Abstract—We present the results of Single Effects Testing (SEE) testing with high energy protons and with low and high energy heavy ions for electrical components considered for Low Earth Orbit (LEO) and for deep space applications.

INTRODUCTION

The human space exploration program at NASA is focused on destinations in cis-lunar space and eventually to Mars with the Orion Multi-purpose Crew Vehicle being the primary spacecraft for this effort. Additionally, smaller-scale projects such as small satellites, robotic rovers, and various science payloads will be expected to be launched in these environments. As all of these missions will be exposed to Galactic Cosmic Radiation (GCR) and possibly Solar Particle Events (SPE). For these missions, program performance and reliability requirements state the need for heavy ion certification. To date, this has been done primarily through traditional (low energy) heavy ion testing as well as using the Variations in Depth Bragg Peak (VDBP) method for part characterization and for destructive testing screening. Often, a proton screening test is used prior to heavy ion testing.

PROTON TESTING

NASA JSC uses 200 MeV protons to test for destructive and nondestructive errors for hardware intended for LEO, i.e., for the International Space Station (ISS) [6][7]. This test exposes most known failure modes that have a Mean Time Before Failure (MTBF) < 10 years in the LEO environment. Proton testing replicates approximately 6-10 years of the heavy ion linear energy transfer (LET) environment up to an LET of approximately 10-14 MeV·cm²/mg in silicon. A typical test exposes the device under test to a fluence of 2×10⁹ protons/cm² which accomplishes two goals. The first is to find simple short effects caused by high energy ions up to LET of 90 cm²/mg. Secondly, the test produces a total ionizing dose (TID) of at least 600 rad (S), which corresponds to about 10 years of the total ionizing dose expected on LEO. This NASA method does not fully characterize the part, but it intends to screen for hard errors and provide very conservative estimates up to a 10 year mission [6][8]. This test is typically performed at the board or chip level which provides a means to reduce the cost of testing, especially with modern Commercial-Off-The-Shelf (COTS) units.

TRADITIONAL HEAVY ION TESTING

NASA uses traditional methods to perform heavy ion testing and requires each part to be characterized to high LET (depending on mission) for failure. Traditional methods require parts to be tested for single piece part testing and characterization because the beam energies are too low to penetrate through the packaging. Often time consuming, each specific application has specific requirements with respect to the conditions that are used to test. Transient radiation induced responses to these tests are used for the electronics. A signature of the SEE signatures at the system level are required to determine the system effects and what mitigations are necessary.

HIGH ENERGY HEAVY ION TESTING

Increasingly, the human rated missions are incorporating complex parts that are too difficult (or costly) to de-lid or have sensitive volume depths unreachable by low energy heavy ion beams. This problem has been encountered on the new purpose Crewed Vehicle Program [9]. Additionally, designs include more Commercial-Off-The-Shelf (COTS) units that are not available in the rad-hard versions available. In these cases, the traditional test facilities at TAMU and LBNL cannot provide beams with enough energy to penetrate these devices. Furthermore, NASA JSC is a trend toward screening flight boards to certain LET levels for destructive effects while also using the high energy beams to screen flight boards for evaluation of system level soft errors. The traditional part characterization we employ the Variations in Depth Bragg Peak (VDBP) method [3][10]. A modified VDBP method which uses variable LET steps to ensure all locations in the board are exposed to a certain LET level desired by the spacecraft manufacturer. The VDBP testing reported in this report was accredited for the ion beam tests listed in Table 1 and the testing was performed at the NASA Space Radiation Laboratory (NSRL).

For VDBP destructive screening, a series of degrader steps are used to slide the Bragg curves through the whole device. Where the Bragg curves intersect will define a minimum LET exposure at all locations in that device and this value is a function of the degrader step size. The VDBP figure below shows the 160 μm of degrader, with 0.3 mm of degrader will expose the whole part to an LET of 69 MeV·cm²/mg or higher.

(References Available in Paper)