

## **Protection from Space Radiation**

R. K. Tripathi, J. W. Wilson, J. L. Shinn, R. C. Singleterry, M. S. Cloudsley,  
NASA Langley Research Center, Hampton, VA 23681-2199 USA  
F. A. Cucinotta, G.D. Badhwar, NASA Johnson Space Center, Houston, TX  
M. Y. Kim, College of William and Mary, Williamsburg, VA  
F. F. Badavi, Christopher Newport University, Newport News, VA  
J. H. Heinbockel, Old Dominion University, Norfolk, VA  
J. Miller, C. Zeitlin, L. Heilbronn, Lawrence Berkeley National Laboratory,  
Berkeley, CA

### **Introduction**

The exposures anticipated for our astronauts in the anticipated Human Exploration and Development of Space (HEDS) will be significantly higher (both annual and carrier) than any other occupational group. In addition, the exposures in deep space result largely from the Galactic Cosmic Rays (GCR) for which there is as yet little experience. Some evidence exists indicating that conventional linear energy transfer (LET) defined protection quantities (quality factors) may not be appropriate [1,2]. The purpose of this presentation is to evaluate our current understanding of radiation protection with laboratory and flight experimental data and to discuss recent improvements in interaction models and transport methods.

### **Methodology**

Space radiation consists of electrons and ions associated with all the known chemical elements (with the orbital electrons removed) over a broad energy spectrum with significant fluence in the 0.1 to 10 GeV/nucleon region. In passing through shield materials, ions are fragmented into nuclear constituents generating new particles by colliding with nuclei in the shield, and transferring energy to orbital electrons in atomic collisions. The primary means to control the adverse biological effects is not to prevent ions from penetrating the interior environment. Rather it is to control the adverse effects by selecting the types and number of reactions and the resultant product types and numbers by considering the nature of the biological effects generated by specific ion and

reaction product types. This is done by selecting the material constituents within shielding configurations. The types and energy distributions of particles transmitted through a shield material requires the solution of the linear Boltzmann equations for the flux density  $\phi_j(\mathbf{x}, \Omega, E)$  of type  $j$  particles as

$$\Omega \cdot \nabla \phi_j(\mathbf{x}, \Omega, E) = \sum_k \int \sigma_{jk}(\Omega, \Omega', E, E') \phi_k(\mathbf{x}, \Omega', E') d\Omega' dE' - \sigma_j(E) \phi_j(\mathbf{x}, \Omega, E) \quad (1)$$

where  $\sigma_j(E)$ ,  $\sigma_{jk}(\Omega, \Omega', E, E')$  are the media macroscopic cross sections for various atomic and nuclear processes including spontaneous disintegration. In general, there are hundreds of particle fields  $\phi_j(\mathbf{x}, \Omega, E)$  with several thousand cross-coupling terms  $\sigma_{jk}(\Omega, \Omega', E, E')$  through the integral operator in equation (1). The solution to equation (1) can be symbolically written in terms of the Green's function as

$$\Phi(\rho, \mathbf{x}) = G(\rho, \sigma, \mathbf{x}) \Phi_B(\Gamma) \quad (2)$$

where  $\Phi(\rho, \mathbf{x})$  is a vector array representation of the particle fields at location  $\mathbf{x}$  and direction  $\Omega$  within the shield. The shield material is represented by the vector of material compositional densities  $\rho$  and the boundary condition related to the space source of radiation is  $\Phi_B(\Gamma)$  at the boundary  $\Gamma$ . The particle fields at  $\mathbf{x}$  are related to biological injury through a linear integral operator. The principal research is developing interaction models defining the many required cross sections and developing fast computational procedures for solving equation (1).

## Results

Recent blind test of the fragmentation models in Fe ion beam experiments show maturity of the existing models [3] although tests with other ions are still required. Recent evaluation of media modification of microscopic amplitudes hold great promise (see figure 1) for even better model development [4]. Recent code validation for Shuttle tissue equivalent proportional counter (TEPC) experiments are likewise encouraging [6]. Recent developments to solve equation (1) are to add angular dependence to the transport starting with the highly scattered neutron component [5]. An important component of

neutrons is found to be the backscattering from the bulk of the vehicle or from the regolith of the Martian surface as seen in figure 2.

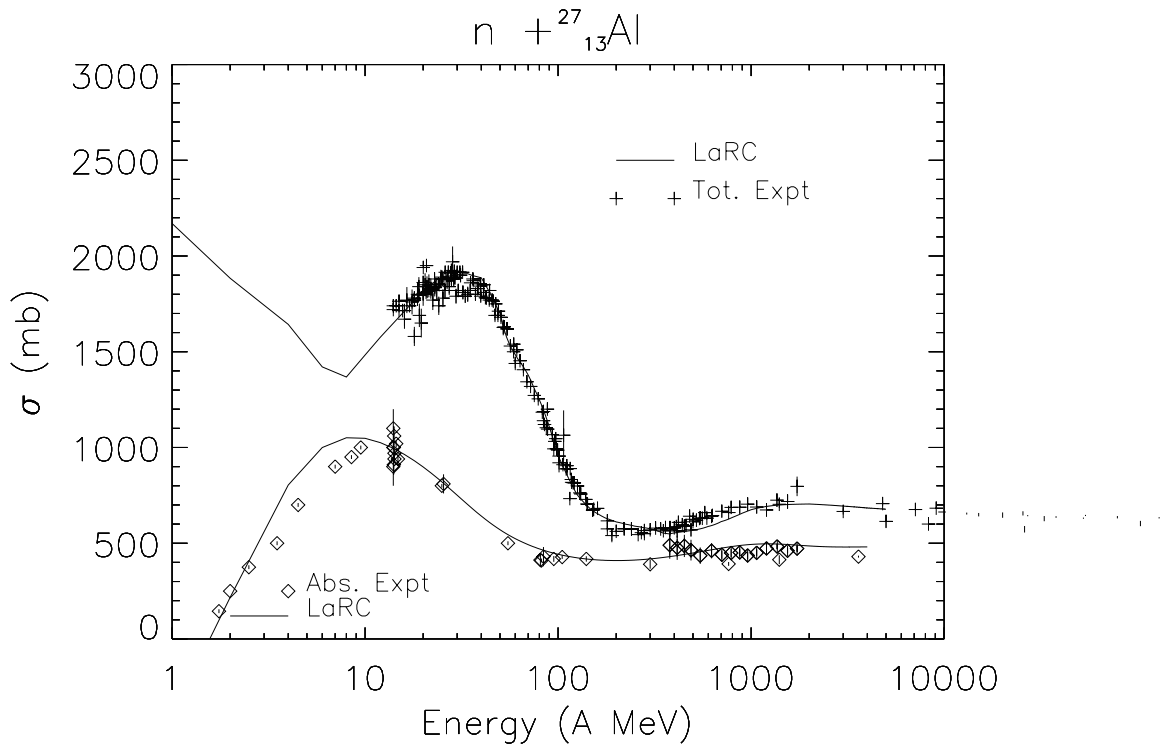


Figure 1. Aluminum Cross sections vs. neutron energy

Figure 2. Galactic cosmic rays on Mars Surface (predicted)

## Conclusions

Great progress has been made in predicting radiation in the local tissue environment within astronaut organs. However, testing of transport solutions and data bases needs to continue to assure accuracy and quantify uncertainties in all material types.

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