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Poster Presentation Abstract

STUDIES OF HZE PARTICLE INTERACTIONS AND TRANSPORT FOR SPACE RADIATION PROTECTION PURPOSES

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As the era of Space Station, lunar bases, and manned Mars missions approaches, cumulative radiation exposures of career astronauts to biologically significant levels of the high-energy heavy ion (HZE) component of solar and galactic cosmic rays will occur for the first time in the history of manned spaceflight. Since these HZE particles include nearly all nuclear species, and possess a very broad range of incident energies, considerable attention must be devoted to developing accurate methods of describing their physical interactions and transport through bulk matter in order to properly assess spacecraft shielding effectiveness, and to evaluate the self-shielding factors of the astronauts' bodies themselves. As these extremely energetic cosmic rays traverse bulk matter, their radiation fields change composition through interactions with any target materials encountered. Aside from continuously losing energy through collisions with atomic orbital electrons, the incident ions collide with target nuclei within the shield and experience nuclear attenuation (absorption) and breakup (fragmentation) reactions. The struck target nuclei also recoil leaving highly ionized tracks in their wakes. These interactions remove particles from the incident field while concomitantly producing secondary and subsequent generation reaction products. The altered composition of the transported field then results in an internal radiation field within some critical organ of the astronaut's body which differs appreciably from that incident upon the external spacecraft structure. Proper evaluation of the biological damage to this critical organ requires an adequate knowledge of the physical characterizations (energies and composition) of the complex radiation fields incident upon that organ. Studies of the physical transport and interactions of these space radiation fields are presently hampered by a paucity of experimental HZE interaction and transport data. Consequently, an experimental apparatus has been built to study the composition and spectra of heavy ion beams of different types as they pass through various materials of variable thickness. Sufficient measurements will be made to fully specify biologically interesting dosimetric quantities as a function of shield type and depth for each beam type. Because of the large numbers of projectile/target combinations and their nuclear fragmentation products, it is unreasonable to expect that experimental measurements alone will ever provide the necessary interaction and transport data. Therefore, experimentally-validated calculational methods are needed to accurately describe them. To this end a NASA-supported collaborative research effort involving theoreticians at Langley Research Center (LaRC) and experimentalists at Lawrence Berkeley Laboratory (LBL) has been established to develop the necessary radiation physics methodologies for properly evaluating future HZE particle shielding and dosimetry requirements for manned spaceflight. In this presentation current and planned research efforts for the LaRC-LBL collaboration will be described.

The main emphasis in the theoretical research program at Langley is to develop general methods for accurately predicting HZE particle interactions and transport for use by researchers at Langley, Johnson Space Center, and elsewhere, in mission planning studies, in evaluating astronaut self-shielding factors, and in spacecraft shield design and optimization studies. To accomplish these goals, research efforts are focussed upon two interrelated tasks: (1) to develop computationally fast and accurate solutions to the Boltzmann (transport) equation, and (2) to develop accurate HZE interaction models, from fundamental physical considerations, for use as inputs into these transport codes. We have formulated accurate solutions to the HZE transport problem through a combination of analytical and numerical techniques. Representative results for the absorbed dose due to a 670 MeV/amu neon beam incident upon a thick water target are displayed in figure 1 and compared to experimental data from the LBL experimental effort. In figure 2 we display calculated LET (Linear Energy Transfer) spectra in aluminum for a typical LEO (Low Earth Orbit) mission using the GCR transport code. Validation of these solution methods has been established to within one percent by direct comparison to a realistic, nontrivial, analytic benchmark solution to the Boltzmann equation. Therefore, the main sources of uncertainty in HZE transport are the input interaction parameters, and the physical assumptions used to simplify the Boltzmann equation from its original six-dimensional integro-differential form. Testing of these simplifying assumptions is a major goal of the thick target transport experiments at Lawrence Berkeley Laboratory.

In addition to the development of HZE transport codes, extensive efforts are underway at Langley to develop accurate theoretical models for the input interaction parameters: stopping powers, nuclear absorption cross sections, and fragmentation parameters. Methods for estimating stopping powers are reasonably well-developed; therefore, the main focus is upon modelling the nuclear absorption cross sections and fragmentation parameters. Because the transmitted flux in a thick target transport calculation possesses an exponential functional dependence upon the absorption cross sections, accuracy is crucial since even small cross section inaccuracies can result in large calculated flux errors. We have formulated, from first principles, a fully energy-dependent quantum-mechanical theory for nuclear absorption cross sections which is applicable to any projectile nucleus-target nucleus combination at any energy above 25 MeV/amu. Typical accuracies, when compared with available experimental data, are within three percent for energies greater than 80 MeV/amu and within ten percent for energies as low as 25 MeV/amu. For illustration purposes, sample calculations will be presented and compared with available experimental data.

Unlike absorptive processes, the physics underlying nuclear fragmentation is not well understood and the scope of the experimental data base is inadequate. The lack of a suitably-accurate nuclear fragmentation theory is a major hindrance to present HZE transport modelling. Although some progress has been made in developing fundamental fragmentation models, current efforts are hampered by the paucity of relevant experimental data. Hence, existing quantum-mechanical models are typically cumbersome to use and limited in scope. To correct this situation, theoretical models at both the fundamental and semiempirical levels are being developed at LaRC for further experimental validation at LBL. Aside from expanding the data base of experimental fragmentation measurements, the recently initiated LBL experiments will emphasize measurements of elemental and isotopic production cross sections for iron beams onto various targets over a broad range of incident ion energies. Iron was chosen because it is a major cosmic ray ion of radiobiological interest. This experimental approach will also systematically evaluate the fragmentation cross section energy dependence, if any, for a given projectile-target combination over a range of incident energies. Knowledge of any possible energy dependence is critical because major reductions in computational times for HZE transport calculations are attainable if the fragmentation cross sections are essentially independent of the incident projectile's energy. We have recently developed a semiempirical fragmentation model for use in HZE transport calculations. Unlike alternative formulations from astrophysical studies which have numerous arbitrarily-adjusted parameters, the LaRC semiempirical model has only a single adjustable parameter. This fragmentation model, which is independent of the incident ion's energy, predicts fragment elemental cross sections which agree with the limited experimental data base to the extent that these data agree among themselves. Representative comparisons between theoretical predictions and experimental data will be presented.

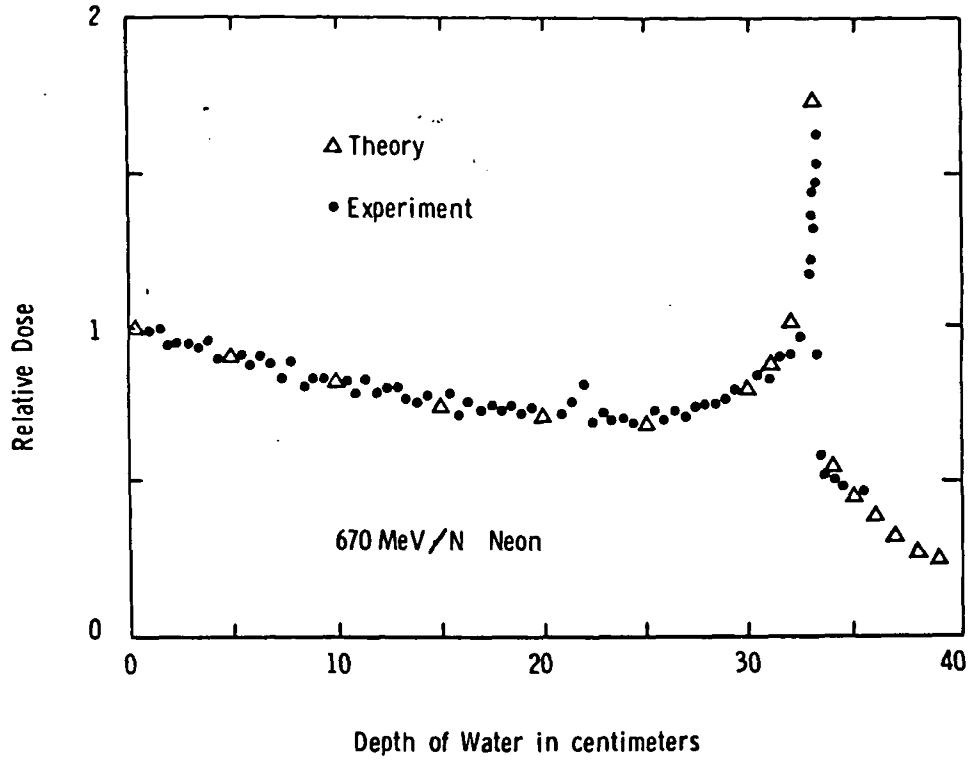

Figure 1. - Dosė versus depth in a thick water target for 670 MeV/amu neon beams.

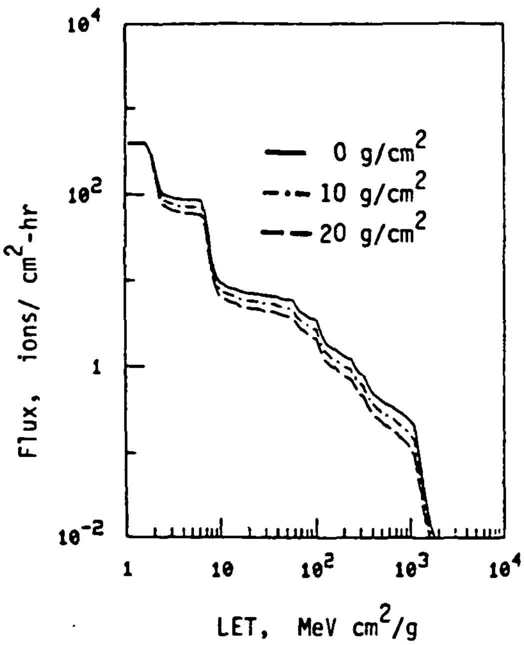

Figure 2.- GCR integral LET spectra in aluminum for a 30° orbit at 400 km altitude