Radiation Transmission Properties of *In-Situ* Materials

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Exposure to Galactic Cosmic Radiation (GCR) and Solar Particle Events (SPE) is an inherent risk to human personnel working in Earth orbit and in deep-space missions. Future NASA manned missions, such as the construction and manning of the Space Station, the mission to Mars, and the return to the moon, will require longer duration stays in space, which in turn increase the risk from exposure to radiation. To accurately predict the radiation risk to humans engaged in long-term, deep space missions, and to develop shielding scenarios which afford the best possible protection while keeping mission costs reasonable, an understanding of how shielding materials affect the primary GCR must be gained. The alteration of the primary GCR by nuclear interactions between GCR and shielding materials is not well understood, due mainly to the lack of relevant experimental data needed for input to and verification of current nuclear fragmentation models. The effect of nuclear fragmentation makes an already complex and varied primary GCR flux even more complex. The possible fragmentation products from the interaction of a single GCR ion range over charges of 1 (protons) up to the charge of the primary, and range over any isotopic mass physically possible within those atomic numbers.

The neutron is an important component of the fragmentation field, and is unique in that it is not found in the primary GCR, but instead is produced only by GCR interactions with shielding components. Neutrons can be produced from <u>all</u> possible GCR – shielding collisions and thus can make up a significant portion of the particle flux behind shielding, especially thick shielding. When the biological weighting factors for neutrons are used to calculate the dose equivalent behind shielding, neutrons become an even more important component of the radiation field. In one series of calculations that looked at dose equivalents behind thick shields on lunar and Martian bases, it was estimated that close to 50% of the dose equivalent behind 50 g/cm^2 of Martian regolith and 75 g/cm^2 of lunar regolith comes from neutrons.[1,2] Other calculations[3] have shown similar results using other shielding materials of similar areal density.

Any calculation of the radiation risk from neutrons produced by GCR interactions in *in-situ* materials has a high degree of uncertainty, due to the lack of data concerning neutron production from such interactions and due to the lack of data in regards to the biological effect of high-energy (>25 MeV) neutrons. From the standpoint of neutron production, the range of GCR ions and energies that must be taken into consideration is enormous. This range includes GCR from protons up to iron and energies from 100 MeV/nucleon up to the highest energies possible (on the order of TeV/nucleon). Neutrons will be produced at all energies from a few keV up to several TeV and will be produced at all angles inside the shielded environment. Because the weighting factors used to determine the dose equivalent are large at all neutron energies, especially low energies, the range of energies that must be taken into account is very large. It becomes readily evident, then, that solely using an empirical approach to the problem of neutron production is impractical, if not impossible, and a calculational approach is required. Current model predictions of thick target neutron yields using cross sections generated by state-of-the-art nuclear physics calculations are unable to fit the limited available data sets, however. Therefore, in order to

adequately predict the risk to humans in space from irradiation by neutrons, development of an accurate neutron production model is required. And in order to develop such a model, a data base must be obtained to verify both the cross sections used in the models and thick target yields calculated by the models.

The research program described here plans to improve an existing model based on a two-stage, quantum-mechanical abrasion-ablation collision formalism to better predict neutron production from GCR interactions, including the heavy-ion component of the GCR. The initial version of this model was found to reproduce the measured 0° energy spectra of secondary neutrons produced in Ne-NaF and other reactions quite well. Finishing the model development and validating it is the goal of this proposed work.

In an abrasion-ablation fragmentation model, the projectile nuclei, moving at relativistic speeds, collide with target nuclei. In the abrasion (knockout) step, those portions of the nuclear volume that overlap are sheared away by the collision. The remaining projectile piece, called a prefragment, continues its trajectory with essentially its precollision velocity. As a result of the dynamics of the abrasion process, the prefragment is highly excited and subsequently decays by the emission of gammas and/or nuclear particles. This step is the ablation stage. The abrasion or knockout process can be analyzed with classical geometric arguments or with quantum scattering theory. The ablation stage can be analyzed using geometric arguments or methods based upon Monte Carlo or intranuclear cascade techniques. These models have been very successful for accurately predicting mass yields in heavy ion collisions. However, until recently, they have met with little success in predicting nucleon production, including momentum distributions.

Funding for this research program has just started and is expected to run through the year 2001. The goals of this program are:

1. Continue development of the abrasion-ablation neutron production model by incorporating the higher order cascade effects of the projectile knockouts into the model.
2. Incorporate production and decay of nucleon isobars into the model.
3. Develop a data base of neutron production from interactions relevant to risk estimation to long-term and deep-space missions.
4. Validate predictions of the abrasion-ablation neutron production model with existing data.

References

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3. F.A. Cucinotta. Calculations of Cosmic-Ray Helium Transport in Shielding Materials, NASA Technical Paper 3354 (1993).