

## A Monte Carlo Model for LET Spectra of 200 MeV Protons Used for Microelectronic Testing<sup>[1]</sup>

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### Introduction

The direct ionization Linear Energy Transfer (LET) for 200 MeV protons in silicon is much smaller than that for higher charged particles since LET increases as the square of the ion charge. However, occasionally the proton interacts with the silicon nuclei and produces a shower of fragments and a recoiling nucleus. When this happens, the LET produced is much greater than the direct ionization LET.

Testing the single event effect susceptibility of components using energetic (200 MeV) protons is often the only viable option for system level testing commercial - off - the - shelf (COTS) avionics that have not been designed for space environments. However, the question of how a system tested with protons will perform in a heavy ion environment arises. Here the concern is not only with prediction of on-orbit upset rate, but also about possibility of on-orbit failures that were not observed during proton testing.

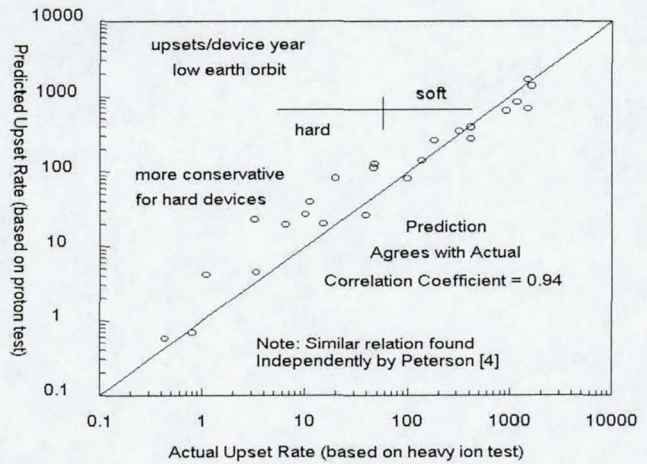
### Nuclear Interaction Model

The production of ions in bulk silicon by the interaction of high-energy protons with the silicon nucleus is a two stage process. In the cascade stage, the proton collides with the individual nuclei of the silicon, knocking out nuclei, imparting energy to the remaining recoil nucleus, and exciting the nucleus. Our CLUST code [2] is a Monte Carlo simulation of the cascade stage. In the evaporation stage, the excited nucleus boils off particles in random directions until it is in the ground state. Our EVAP code was programmed based on the algorithm provided by Tang [3].

The CLUST-EVAP Code tracks all fragment particles and recoil nuclei emitted from the cascade and evaporation stages to determine those that pass through a fixed point that emulates the sensitive volume of a silicon device. At this point, the range and LET of each particle are calculated. Of the spallation products, the heavier recoil particles (nitrogen to silicon) produce LET of 1.5 - 14 MeV cm<sup>2</sup>/mg and many of these have a range in silicon on the order of 10 μ.

### LET Spectrum - Proton and Earth Orbit Heavy Ion

The CLUST-EVAP model LET spectra for a proton test exposure of 10<sup>10</sup> protons / cm<sup>2</sup> is equivalent to 6 years on-orbit in the natural space environment of heavy ions for a low earth orbit (LEO) - 55 degree / 500 km / Quiet / Solar Minimum / 0.1"Aluminum. The graph shows the results of testing a variety of devices with both heavy ions and protons. The "actual" on-orbit heavy ion upset rate is based on measured heavy ion cross section versus LET and the "predicted" rate is simply the number of failures (for a proton test of 10<sup>10</sup> protons / cm<sup>2</sup>) divided by 6 years.



### Risk of Not Detecting Failures

If no failures (such as latch-up) are observed for protons, what is the chance that the part will perform satisfactorily in a LEO heavy ion environment? The CLUST-EVAP model provides the probability of catching failures for devices of various LET thresholds and heavy ion cross sections. In all cases, any failure with a LEO Mean Time Between Failure (MTBF) of 10 years or less is expected to be observed during a typical proton test (10<sup>10</sup> protons / cm<sup>2</sup>).

Older devices such as the NEC-4464 and the HM65162 SRAM's which have latch-up thresholds of 3-9 MeV cm<sup>2</sup>/mg and LEO on-orbit MTBF's of 10 - 20 years are caught with protons - but with only 1 or 2 latch-ups per 10<sup>10</sup> protons / cm<sup>2</sup>. This is less than expected according to the CLUST-EVAP model. However, the model does not account for the requirement that a particle range of 35-40 microns is necessary to induce latch-up for these older technologies.

Newer devices such as the K-5 SRAM and the LSI-64811 processor with latch-up thresholds of 1 - 10 MeV cm<sup>2</sup>/mg and LEO on-orbit MTBF's of 200 and 100 years respectively are easily caught with 200 MeV protons. More than 10 latch-ups are observed for these devices in a typical proton test (10<sup>10</sup> protons / cm<sup>2</sup>). These newer devices have charge collection depths of 10 μ or less.

### REFERENCES

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- [2] K Kwiatkowski, et al., "Energy Deposition in Intermediate-Energy Nucleon-Nucleus Collisions," Phys. Rev. Letters, 50, No. 21, 1648, May 23, 1983.
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- [4] E. L. Petersen, "The SEU Figure of Merit and Proton Upset Rate Calculations," IEEE Trans. Nuc. Sci., 45, No. 6, December 1998.