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Shielding from Space Radiations

A Progress Report Submitted to  
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## ABSTRACT

This Progress Report covering the period of June 1,1991 to December 1,1991 presents the initial development of an analytical solution to heavy ion transport equation in terms of Green's function formalism. The mathematical development will be recasted into an efficient computer code for space applications. The efficiency of this algorithm will be accomplished by a nonperturbative technique of extending the Green's function over the solution domain. The code will also be applied to accelerator boundary conditions to allow code validation in laboratory experiments.

## INTRODUCTION

Future NASA missions will be limited by exposure to space radiations unless adequate shielding is provided to protect men and equipments from such radiations. Adequate methods required to estimate the damage caused by such radiations behind various shields can be evaluated prior to commitment to such missions.

From the inception of the Langley Research Center heavy ion (HZE) shielding program (refs. 1-3), there has been a continued, close relationship between code development and laboratory experiment (ref. 3). Indeed, the current research goal is to provide computationally efficient high charge and energy ion (HZE) transport codes which can be validated with laboratory experiments and subsequently applied to space engineering design. In practice, two streams of code development have prevailed due to the strong energy dependence of necessary atomic/molecular cross sections and the near singular nature of the laboratory beam boundary conditions (refs. 4-6). The atomic/molecular cross section dependence is adequately dealt with by using the methods of Wilson and Lamkin (ref. 7), allowing efficient numerical procedures to be developed for space radiations (refs. 6,8-10). Although these codes could conceivably be applied to the laboratory validation, methods to control truncation and discretization errors would bear little resemblance to the space radiation codes attempting to be validated. Clearly, a radical reorientation is required to achieve the validation goals of the current NASA space radiation shielding program, and such an approach is the main thrust of this research and is briefly described below.

A useful technique in space radiation shielding is the use of the impulse response Green's function (refs. 11,12), which satisfies the Boltzman equation of the form

$$\left[ \vec{\Omega} \cdot \vec{\nabla} - \frac{\partial}{\partial E} \tilde{S}_j(E) + \sigma_j \right] G_{jm}(E, E_0, \vec{\Omega}, \vec{x}) \\ = \sum_k \int \sigma_{jk}(E, E', \vec{\Omega}, \vec{\Omega}') G_{km}(E', E_0, \vec{\Omega}', \vec{x}) d\vec{\Omega}' dE' \quad (1)$$

where  $G_{jm}$  reduces to a monoenergetic unidirectional function at the boundary,  $\tilde{S}_j(E)$  is the stopping power,  $\sigma_j$  is the total cross section, and  $\sigma_{jk}$  is the inclusive differential cross section. An arbitrary solution to the Boltzman equation within a closed convex region can be written as

$$\phi_j(E, \vec{\Omega}, \vec{x}) = \sum_m \int G_{jm}(E, E', \vec{\Omega} - \vec{\Omega}', \vec{x} - \vec{\Gamma}) \\ \times f_m(E', \vec{\Omega}', \vec{\Gamma}) d\vec{\Omega}' dE' d\vec{\Gamma} \quad (2)$$

where  $f_m(E', \vec{\Omega}', \vec{\Gamma})$  is the incident flux at the boundary (ref. 11). Since transport problem is formulated in terms of a single Green's function algorithm, the validation of the Green's function in the laboratory meets the objective of having a space validated code. Since there is hope of a Green's function based on an analytical solution of the Boltzmann equation (ref. 13), the resulting evaluation of the shield properties should be computationally efficient.

The first step in this process is to develop an equivalent Green's function algorithm in one dimension to match the current capability in space radiation transport calculation (refs. 6,14). The algorithm is based on the closed form solution to the one dimensional equation

$$\left( \frac{\partial}{\partial x} - \frac{\partial}{\partial E} \bar{S}_j(E) + \sigma_j \right) G_{jm}(E, E_0, x) \\ = \sum_k \int \sigma_{jk}(E, E') G_{km}(E', E_0, x) dE' \quad (3)$$

for a monoenergetic beam at the boundary. The probability of validation for <sup>20</sup>Ne beams of this algorithm (with multiple scattering corrections) has already shown good correlation (refs. 5,15), but improvements in the nuclear data base are required for achieving higher correlations with experiment. If considerations are restricted to multiple charged ions then the right hand side of equation (3) can be further reduced to

$$\left[ \frac{\partial}{\partial x} - \frac{\partial}{\partial E} \bar{S}_j(E) + \sigma_j \right] G_{jm}(E, E_0, x) \\ = \sum_k \sigma_{jk} G_{km}(E, E_0, x) \quad (4)$$

## ACCOMPLISHED TASKS

An algorithm based on the Green's function method described above is developed and will be coded during the next phase of this project. The current version of the formalism may be computationally inefficient for high order terms.

Furthermore work on two statistical (Monte Carlo) transport codes were initiated in the following manner:

1. Using a low to medium energy Monte Carlo transport code named TIGER, one and three dimensional energy deposition for electrons and photons in various target materials with and without an Aluminum shielding are calculated. The results are used to evaluate the depth dose relations in geometries of interest to radiation shielding.
2. The capabilities of a high energy Monte Carlo transport code named EGS4 is explored. EGS4 is a transport code for electrons, positrons, and photons, and has the flexibility of user interfacing through MORTRAN3 language. With this capability decay of zero pions can be simulated.

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