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Validation of the new trapped environment AE9/AP9/SPM at low Earth orbit

Francis F. Badavi *

Old Dominion University, 5115 Hampton Boulevard, Norfolk, VA 23529, USA

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Abstract

The completion of the international space station (ISS) in 2011 has provided the space research community an ideal proving ground for future long duration human activities in space. Ionizing radiation measurements in ISS form the ideal tool for the validation of radiation environmental models, nuclear transport codes and nuclear reaction cross sections. Indeed, prior measurements on the space transportation system (STS; shuttle) provided vital information impacting both the environmental models and the nuclear transport code developments by indicating the need for an improved dynamic model of the low Earth orbit (LEO) trapped environment. Additional studies using thermo-luminescent detector (TLD), tissue equivalent proportional counter (TEPC) area monitors, and computer aided design (CAD) model of earlier ISS configurations, confirmed STS observations that, as input, computational dosimetry requires an environmental model with dynamic and directional (anisotropic) behavior, as well as an accurate six degree of freedom (DOF) definition of the vehicle attitude and orientation along the orbit of ISS.

At LEO, a vehicle encounters exposure from trapped particles and attenuated galactic cosmic rays (GCR). Within the trapped field, a challenge arises from properly estimating the amount of exposure acquired. There exist a number of models to define the intensities of the trapped particles during the solar quiet and active times. At active times, solar energetic particles (SEP) generated by solar flare or coronal mass ejection (CME) also contribute to the exposure at high northern and southern latitudes. Among the more established trapped models are the historic and popular AE8/AP8, dating back to the 1980s, the historic and less popular CRRES electron/proton, dating back to 1990s and the recently released AE9/AP9/SPM. The AE9/AP9/SPM model is a major improvement over the older AE8/AP8 and CRRES models. This model is derived from numerous measurements acquired over four solar cycles dating back to the 1970s, roughly representing 40 years of data collection. In contrast, the older AE8/AP8 and CRRES models were limited to only a few months of measurements taken during the prior solar minima and maxima.

The dual goal of this paper is to first validate the AE8/AP8 and AE9/AP9/SPM trapped models against ISS dosemetric measurements for a silicon based detector, to assess the improvements in the AE9/AP9/SPM model as compared to AE8/AP8 model. The validation is done at selected target points within ISS-6A configuration during its passage through the south Atlantic anomaly (SAA). For such validation, only the isotropic spectrum of either model is needed.

As a second goal, the isotropic spectra of both trapped models are re-casted into anisotropic spectra by modulating them with a measurement derived angular formalism which is applicable to trapped protons. Since at LEO electrons have minimal exposure contribution, the paper ignores the AE8 and AE9 component of the models and presents the angular validation of AP8 and AP9 against measurements from the compact environment anomaly sensor (CEASE) science instrument package, flown onboard the tri-service experiment-5 (TSX-5) satellite during the period of June 2000–July 2006. The spin stabilized satellite was flown in a 410×1710 km, 69° inclination orbit, allowing it to be exposed to a broad range of LEO regime. Particular emphasize is put on the validation of proton flux profiles at differential 40 MeV and integral >40 MeV, in the vicinity of SAA where protons exhibit east–west (EW) anisotropy and have a relatively narrow pitch angle distribution. Within SAA, the EW anisotropy results in different level of exposure to each side of CEASE instrument package, allowing the extraction of anisotropic proton spectra from the measurements. While the magnitude of the EW effect

* Address: NASA Langley Research Center, MS 188E, Hampton, VA 23681, USA. Tel.: +1 (757) 864 1410; fax: +1 (757) 864 8094.
E-mail address: francis.f.badavi@nasa.gov.

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at LEO depends on a multitude of factors such as trapped proton energy, orientation of the spacecraft along the velocity vector and altitude of the spacecraft, for this part, the paper draws quantitative conclusions on the combined effect of proton pitch angle and EW anomaly.

Keywords: Radiation belts; Anisotropy; Space station; Low Earth orbit

1. Introduction

Space mission planners continue to experience challenges associated with human space flight. Concerned with the omni-presence of harmful ionizing radiation in space, at the mission design stage, planners for a low Earth orbit (LEO) mission must evaluate the amount of radiation the crew of a spacecraft is subjected to. The Earth's geomagnetic field which depending on latitude extends out some 40,000–60,000 km, contains the Van Allen trapped electrons, protons, and low energy plasmas such as the nuclei of hydrogen, helium, oxygen and to a lesser degree other atoms. In addition, there exist the geomagnetically attenuated energetic galactic cosmic rays (GCR). These particles are potentially harmful to an improperly shielded spacecraft crew and onboard subsystems. At LEO, a challenge arises from properly calculating the amount of exposure acquired, as within this field, in the absence of solar energetic particles (SEP) such as flare or coronal mass ejection (CME), a vehicle has to transit through a weak trapped inner electron belt, a proton belt and an attenuated GCR field.

At LEO, the commitment of astronauts to the long term exposure of the space environment in the international space station (ISS) requires resolution of health issues directly related to the effects of ionizing radiation on the crew. For the high inclination of ISS (51.6°), prior computational dosimetry using thermo-luminescent detector (TLD), tissue equivalent proportional counter (TEPC) area monitors, and computer aided design (CAD) model of earlier ISS configurations, has indicated that about half of the ionizing radiation exposure near solar minimum results from GCR at about 233 μSv/day, and the bulk of the remainder from trapped particles at about 166 μSv/day (Wu et al., 1996). For lightly shielded regions within ISS, the trapped particle exposure increases relative to GCR as the altitude of the completed ISS is increased to reduce the residual atmospheric drag within the thermosphere layer of upper atmosphere. Excluding the effects of the intervening materials, there is also contribution from the neutron albedo of about 25–54 μSv/day, subjected to the variation of solar cycle (Wilson et al., 1989).

Within the structure of ISS, the ionizing radiation environment is a complex mixture of surviving primary and secondary radiations. Various arrangements of detectors have been used to study the composition of the internal radiation field within ISS which needs to be understood to allow a more comprehensive modeling of the effects of the local radiation environment on the crews' critical tissues. Therefore, an accurate ISS computational dosimetry requires an environmental model with dynamic and directional (anisotropic) behavior, as well as an accurate six degree of freedom (DOF) definition of the vehicle attitude and orientation along the orbit of ISS.

A prior report by the author Badavi et al. (2011) used a relatively complete dynamic model based on scaling relations of the LEO environment as related to the solar activity cycle, to compute the isotropic flux of particles for trapped particles, GCR and albedo neutrons within ISS. In addition, a measurement derived angular formalism was presented which allowed the anisotropic component of the trapped protons and electrons to be studied.

The dual goal behind this work is to first evaluate and more importantly validate the existing isotropic trapped models. Such validation provides analytical tools to study the ionizing radiation exposure aspects of the ISS crew health and safety, to determine ionizing radiation dose rates with a view toward implementation as an analysis tool, and to facilitate the evaluation of potential shield augmentation for the habitation modules within ISS. A computer aided design (CAD) model of ISS-6A configuration, specifically dedicated to exposure analysis was developed as part of this study. The validation is done at selected target points within ISS-6A configuration during its passage through the south Atlantic anomaly (SAA). For such validation, only the isotropic spectrum of a trapped model is needed.

As a second goal, the isotropic spectra of the existing trapped models are re-casted into anisotropic spectra by modulating them with a measurement derived angular formalism which is applicable to trapped protons. Since at LEO electrons have minimal exposure contribution, the paper ignores electron models. For the anisotropic validation, the paper presents the validation of available trapped proton models against measurement from the compact environment anomaly sensor (CEASE) science instrument package, flown onboard the tri-service experiment-5 (TSX-5) satellite during the period of June 2000–July 2006. The spin stabilized satellite was flown in a 410×1710 km, 69° inclination orbit, allowing it to be exposed to a broad range of the LEO regime. Particular emphasize is put on the validation of proton flux profile at differential 40 MeV and integral >40 MeV, in the vicinity of SAA where protons exhibit east–west (EW) anisotropy