Application Note

Heavy Ion Orbital Environment Single-Event Effects Estimations

ABSTRACT

This document discusses the methodology used to calculate on-orbit Single Event Effects (SEE) event rates.

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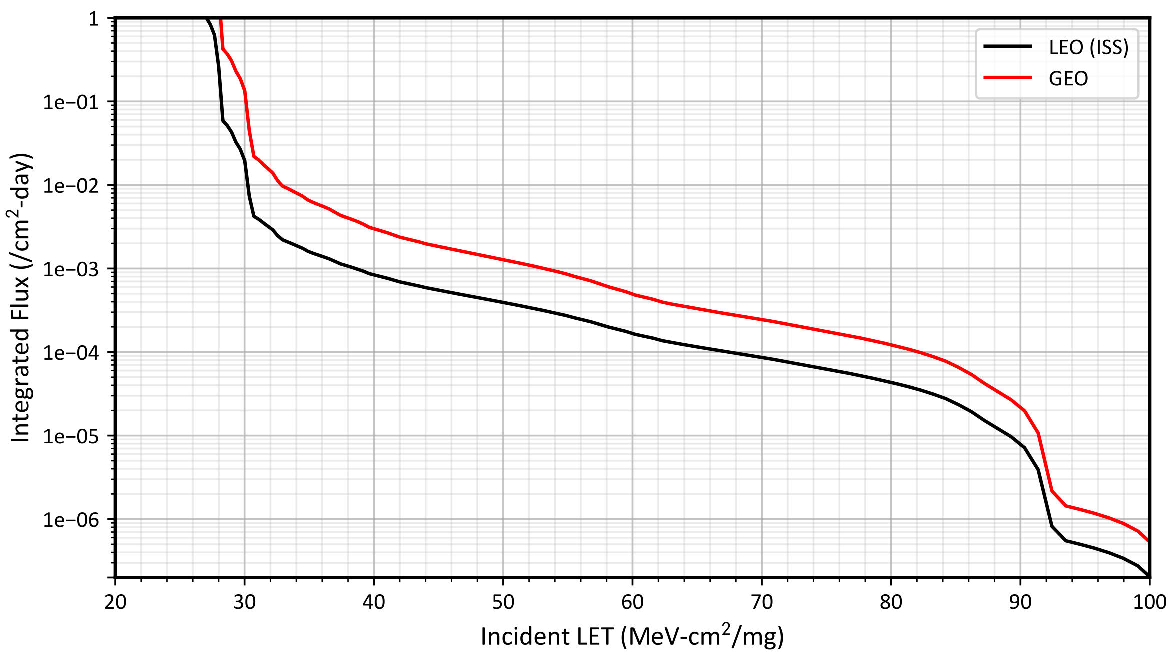
1 Introduction

To calculate SEE on-orbit event rates, both the device SEE cross-section and the flux of particles encountered in a particular orbit are required. Device SEE cross-sections are usually determined experimentally while flux of the particles in orbit is calculated using various software algorithms based on empirical data. For the purpose of generating representative event rates, an example of a Low-Earth Orbit (LEO) and an example of a Geostationary-Earth Orbit (GEO) were calculated using Cosmic Ray Effects on Micro-Electronics 96 (CREME96). Note that these orbit rates are created to be used as a figure of merit to compare event rate calculations across a multitude of electronic devices and can not be directly applicable to the omni-directional flux seen at the International Space Station (ISS). CREME96 code is a suite of programs that enable estimation of the radiation environment in near-Earth orbits[1, 2]. CREME96 is one of several tools available in the aerospace industry to provide accurate space environment calculations. Over the years since its introduction, the CREME models have been compared with on-orbit data and demonstrated accuracy. In particular, CREME96 incorporates realistic “worst-case” solar particle event models where fluxes can increase by several orders-of-magnitude over short periods of time.

For the purposes of generating conservative event rates, the worst-week model (based on the biggest solar event lasting a week in the last 45 years) was selected. This event has been equated to a 99%-confidence level worst-case event[3, 4]. The integrated flux includes protons to heavy ions from solar and galactic sources. A minimal shielding configuration is assumed at 100 mils (2.54mm) of aluminum. Two orbital environments were estimated: that of the International Space Station (ISS), which is in LEO, and the GEO environment. Figure 1-1 shows the integrated flux (from high incident LET to low) for these two environments. Note that the y-axis represents flux integrated from higher LET to lower LET. The value of integral flux at any specific LET value is actually the integral of all ion events at that specific LET value to all higher LETs. These orbit rates are best representative for LETs greater than 30 MeV as event rate calculations below 30 MeV can be overestimated.



Note that the y-axis represents flux integrated from higher LET to lower LET. The value of integral flux at any specific LET value is actually the integral of all ion events at that specific LET value to all higher LETs. These orbit rates are best representative for LETs greater than 30 MeV as event rate calculations below 30 MeV can be overestimated.

Figure 1-1. Integral Particle Flux v. Incident LET for a LEO-ISS (Black Curve) and a GEO (Red Curve) Environment as Calculated by CREME96 Assuming Worst-week and 100 mils (2.54mm) of Aluminum Shielding

Figure 1-1 shows the Integral Particle Flux versus incident LET for an LEO-ISS (black curve) and a GEO (red curve) environment as calculated by CREME96 assuming worst-week and 100 mils (2.54mm) of aluminum shielding. Note that the y-axis represents flux integrated from higher LET to lower LET. The value of integral flux at any specific LET value is actually the integral of all ion events at that specific LET value to all higher LETs.

Using this data, you can extract integral particle fluxes for any arbitrary LET of interest. To simplify the calculation of event rates, assume that all cross-section curves are square, meaning that below the onset LET, the cross-section is identically zero while above the onset LET, the cross-section is uniformly equal to the saturation cross-section. Figure 1-2 illustrates the approximation with the green curve being the actual Weibull fit to the data with the “square” approximation shown as the red-dashed line. This allows you to calculate event rates with a single multiplication, the event rate becoming simply the product of the integral flux at the onset LET, and the saturation cross-section. Obviously, this leads to an over-estimation of the event rate since the area under the square approximation is larger than the actual cross-section curve, but for the purposes of calculating upper-bound event rate estimates, this modification avoids the need to do the integral over the flux and cross-section curves.

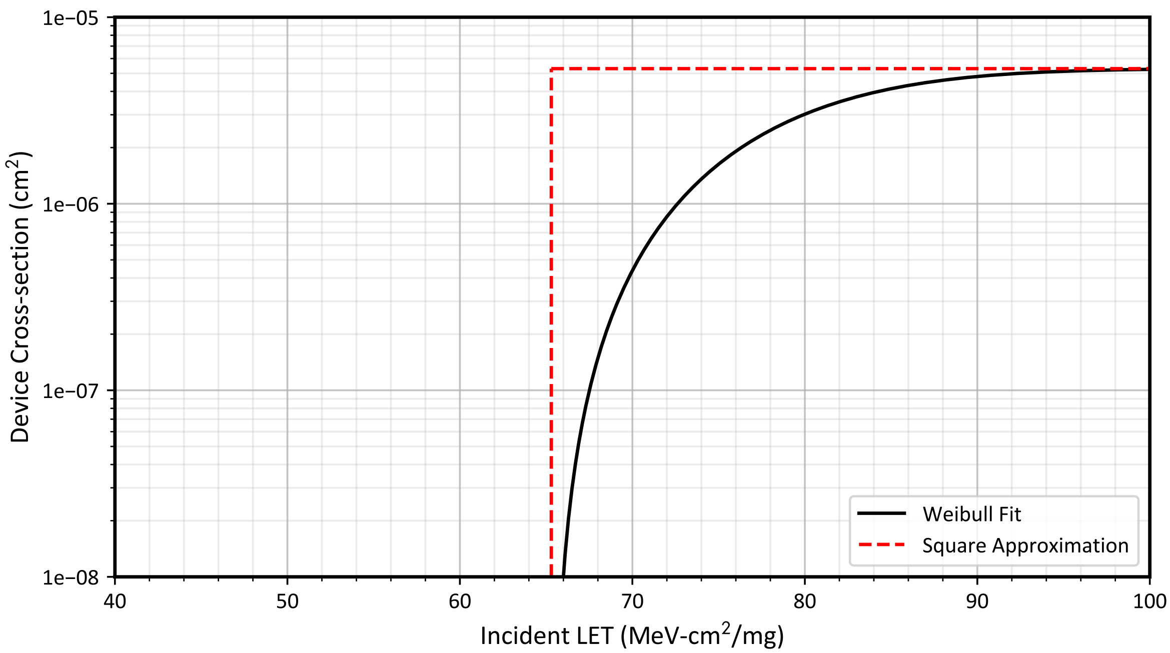


Figure 1-2. Device Cross Section v. Incident LET Showing How the Weibull Fit (Black) is “Simplified” With the Use a Square Approximation (Red Dashed Line)

Figure 1-2 shows a device cross section versus incident LET, showing how the Weibull fit (black) is “simplified” with the use a square approximation (red dashed line).

To demonstrate how the event rates are calculated, assume that you wish to calculate an event rate for a GEO orbit for the device whose cross-section is shown in Figure 1-2. Using the red curve in Figure 1-1 and the onset incident LET value obtained from Figure 1-2 (approximately 65 MeV-cm^2/mg), you find the GEO integral flux to be approximately 3.24×10^{-4} ions/cm^2-day. The event rate is the product of the integral flux and the saturation cross-section in Figure 1-2 (approximately 5.3×10^{-6} cm^2):

$$GEO\ Event\ Rate = \left(3.24 \times 10^{-4} \frac{ions}{cm^2 \times day}\right) \times (5.3 \times 10^{-6}\ cm^2) = 1.71 \times 10^{-9}\ \frac{events}{day} \tag{1}$$

$$GEO\ Event\ Rate = 0.71 \times 10^{-10} \frac{events}{hr} = 0.071\ FIT \tag{2}$$

$$MTBF = 1{,}607{,}820\ Years \tag{3}$$

2 References

1. Vanderbilt University, Crème-MC, webpage.
2. A. J. Tylka, and others, "CREME96: A Revision of the Cosmic Ray Effects on Micro-Electronics Code", IEEE Trans. Nucl. Sci., 44(6), 1997, pp. 2150-2160.
3. A. J. Tylka, W. F. Dietrich, and P. R. Boberg, “Probability distributions of high-energy solar-heavy-ion fluxes from IMP-8: 1973-1996”, IEEE Trans. on Nucl. Sci., 44(6), Dec. 1997, pp. 2140 – 2149.
4. A. J. Tylka, J. H. Adams, P. R. Boberg, and others, “CREME96: A Revision of the Cosmic Ray Effects on Micro-Electronics Code”, Trans. on Nucl. Sci, 44(6), Dec. 1997, pp. 2150 – 2160.

3 Revision History

Changes from Revision A (November 2022) to Revision B (June 2025)	Page
• Updated text and plots to reflect all calculations are determined with respect to incident LET	2
• Updated website reference	4

Changes from Revision * (May 2020) to Revision A (November 2022)	Page
• Updated the numbering format for tables, figures and cross-references throughout the document	1