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Developing a Safe Test System for High-energy Electron Flux Environments Testing

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Spacecraft in low earth orbit (LEO) through geostationary Earth orbit (GEO) undergo significant electron flux from trapped particles in earth's magnetosphere due to solar wind [1]. Solar wind is the continuous flow of high energy electrons, protons and free ions ejected from the sun through coronal holes. Electron radiation can damage sensitive electronics, alter optical properties, deteriorate components, and reduce the overall lifetime of satellites and spacecraft [2].

Mimicking the Electron Energy Spectra of LEO/GEO

A 100 mCi Sr-90 beta radiation source approximately mimics the high energy electron spectra of GEO. The source was installed into the SST chamber to irradiate various materials, in-the-loop hardware, and components in order to forecast radiation damage, predict lifetimes of electronics, and authenticate the ability of the test chamber to mimic space environment.

Radiation in Space

Overview

In order to predict and mitigate adverse environmental effects prone to spacecraft in orbit about Earth, a versatile pre-launch test capability for assessment and verification of small satellites, systems, and components was developed by Utah State University’s Materials Physics Group. To further diversify this project, a 100 mCi Sr-90 beta radiation source (0.5 MeV – 2.5 MeV) was exploited to simulate high energy electron flux characteristic of geostationary orbit. Various samples including in-the-loop hardware, spacecraft materials, optical components, and solar arrays are irradiated to gain a better understanding of how these materials and electronics break down in space environments. For employee protection, various high and low Z shielding materials were implemented to minimize x-ray dose rates near the test chamber. In order to forecast employee dose while working around the source, x-ray attenuation through the various shielding materials was calculated. Upon discovering a deficiency in shielding capability, additional lead shielding was implemented to lower dose rates outside of the test chamber to nearly background. Predictions of attenuated dose rates strongly correlate with actual measurements post installation of the source.

Simulation Capabilities

The Space Survivability Test (SST) chamber is a versatile accelerated ground-based test facility designed to simulate environmental-induction modified conditions of GEO. Simulation capabilities include neutral gas atmosphere and vacuum environments (< 10^-9 Torr), temperature (~ 60 K – 450 K), ionizing radiation, electron fluxes (~ 10^6 – 2.5 MeV), and photon fluxes ranging from far-ultraviolet to near-infrared (FUV/VIS/NIR).

Scattering Length and X-ray Attenuation of Shielding Materials

Attenuation depends on the thickness and density of a material.

\[ I(x) = I_0 e^{-\mu x} \]

\[ L = \frac{\mu}{\rho} \]

With these predicted scattering lengths, the attenuation factor \( \xi \) was calculated through each shielding material. The attenuation factor simply represents the percent of radiation that gets through the material.

\[ \xi = e^{-x / L} \]

Error Analysis

The standard deviation for the predicted attenuated dose rate was calculated by adding error in quadrature as

\[ \sigma_D = \sigma_{\mu} (\partial I_0 / \partial \mu) + \sigma_{\rho} (\partial I_0 / \partial \rho) + \sigma_{x} (\partial I_0 / \partial x) + \sigma_{L} (\partial I_0 / \partial L) \]

The \( x^2 \) value for the predicted attenuated dose rates against the actual measured values was calculated as

\[ x^2 = \sum \left( \frac{MD - CD}{\sigma_D} \right)^2 \]

Where \( M \) is the measured dose rate, \( \sigma_D \) is the error in \( MD \), and \( CD \) is the calculated dose rates. This calculation provides

\[ x^2 = 10.03 \]

Conclusion

A safe test system for simulating high energy electron flux was developed. In order to ensure legal and safe employee dose, predictions of dose rate through the Sr-90 source shielding were calculated. The \( x^2 \) value is about the number of data points (Figure 9), which provides a good argument that the calculated dose are well correlated with the actual measured values. Predicted values were thus calculated correctly and reflect the actual dose rate. Dose rates escaping the tests chamber through the shielding are low enough to allow employees to safely work around the source for extended periods of time. Incorporation of the Sr-90 source has diversified the Space Survivability Test chamber by allowing simulation of high energy electron radiation akin to geostationary orbit.