An Examination of Environment Perturbation Effects on Single Event Upset Rates

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ABSTRACT

This paper presents an analysis of the sensitivity of single event upset (SEU) rate predictions to changes in the direct ionization-inducing environment. An examination based on the nature of the SEU rate equation is presented for the case in which the perturbation is constant across varying particle linear energy transfer (LET). It is shown that the relative variation in SEU rate is equal to the relative perturbation in flux. Results are also presented for the case in which the environment perturbations exist in small LET bins. Through this analysis it is shown that the relative variation in expected SEU rate is equal to that in flux *only* for the LET regime in which the product of the cross section and differential flux is maximum.

NOMENCLATURE

σ = error cross section (cm^2), or ratio of the cumulative number of errors to the total ion fluence

F = differential flux of ions (ions/cm2.time.steradian.MeV) with atomic number Z, mass number A, energy E

f = integral flux of ions (ions/cm2.time.steradian) with atomic number Z, mass number A, energy E

L = linear energy transfer (LET) = dE/dx

θ = azimuthal angle

ϕ = polar angle

METHODOLOGY

Single event effect rate prediction is typically based on the following equation[1]. The assumptions involved in Equation 1 will not be discussed here, but are described in the reference.

$$\text{Rate} = \int\int\int \sigma(L,\theta,\phi)\, F(L,\theta,\phi)\, dL \sin\theta \, d\theta \, d\phi \qquad (1)$$

The integral environment spectra, f(L), is implemented and is given in Equation 2.

$$f(L) = -\int_{L_{th}}^{\infty} F(L)\, dL \qquad (2)$$

The limits of integration of LET are from the threshold for the effect, L_{th}, to infinity, or the largest LET under consideration. The expression for SEU rate is then simplified into one integral over solid angle and one over the environment integral flux, as given in Equation 3.

$$R = \int\int \sigma \, df \, d\Omega \qquad (3)$$

Suppose we introduce a perturbation into the integral flux, δf. The perturbed integral flux then becomes $(f + \delta f)$, and the resulting variation in SEU rate, δR, is given in Equation 4.

$$\frac{\delta R}{R} = \frac{\iint \sigma \, d(f+\delta f) \, d\Omega - \iint \sigma \, df \, d\Omega}{\iint \sigma \, df \, d\Omega} \qquad (4)$$

The first integral in Equation 4, which is a linear combination of the SEU rate induced by one set of particles and that induced by a second set of particles, may be separated. We may also introduce the variable ε, the relative perturbation in integral flux, as shown in Equation 5.

$$\varepsilon = \delta f/f \qquad (5)$$

The relative variation in SEU rate may then be simplified to yield the ratio of the SEU rate induced by the particle flux δf to that induced by the particle flux f.

$$\frac{\delta R}{R} = \frac{\iint \sigma \, d\varepsilon f \, d\Omega}{\iint \sigma \, df \, d\Omega} \qquad (6)$$

For the case in which the variation in the environment flux is constant across the range of LET, Equation 6 is reduced to Equation 7.

$$\frac{\delta R}{R} = \varepsilon \qquad (7)$$

Hence, the total percent change in SEU rate is equal to the total percent change in integral flux, for the case in which the variation in integral flux is constant over all LET. For the case in which ε is not constant across the range of LET, consider an integral environment flux approximated by the monotonically decreasing function given in Equation 8.

$$f = 4.1E{+}02 \, (L^{-4.6}) \qquad (9)$$

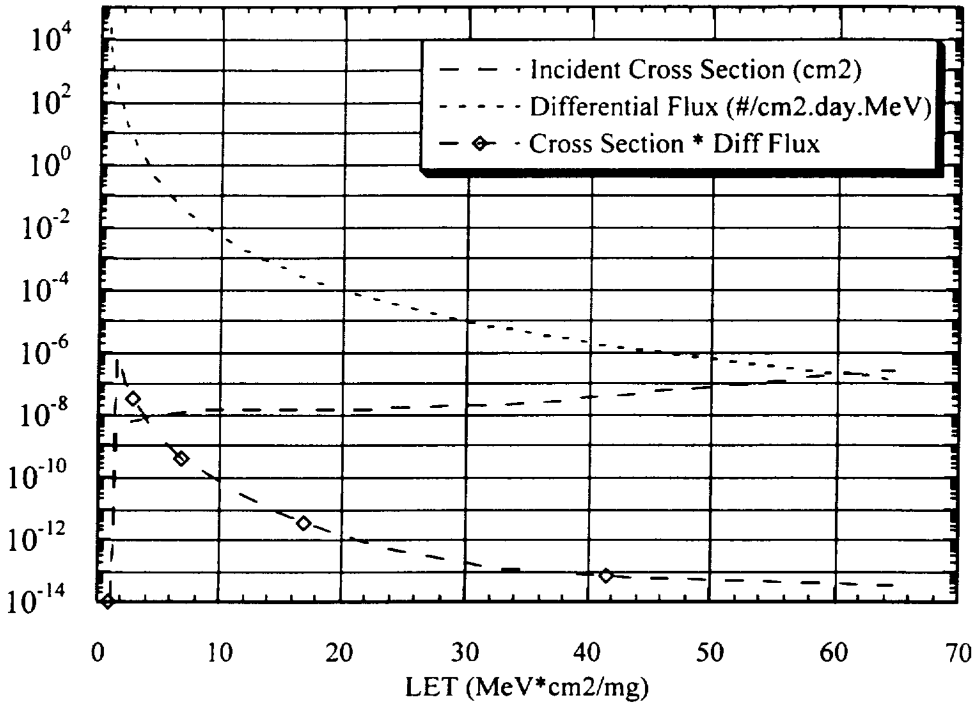

Figure 1 An Environment Differential Flux, Device Cross Section, and Their Product

From Equation 1 it is expected that the highest contribution to SEU rate will occur in the regions of LET in which the product of the cross section and the differential flux are largest. The differential flux is obtained by differentiating Equation 9, and is shown in Figure 1 as the compact dashed line. For purposes of example,cross section data for a Toshiba 16 Mbit DRAM were utilized, and are shown in Figure 1. The product of the differential flux and cross section are also given in Figure 1. Note that the three functions have in common LET dependency, shown as the x-axis, and that distinct units for each are given in the legend. Note that the product term is maximum in the LET regime near threshold. The SEU rate corresponding to this case study was calculated to be 5.18 SEUs per device per day, by integrating the environment with the cross section curve over the LET range above threshold.

A factor of ten perturbation in the differential flux was introduced in three LET regimes: 1.5 to 3.5 MeV*cm2/mg, 4.5 to 11 MeV*cm2/mg., and 21 to 65 MeV*cm2/mg. Figure 2 presents these perturbations, as well as resulting variations in the product terms, which scale by a factor of ten in the same LET regions.

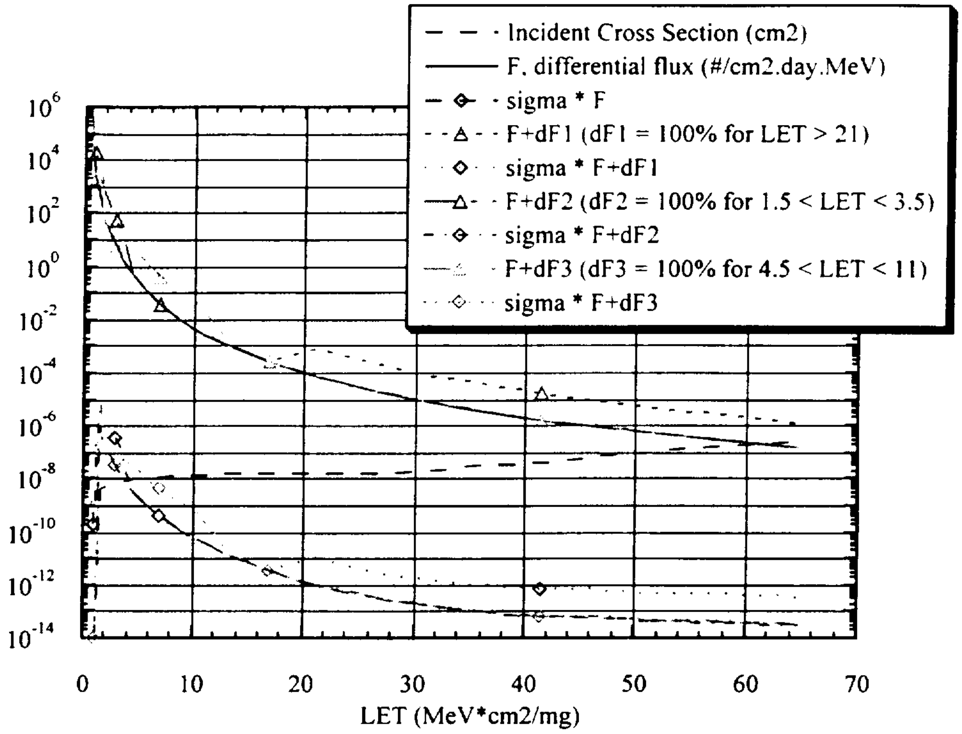

Figure 2 Factor of Ten Perturbation in Three Differential Flux Environments

SEU rate predictions were performed for each of the three scenarios using Equation 3, for which the interior integral is graphically presented in Figure 3. The variation of cross section with solid angle was assumed constant in the calculations. Note that the baseline case result, earlier stated to be 5.18 SEUs per device per day, is shown in Figure 3. For the case in which the baseline flux was perturbed by a factor of ten increase for LET between 21 and 65 MeV*cm2/mg, there was no change in the reported SEU rate. For the case in which the perturbation was introduced for LET between 4.5 and 11 MeV*cm2/mg, the percent change in SEU rate was 3%. However, for the case in which the perturbation occurred in the LET regime between 1.5 and 3.5 MeV*cm2/mg, the SEU rate increased by a full factor of ten. Notice that this is the case in which the product of differential flux and cross section is maximum.

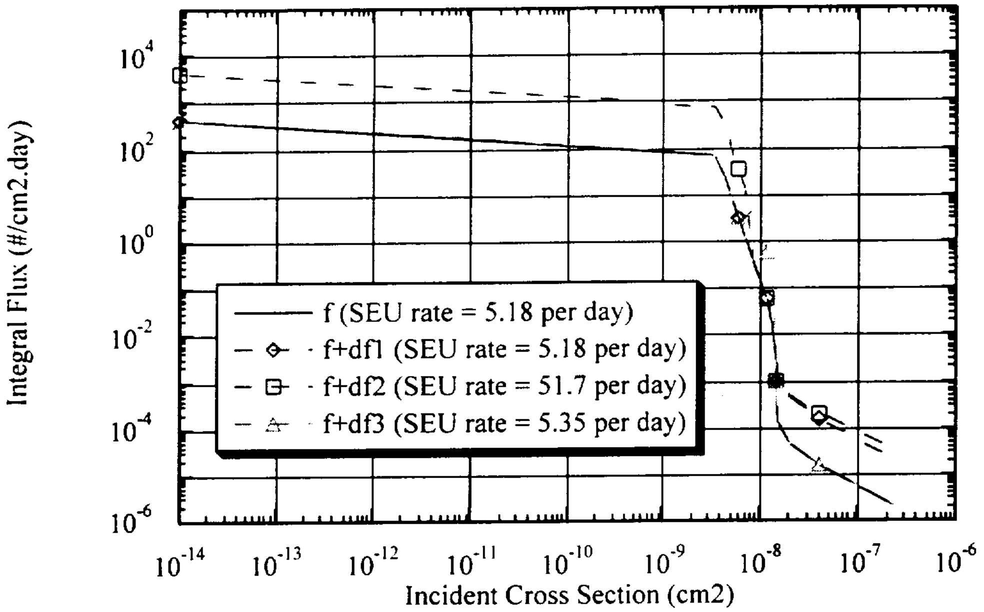

Figure 3 Factor of Ten Perturbation in Three Differential Flux Environments

CONCLUSIONS

These results demonstrate that the SEU rate is dominated by the values of cross section and flux in the LET region where the product of the two is largest. Variations in the differential flux in all other regions of LET produced negligible change in the total SEU rate. Thus, Equation 7 holds for cases in which the variation in LET is constant over all LET, *and* over the regions of LET in which the product of the device cross section and the differential flux are maximum.

It has been shown here that for this typical LET spectral shape and cross section variation, the SEU rate is dominated by the LET regime of 1.5 - 3.5 MeV*cm2/mg, which is near the threshold for this device. These results strengthen the support the recommendations for test procedure attention to providing comprehensive testing near device threshold.

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