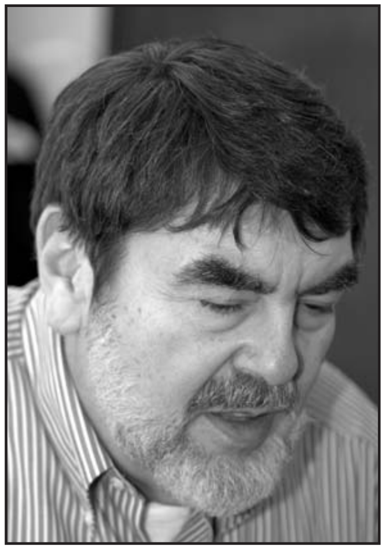
Space Radiation Shielding Modeling Consortium

by Lawrence S. Pinsky

ABSTRACT—Our objective is to provide a Monte Carlo-based software tool to model the radiation environment in space that will enable the evaluation of radiation shielding materials. The tool is to include the basic physics transport code known as FLUKA embedded in a graphical user interface infrastructure that includes the capability to provide the input for simulation and analysis tools needed to evaluate and display the results. The practical goal of this project is to produce a code considerably more accurate and user-friendly than existing Monte-Carlo-based tools for the evaluation of space radiation shielding. We will cooperate with other members of the consortium to develop an event generator for Nucleus-Nucleus interactions that is accurate to within 25 percent in any significant channel over energies relevant for evaluating issues of space radiation.



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WE HAVE CHOSEN TO ADAPT THE EXISTING FLUKA Monte Carlo code to the task of simulating the radiation environment in space. In a prior NASA-funded project (NAG8-1648), we succeeded in embedding two existing event generators within FLUKA to allow the direct simulation of nucleus-nucleus interactions. For energies above a few GeV/nucleon, we chose the DPMJET event generator and for the energy range below that down to ~100MeV/nucleon we incorporated an existing version of the RQMD event generator. This intermediate energy range is the focus of this project. The principal tasks at hand for the current project are the development of a more accurate replacement for the current RQMD version and an extension down to the lowest threshold energies for nucleus-nucleus inelastic interactions. Finally, we hope to be able to contribute to the task of creating a new graphics representation format optimized for transport type problems that can be used by a subsequent conversion tool from existing CAD formats. The acronym FLEUR-S (FLuka Executing Under Root-for Space applications) was adopted for the code during prior development. That acronym will continue to be employed during this project.

Task Significance

The ability to simulate the radiation environment in space and the transport of these particles through spacecraft shielding materials are crucial to concerns such as crew health and electronic equipment performance. The need exists to understand the actual measurement of crew radiation doses recorded on current missions and to explore the predicted doses for future missions and new spacecraft designs. These planning tasks call for significant flexibility to simulate a wide variety of conditions such as those likely to exist within spacecraft in interplanetary space and on the surface of the moon and Mars. In addition, many experiments need to simulate the effects that space radiation will have on their instruments. These effects can either be direct, as part of the actual measurements, in the case of experiments like MARIE or AMS (Alpha Magnetic Spectrometer), or as a background, as in GLAST (Gamma-ray Large Area Space Telescope), HUBBLE, or the JWST. Further, there can be operational concerns such as degradation of instruments from radiation damage or data interference, as in the case of single event upsets.

Finally, the development of flight hardware to serve as active dosimeters onboard the next generation of spacecraft will require Monte Carlo-based codes as part of the design and evaluation process, as well as their use during the subsequent analysis of the mission data. Improvement in the accuracy of the software that NASA currently uses for these tasks will result from this project. This research will substantially increase the reliability of the projected results.

Summary of Task Accomplishments

During the performance of this effort as part of the NASA Space Radiation Modeling Consortium, the University of Houston Group focused its attention upon tasks related to the FLUKA code and its evolution as a useful tool in the simulation of the Space Radiation environment. At present, the FLUKA code that has resulted from this project is the sole integrated Monte Carlo code in the world that has the full capability to simulate the Space Radiation environment over the full range of energies up to those primary particles detected in air showers.

As a result of the efforts of the Houston Group in concert with the FLUKA team at CERN and in the INFN Milan Group, FLUKA now embeds two of the most respected heavy ion event generators in existence, RQMD and DPMJET. Both of these event generators have been checked to validate their ability to replicate the available measurements of heavy ion interactions, including those made by our complementary NASA-sponsored Measurement Consortium. Further, in developments in physics, FLUKA now has the ability to provide detailed predictions of the post irradiation environment attributed to activation of the ambient material. With respect to user interface, considerable effort has been expended in producing a user-friendly GUI interface to prepare FLUKA simulations and to analyze and view the results.

These user interface tools are designed to incorporate standard space radiation fields of interest to NASA, such as the modulated GCR environment, the trapped radiation environment, and models for some of the benchmark prior solar particle events.

Although this project is coming to a close, FLUKA will continue to be supported by the FLUKA Collaboration. Improvements will continue to evolve in physics-simulated tools, as well as in user-interface tools. Because of their prior support of this program, NASA has been assured continued access to these future improvements under the standard CERN/INFN FLUKA License.

This past year has seen several major accomplishments by the UH group in support of the Modeling Consortium, in general, and our FLUKA-based tasks, in particular.

The UH Group has long advocated acquiring data in the energy range above 1 GeV/A for several reasons. Not only is the primary Cosmic Ray flux still significant through these higher energies, but there is currently a wide disagreement between existing nucleus-nucleus interaction models in this regime.

The decision was made to pursue measurements at the AGS during the summer of 2005, before the AGS floor itself was to become unavailable for several years. To that end and because of the lack of time and funding to develop additional detectors, the UH group agreed to employ existing detectors and expertise to enhance the date acquired during those runs. Additional funding was requested to cover expenses, and in concert with the LBL Measurement Consortium Group, an additional stipend had been awarded a graduate student to work on these measurements as his Ph.D. thesis. In addition, the UH group also participated in measurements at the HIMAC facility at NIRS in Chiba, Japan, this past February. Professor Billy Mayes of the Physics Department at UH has joined our effort for these measurements, along with Andrea Mairani, a graduate student.

During the AGS run, data were taken with *C*, *Si* and *Fe* beams of ~3, 5 and 10 GeV/A incident on thin (~ 0.5 interaction length) targets of *C*, *Al*, *Fe* and *Cu*, as well as a number of thick and compound targets including polyethylene. Data taken during the process represent the Ph.D. thesis project for Najib Elkhayari; these data are currently being analyzed. That analysis is separately funded through 2007. The results of that effort will be made available to the FLUKA Collaboration to guide the needed modifications to the event generators.

During the HIMAC run, data were acquired for *Si* at 800 MeV/A, *Fe* at 500 Mev/A and Oxygen at 270 MeV/A. Similar targets to those used at the AGS were used. The data taken will be analyzed by Mr. Mairani and also made available to the FLUKA Collaboration.

Models within Fluka

The past year has also seen significant progress in the primary effort of the UH Group to enhance the models within FLUKA and the user interfaces to the FLUKA code itself. While we are closely tied to the entire FLUKA team at CERN and INFN in Italy, and we have a significant influence on the direction that this broader team chooses to focus upon in its effort, the items reported here are exclusively those which have been directly supported by the funding received through the Modeling Consortium.

Dr. Anton Empl has developed and released via the project website a ROOT-based GUI analysis tool to allow visualization of color-coded fluence plots superimposed on line drawings of the input geometry. Work is in progress to expand that capability to allow the plotting of all standard FLUKA scoring capabilities via an entirely new GUI interface based on the use of the GTK graphics software. Significant progress has also been made on the coding of an XML-based GUI front-end tool, known as FLAIR, to enable the user to start and control FLUKA jobs completely from a GUI environment without the need for command-line interactions. Beta versions of that software are currently under test, and there should be a public release of this software in early 2007.

In July, the long awaited release of the FLUKA source code under a CERN-INFN license agreement occurred. Along with that release, several improvements to the core FLUKA code were made, the most visible of which from the user's standpoint is the elimination of the need to make an "EGS-like" pre-run to set up the so-called "pemf" file necessary for the implementation of electromagnetic interactions. That initialization activity is now seamlessly embedded within the core FLUKA code. NASA users thus have full access to the FLUKA Source code via the FLUKA Website and under the terms of the general public license agreement.

Considerable work implemented and upgraded the treatment of electromagnetic dissociation in Nucleus-Nucleus interactions in FLUKA. In this effort, Dr. Georgi Smirnov made use of large volumes of data now accessible from Russian sources.

This past year has also seen the extension of the capabilities in FLUKA to calculate directly dose rates owing to activation as a function of time after irradiation of material in any representable geometry. This capability has already been employed to predict the Positron Emission Tomography images from proton and heavy ion beam cancer therapy irradiations.

Neal Zapp has continued to develop his Hamiltonian Molecular Dynamics-Based Nucleus-Nucleus Interaction code. He now has a working version that includes only the internal elastic scattering cross sections for the constituents. He is currently in the process of exploring the introduction of the inelastic cross sections for the constituent particles.

Dr. Lawrence Pinsky has been working on the refinement of software tools to compare the direct output of event generator models and to identify flaws in the output of current versions of these codes that are employed within FLUKA. In addition, with the help of Kerry Lee, UH Ph.D. candidate, models of solar modulation of the GCR flux are being explored. Likewise, Dr. Victor Andersen of the UH group has been involved in modeling SPEs for inclusion in the standard FLUKA input package. Lee completed and defended his Ph.D. thesis utilizing FLUKA to simulate the response of the MARIE experiment. His Ph.D. degree was awarded May 14, 2006.

Jeffrey Chancellor began his Ph.D. research by exploring comparisons between predictions of HZETRN and FLUKA for several benchmark incident fluxes. He will continue the development of FLUKA as a tool to model the response of proposed active dosimeters for use in spacecraft and space suits.

Finally, efforts have been under way not only to improve the tools for the input of geometry information into FLUKA, but to develop a broad tool for general use in the conversion of CAD files into Monte Carlo Geometry input files. The Virtual Monte Carlo (VMC) project at CERN is progressing well. A version of FLUKA is currently being tested in that new environment. The

Generic ROOT-based geometry included in this package would be a strong candidate for the common Monte Carlo geometry targeted for such a conversion software code.

Copies of all of the released software are being supplied as deliverables under the Consortium contract and are furnished under the general CERN/INFN License Agreement.

Acronyms associated with this project

AMS – Alpha Magnetic Spectrometer. A cosmic ray spectrometer experiment that has flown previously on the Space Shuttle scheduled to fly for several years on the International Space Station.

ACCESS – A Cosmic-ray Composition Experiment planned for deployment on the International Space Station. This large-aperture experiment is being designed to determine the composition of the cosmic-ray flux at energies on the order of 100 TeV around the so-called "knee" in the energy spectrum.

ALICE – A Large Ion Collider Experiment, one of the major experiments at the new Large Hadron Collider (LHC) facility at CERN. ALICE is primarily concerned with the measurement of relativistic heavy ion collisions and is similar to the STAR detector at RHIC. Because LHC will operate at considerably higher energies than RHIC, these two experiments are complementary.

ALIROOT – (ALICE ROOT) ALIROOT is a software adaptation of the ROOT software infrastructure for the simulation of the ALICE (A Large Ion Collider Experiment) experiment at CERN.

BME – Boltzmann Master Equation. A theory describing the preequilibrium deexcitation of the composite system created by the interaction of two ions at some tens of MeV/nucleon.

CAD – Computer Aided Design. CAD generally refers to the software engineering drawing tools that have largely replaced mechanical drafting. The most sophisticated CAD tools allow the complete specification of geometric shapes and detailed compositions of mechanical and electronic assemblies.

CERN – European Organization for Nuclear Research. Originally "Centre," now "Organization" Europenne pour la Recherche Nucleaire (located in Geneva, Switzerland).

CME – Coronal Mass Ejections. An eruptive phenomenon in the solar corona that results in the ejection of large numbers of particles.

DPMJET – Dual Parton Model JET. A version of the DTUNUC event generator code. (See http://www.physik.unisiegen.de/kolloquium/dpmjet.)

DTUNUC – Dual-Parton-Model Two-component Universal NUCleus-Nucleus event generator. DTUNUC is a Monte Carlo event generator for high-energy hadron-hadron, hadron-nucleus, nucleus-nucleus and photon-nucleus collisions. It is based on the Gribov-Glauber approach and treats both soft and hard scattering processes in a unified way. Professor Johannes Ranft, University of Leipzig (retired), is the principal author of the code.

EVCPDS – External Vehicular Charged Particle Detector System – A charged particle spectrometer instrument similar to the MARIE instrument in design that has been deployed on the ISS to measure the charged particle spectrum between about 10 MeV/n and 450 MeV/n. Three such instruments are deployed externally pointing in different directions

FLEUR-S – FLuka Executing Under Root-Space – The ROOT-based simulation application using FLUKA for simulating the space radiation environment that is the object of this project.

FLUKA – FLUctuating KAskad. A Monte Carlo-based particle transport code initiated in 1964 by Professor Johannes Ranft at the University of Leipzig. The code has been continually improved and upgraded to include the latest physics and is now being maintained by Dr. Alfredo Ferrari and others. Although Dr. Ferrari holds a permanent appointment with INFN in Milan, Italy, he is currently based at CERN.

GCR – Galactic Cosmic Rays, as distinguished from SEPs.

GEANT – GEometry ANd Tracking. A Monte-Carlo based particle transport code that has been maintained at CERN since the early 1970's. The best known previous version (GEANT3.21) was written by Dr. Rene Brun (one of the co-investigators on this project). The most recent version is titled GEANT4 and has incorporated an object-oriented structure.

GeV *(or MeV or TeV)*–Giga (or Mega or Tera) electron Volts – 109 (Giga), 106 (Mega), and 1012 (Tera) electron volts.

GUI – Graphical User Interface. A computer user interface that provides graphic interaction with a mouse and clickable buttons and menus, as opposed to a command line interface that requires the user to enter text commands.

INC – Intra-Nuclear Cascade. This is an approach to modeling nucleus-nucleus collisions wherein individual nucleons are propagated through the collision using Monte Carlos techniques. When individual nucleons are deemed to have interacted using their free cross sections, either unchanged or modified in some way, the resulting final state is drawn from the free particle cross sections. In this model, other particles such as mesons can be included. The influence of the surrounding nuclear field is typically handled using a mean field approximation, which is one of the principal distinguishing characteristics between these models and QMD-based codes.

INFN – Instituto Nazionale de Fisica Nucleare. The Italian National Nuclear Research Funding Agency.

ISSO – Institute for Space Systems Operations. An institute at the University of Houston funded by the State of Texas to facilitate NASA-University programs.

IVCPDS – Internal Vehicular Charged Particle Detector System. A charged particle spectrometer instrument similar to the MARIE instrument in design that has been deployed on the ISS to measure the charged particle spectrum between about 10 MeV/n and 450 MeV/n. This detector is complementary to the externally mounted EVCPDS instruments, but it is located internally within the ISS. Its location and orientation are variable and can be changed by the crew.

JWST – James Webb Space Telescope. The Next Generation Space Telescope (NGST), which will be the follow-on optical on-orbit telescope to Hubble, was recently renamed in honor of former NASA Administrator James Webb.

LBL – Lawrence Berkeley Laboratory. The Lawrence Berkeley National Laboratory in Berkeley, California, managed by the University of California under contract from the U.S. Department of Energy (DoE).

DOCIMETRY—Dr. Lawrence Pinsky, Physics Department chairman, shows a computer rendering captured from a newly designed docimeter which had been exposed to an alpha source. The circles on the display represent alpha particles hitting the detector.

LHC – Large Hadron Collider. The major new hadron collider facility being constructed at CERN. LHC will be used to accelerate both protons and relativistic heavy nuclei through *Pb* (lead) with center of mass energies up to 5.5 TeV/Nucleon. LHC was to have begun operation in 2005.

MARIE – MArs Radiation envIronment Experiment. A charged particle spectrometer flown on the Mars Odyssey 01 mission to assess the radiation environment in the interplanetary medium and in the orbit of Mars.

QMD – Quantum Molecular Dynamics. A microscopic model and the name of an event generator code to describe heavy ion reactions at low and intermediate energies that explicitly treat nuclear resonances. QMD can be used for incident projectile energies below a few GeV/n.

RHIC – Relativistic Heavy Ion Collider. The new facility at the Brookhaven National Laboratory in Upton, Long Island (NY), that began operation in the summer of 2000. RHIC can provide beams of nuclei through *Ag* (gold) at center of mass energies up to 130 GeV/nucleon.

rQMD – Relativistic Quantum Molecular Dynamics. A microscopic model and an event generator code to describe heavy ion reactions at ultrarelativistic energies that explicitly treat high nuclear resonances, string formation, strangeness production and that uses a relativistic covariant formalism for particle propagation. RQMD can be used from below 1 GeV/n up to TeV energies.

ROOT – Although not strictly an acronym, the "OO" in ROOT is motivated by Object-Oriented programming. ROOT is a software package originally developed by René Brun at CERN. It provides an object-oriented graphical user interface (GUI) data analysis infrastructure.

SEP – Solar Energetic Particles. Space Radiation originating from the Sun as opposed to GCRs, which are galactic in origin.

STAR – Solenoid Tracker At RHIC. STAR is one of the major RHIC experiments.

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FOUNTAIN—Between classes, students sit at the NSM fountain, designed to lay a continuous film of water across metal plates.

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