crew and passengers of long duration commercial air flights. Nonetheless, it will be prudent to require the providers of commercial suborbital missions to provide passengers with a detailed briefing of the effects of radiation and the anticipated exposure the crew and passengers will accumulate from their mission(s). In addition, the providers should have the tools and expertise to predict and subsequently to monitor the exposure.

The radiation model used was the QinetiQ Atmospheric Radiation Model (QARM). It is a comprehensive atmospheric radiation model constructed using Monte Carlo simulations of particle transport through the atmosphere. It uses atmospheric response matrices containing the response of the atmosphere to incident particles on the upper atmosphere. It was run through the internet-accessible interface at:

http://geoshaft.space.qinetiq.com/qarm/index.jsp?URL=start.jsp

This model is optimized for calculation of the radiation environment at aircraft altitudes, and has been validated up to 40 km. An alternative model considered was the CREME96 model, but it provides orbit-average doses, not point doses, and it is optimized for orbital altitudes. Since less than five minutes on each trajectories is above 40 km, it was decided that QARM would provide a good initial representation of the exposure. It is important to note that QARM does not include vehicle shielding in its calculations.

Solar storm exposure can be orders of magnitude greater than experienced during quiet geomagnetic and solar conditions. QARM was used to estimate the impact of a solar storm on suborbital missions at high latitude. To do this, the dose equivalent versus altitude was generated for two representative storms, one from 29 September 1989 and one from 24 October 1989. The September storm represents a severe storm. The October 89 storm was also large, but did not have the impact of the September 89 storm. It is important to note that these cases were used because they were readily available with the internet-accessible interface to QARM. It would be highly advisable to do similar analysis for other storms, particularly the August 1972 storm and the January 2007 storm, which had a very rapid increase in flux from event onset. It would also be important to model the impact with other radiation transport codes and with vehicle shielding.

Table 1-1 in the addendum shows the dose equivalent under no additional shielding for the four trajectories and three launch locations for quiet solar conditions, solar minimum, GCR maximum. Note the range is roughly from 0.3 μSv to about 3 μSv.

Table 1-2 shows the dose equivalent under no additional shielding for the four trajectories at 65 N 150 W for the solar storms and for comparison, quiet solar conditions. Note the 29 September dose equivalent is over 1 mSv, three orders of magnitude more than the microSievert range for GCR exposure. This exposure would drop significantly at lower latitudes. It is also likely that the exposure would drop significantly with even modest vehicle shielding, but that conjecture remains to be demonstrated with a transport code that includes vehicle and even body self shielding.

References

QinetiQ Atmospheric Radiation Model (QARM)  
http://geoshaft.space.qinetiq.com/qarm/index.jsp?URL=start.jsp

Acknowledgements

This study was funded by the Office of Commercial Space Transportation, FAA.
Estimates of Suborbital Exposure

The following methodology was used to quantify the effect of the space weather environment on suborbital flights:

- A model of the radiation environment from the surface to 100 km was used to estimate the radiation exposure at representative latitudes and longitudes
  - Alaska (65N 150W)
  - Intermediate (50N 128W)
  - New Mexico (35N 105W)

- Suborbital flight trajectories were generated to represent nominal profiles (altitude vs. time)
  - Airlaunch, New Mexico Spiral
  - All Rocket, New Mexico Spiral
  - Horizontal TakeOff/Horizontal Landing Combined Jet and Rocket
  - Vertical TakeOff/Vertical Landing New Mexico to the East

- Dose Equivalent was generated for each trajectory at each location under the following conditions
  - Quiet solar conditions at solar minimum (maximum GCR contribution)
  - Two solar storm conditions
    - 29 September 1989
    - 24 October 1989

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<th>Cumulative Dose Equivalent (microSievert)</th>
<th>65N 150W</th>
<th>50N 128W</th>
<th>35N 105W</th>
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<td>All Rocket, NM Spiral</td>
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<td>VTVL Jet and Rocket</td>
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Table 1-1 Cumulative Dose Equivalent for suborbital trajectories for quiet solar conditions, solar minimum, GCR maximum from the QARM model

<table>
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<tr>
<th>Cumulative Dose Equivalent (microSievert)</th>
<th>Quiet GCR</th>
<th>29 Sep 89</th>
<th>24 Oct 89</th>
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<tr>
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Table 1-2 Cumulative Dose Equivalent under no additional shielding for the four trajectories at 65 N 150 W for the solar storms and for comparison, quiet solar conditions.

A few conclusions can be drawn from the QARM calculations. If a suborbital mission were to launch at high latitude during the peak of a solar storm, the exposure could be as much as two to three orders of magnitude greater than the same mission launched during quiet solar conditions at peak GCR. However, the exposure drops exponentially with decreasing latitude, dropping below GCR exposures below 45 degree N latitude. It is significant to note that while solar storms cannot be forecast days or even hours in advance, they can be reliably detected minutes to tens of minutes in advance. Even this short notice should be adequate to cancel or delay suborbital missions, which have durations on the order of 15 to 30 minutes.
**Summary Observations**

Exposure during suborbital missions under quiet solar conditions is not likely to be significant—somewhat less than a cross country commercial air flight. Exposure during a severe solar storm at high latitude would be modest, but it potentially could be large enough to have a detectable impact on long-term cancer rates. Suborbital missions should be avoided during solar storms, particularly if the launch site is at high latitudes.

Since these conclusions are drawn from a single transport code designed for aircraft calculations, more measurements and better models of the radiation environment are needed in the range from 40 to 100 km at all latitudes under varying solar conditions, with independent transport codes that include vehicle shielding.

Effective implementation of a policy of “informed consent” will require the providers have as part of their support staff a team of experts familiar with or active in current research in:

- The space environment (“space weather”)
- Techniques to measure and monitor the radiation environment
- Techniques and models to estimate the doses within the body under realistic shielding
- Biological effects of radiation

In addition, the providers should include instrumentation in the vehicle to directly measure the radiation environment inside the vehicle throughout the mission. Providers should maintain the models and expertise needed to translate the measured environment into estimates of the dose within the bodies of the crew and passengers at a variety of locations, and they should be prepared to continuously compare predicted dose with observed dose.

One final note of a practical nature: radiation exposure is a volatile issue. The perception that ANY exposure to radiation is bad is widespread, in spite of the fact that a low level of exposure is always present. The risks of radiation exposure to astronauts spending weeks to months in orbit and in deep space are well known to the public, and the perception that the risk will be significant to any type of space travel, even suborbital travel, will always exist. Compound that with the fact that some space tourists will inevitably, within a few years of the experience, die of some form of cancer. It therefore seems incumbent on the providers to meet or exceed any regulatory requirement of monitoring imposed by quantifiable risk estimates.