# GCR MODEL PROPAGATED UNCERTAINTIES

T.C. Slaba[1], S.R. Blattnig[1], R.B. Norman[1], and X. Xu[2]
[1]NASA Langley Research Center, Hampton, VA, USA, [2]Science Systems and Applications, Inc., Hampton, VA, USA.

Models of the ambient galactic cosmic ray (GCR) environment in deep space are a critical component of vehicle design and astronaut risk assessment. The uncertainty of GCR models commonly used in such analysis has been stated to be within 15% [1]. However, if two models are evaluated over a common epoch and transported through to effective dose, relative differences can easily exceed 50% [2, 3]. This type of inconsistency indicates the need for a more rigorous validation approach with uncertainty metrics that are better tied to exposure quantities of interest for space radiation shielding applications. In this work, the 2010 and 2011 versions of the Badhwar-O'Neill GCR model [4,5] as well as the recently developed model of Matthia et al. [6] are examined. First, the extent to which each GCR ion and energy, before impinging on any shielding material, contributes to effective dose behind shielding is quantified. This is often referred to as a sensitivity analysis and quantifies the relative importance of each GCR ion and energy to exposures quantities of interest for human space missions. Second, it is shown that the results of this sensitivity analysis can be used to efficiently propagate GCR model uncertainties into effective dose behind shielding, thereby allowing error bars to be placed around a point estimate of effective dose. Third, a rigorous validation metric is developed to determine GCR model uncertainty distributions, and the uncertainties are propagated into effective dose values behind shielding.  It is found that GCR ions with Z = 5 – 28 and energies below 500 MeV/n induce less than 5% of the effective dose behind shielding. Given that most of the GCR models are heavily calibrated and validated against measurements taken below 500 MeV/n by the Advanced Composition Explorer/Cosmic Ray Isotope Spectrometer (ACE/CRIS) instrument, it is plausible for two GCR models to accurately reproduce the ACE/CRIS data, and have similar overall uncertainty statements, while inducing very different effective dose values behind shielding. By segregating the validation results into charge and energy groups, it is shown that the BON2011 model more accurately reproduces the ACE/CRIS data than the BON2010 model; however, the updated BON2011 models systematically over-estimate heavy ion fluxes in the energy range 0.5 - 4 GeV/n that contributes significantly to effective dose behind shielding. The BON2010 and BON2011 also show moderate and large errors in reproducing past solar activity near the 2000 solar maximum and 2010 solar minimum. Using the fast uncertainty propagation methods, it is found that all three models induce relative errors in effective dose in the interval [-20%, 20%] at a 68% confidence level. The BON2010 and Matthia models are found to have similar overall uncertainty estimates and are preferred for space radiation shielding applications at this time. Future GCR model development could reduce this uncertainty by recalibrating free parameters away from ACE/CRIS data and toward energies that contribute more heavily to effective dose. Results from the sensitivity analysis provide quantitative evidence for prioritization of future GCR measurements, nuclear cross section experiments, and radiobiology experiments.

[1] NCRP Report 153, Bethesda, MD (2006).
[2] Mrigakshi, A.I. et al. (2013) Adv Space Res 51, 825-834.
[3] Slaba, T.C. et al. (2013) Space Weather, to be submitted.
[4] O'Neill, P.M., (2010) IEEE Trans Nuc Sci 57, 3148 – 3153.
[5] Cucinotta, F.A. et al. (2013) NASA TP 2013-217375.
[6] Matthia, D. et al. Adv Space Res 51, 329-338.