Single Event Effects Testing For Low Earth Orbit Missions with Neutrons

Brandon Reddell, Pat O'Neill, Chuck Bailey, and Kyson Nguyen – NASA Johnson Space Center, Houston, Texas, 77058

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Brandon Reddell
Radiation Environments and Effects
Avionic Systems Division
NASA Johnson Space Center
Houston, Texas 77058
(281) 483-5050
brandon.d.reddell@nasa.gov

35 word Abstract

Neutrons can effectively be used to screen electronic parts intended to be used in Low Earth Orbit. This paper compares neutron with proton environments in spacecraft and discusses recent comparison testing.

For the last 20 years, NASA has used 200 MeV proton beams to test and screen thousands of electronic parts quite successfully for the Space Shuttle and International Space Station programs [1, 2]. All of this testing has been completed at the Indiana University Cyclotron Facility (IUCF), which has recently closed permanently. This closure is a huge impact to NASA and industry and other facilities will need to be identified as replacements. This paper investigates the feasibility of using neutrons to test for single event effects, excluding those parts susceptible to proton direct ionization, for the Low Earth Orbit (LEO) environment. Neutrons are attractive for the following reasons:

1) neutron and proton inelastic cross sections are practically identical above 50 MeV
2) neutron environments inside thick shielded spacecraft are significant
3) previous comparisons of neutron vs. proton testing has been successful
4) the Los Alamos LANSCE facility is currently available to the community and provides neutrons that cover the LEO space environment
5) because neutrons do not have ionization losses, lower fluxes of poly-energetic beams can allow for stacking of parts/boards to test multiple items simultaneously

Environment and Motivation

The ISS is at a 51.6 degree inclination, 200 nautical mile orbit. This trajectory allows it to pass through the South Atlantic Anomaly (SAA) several times per day, with each pass approximately 10 minutes in duration. The SAA is a segment of the proton Van Allen belt that dips to low altitude over the South Atlantic/South America region as a result an offset of the Earth's dipole moment of the magnetic field. Additionally, because of the 51.6 degree inclination, the ISS passes through very high magnetic latitudes, thereby passing through regions of pace near the open magnetic field lines and receiving close-to the free space Galactic Cosmic Rays (GCR) fluxes. These two radiation sources produce the spacecraft internal neutron environments.

The Badhwar-O'Neill GCR model along with the NASA HZETRN transport code were used to determine the neutron fluxes inside the ISS [3-5]. This data was validated with FLUKA Monte-Carlo transport code [6-8]. Figure 1 shows that the neutron environment inside the ISS is several orders of magnitude higher than protons generated by SAA protons and GCR's. Furthermore, the secondary neutrons created by the GCR's are the dominate source of the total neutron spectrum. Given the similarity of the neutron interaction cross section to the proton interaction cross section, the neutron environment may be the critical environment for electronic parts with low Linear Energy Transfer (LET) thresholds.

Modeling and Testing

The Los Alamos Neutron Science Center (LANSCE) provides the best neutron spectrum for creating neutron environments for atmospheric and LEO studies [9]. FLUKA was used to investigate the secondary LET environment produced by a typical LANSCE neutron spectrum as well as the 200 MeV mono-energetic proton beam, typically provided by IUCF.

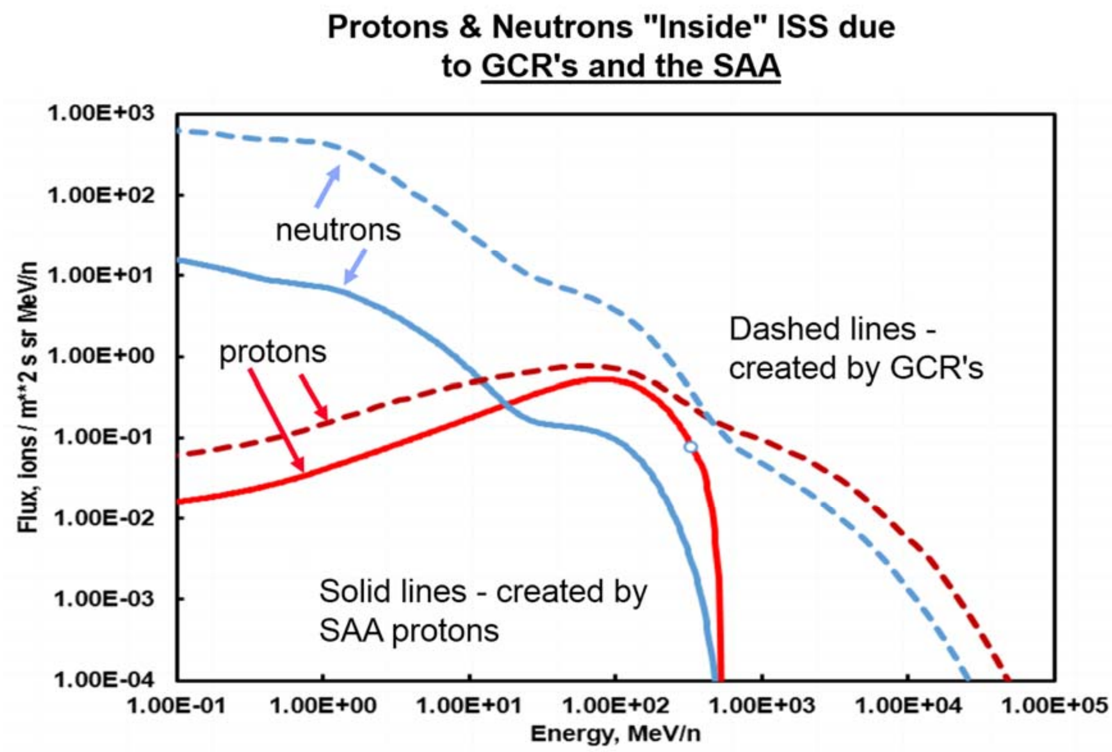

Figure 1: Comparison of protons and neutrons inside the ISS produced by the interaction of Van Allen belt protons and Galactic Cosmic Rays interactions with shielding.

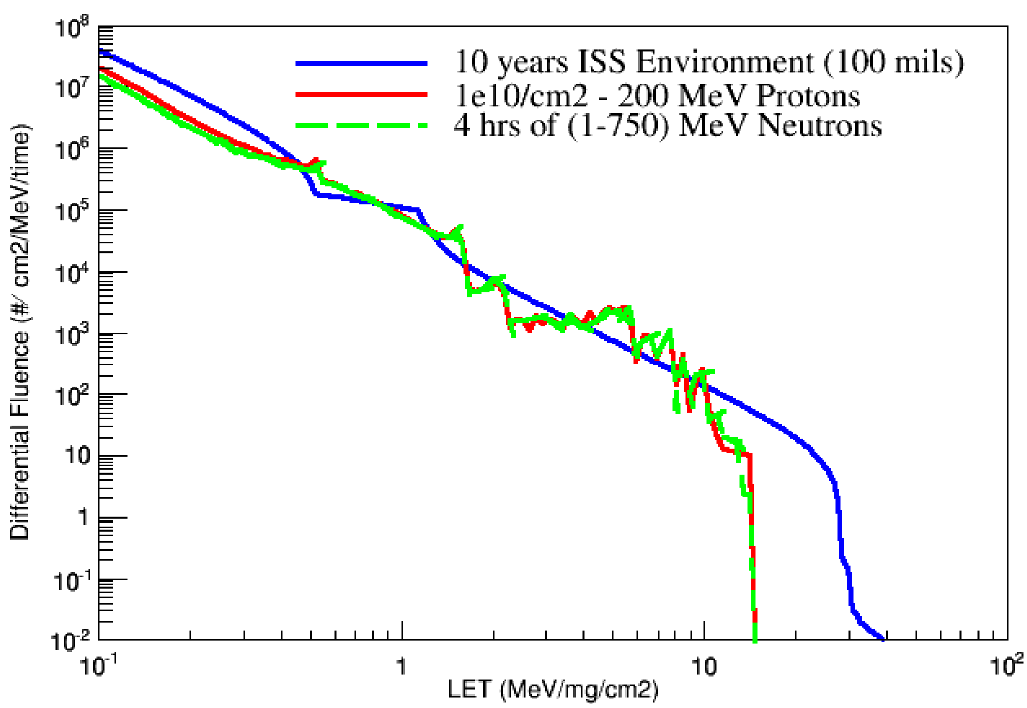

Figure 2: Comparison of 10 years of ISS Environment data with a typical 1e10/cm2 proton test with 200 MeV protons and with 4 hours of poly-energetic (1-750 MeV) neutron beam.

The simulation validates the 1998 O'Neill result [10-11] that protons can reasonably reproduce the LEO secondary LET spectrum. Additionally, as expected based on the similarity of the interaction cross sections, the neutron spectrum also reproduces the secondary LET spectrum in a similar fashion. Additionally, it should be noted that protons and neutron interactions with silicon cannot produce secondary heavy ions with LET's greater that approximately 14-15 MeV/mg/cm2. There is some residual risk in LEO for not evaluating between 14< LET <36 (or higher) MeV/mg/cm2.

Previous testing has shown very good agreement between measured error cross-sections using proton and neutron beams [9, 12, TBD]. In January, 2015, NASA tested various Flash Memories and Solid State Drives, whose soft and destructive errors have been observed in standard proton testing, at the LANSCE facility. Table 1 shows the summary and comparison of the results of such testing to indicate that neutron beams can be usable to screen for single event effects.

		Average Measured Cross Section (cm2)		
Part type	SEFI - Proton	SEFI - Neutron	Failure - Proton	Failure – Neutron
SanDisk	1.01e-9	2.71e-9*	1.46e-9	1.71e-9*
Delkin	2.13e-9	1.70e-9*	1.04e-9	2.43e-9*
ADATA 128GB	1.44e-9	3.39e-9*	none	none
Crucial 480GB	2.80e-9	2.44e-8*	1.40e-9	1.35e-9*

*Analysis is on-going, to be refined

Table 1: Summary of testing results. Flash Drives and Solid State Drives where tested with both the 200 MeV proton beam from IUCF and the (1-750 MeV) LANSCE neutron beam. Single event functional interrupt as well as destructive failure cross sections were measured.

The results show that for both SEFI and for destructive failures, that the neutron beam stimulated both error modes as well as produced cross sections generally less than a factor of 2 relative to the proton test. The sample size used during the neutron test was significantly different than the sample size used in the proton test, which may explain for some of the difference.

Summary

For LEO space environments, neutrons can be the dominant interior energetic particle source and should be considered when evaluating part performance. Fundamental physics modeling validates that the secondary LET environment is identical to that produced from the standard 200 MeV proton test. Simple commercial parts have been tested with both the mono-energetic proton beam as well as the poly-energetic neutron beam and show very good agreement with each other. Additionally, for the devices tested, both soft errors and destructive errors were stimulated consistently. The results presented here indicate that neutrons are important inside spacecraft and that they can be used effectively to screen for single event effects.

References

[1] K. Allums, P. O'Neill, B. Reddell, C, Bailey, and K. Nguyen, "Radiation Test Results on COTS and non-COTS Electronic Devices for NASA Johnson Space Center Spaceflight Projects", 2012 IEEE Nuclear and Space Radiation Effects Conference, Radiation Effects Data Workshop Paper, pg. 41-49, http://doi.org/10.1109/REDW.2012.6353731, July 2012

[2] C. Kouba, K. Nguyen, P. O'Neill, and C. Bailey, "Proton Radiation Test Results on COTS-Based Electronic Devices for NASA Johnson Space Center Spaceflight Projects", 2016 IEEE Nuclear and Space Radiation Effects Conference, Radiation Effects Data Workshop Paper, pg. 26-36, http://doi.org/10.1109/REDW.2006.295464, July 2006

[3] P. O'Neill, "Badhwar-O'Neill 2014 Galactic Cosmic Ray Flux Model Description", NASA/TP-2015, TBD, 2015.

[4] P. O'Neill, "Badhwar-O'Neill 2010 Galactic Cosmic Ray Flux Model - Revised" *IEEE Trans. Nucl. Sci*. vol. 57, No 6, pp. 3148, 2010

[5] NASA, "OLTARIS," Available: [Online]. https://oltaris.nasa.gov/

[6] FLUKA Team, "FLUKA," Available: [Online]. Available: https://www.fluka.org

[7] G. Battistoni, F. Cerutti, A. Fasso, A. Ferrari, S. Muraro, J. Ranft, S. Roesler, and P. R. Sala, "The FLUKA code: Description and benchmarking, "in AIP Conf. Proc., 2007, pp. 31–49.

[8] A. Ferrari, P. R. Sala, A. Fassò, and J. Ranft, "FLUKA: A Multi-Particle Transport Code," CERN, Geneva, Switzerland, CERN Rpt.CERN-2005-010, (INFN TC 05/11, SLAC-R-773), 2005.

[9] S. Wender, "Neutron-Induced failures in Semiconductor Devices", LA-UR-14-23043, April, 2014.

[10] P. M. O'Neill, G. D. Badhwar and W. W. Culpepper, "Internuclear Cascade-Evaporation Model for LET Spectra of 200 MeV Protons Used for Parts Testing," *IEEE Trans. Nucl. Sci*. vol. 45, pp. 2467-2474, 1998.

[11] G. D. Badhwar. and P.M. O'Neill, "Galactic Cosmic Radiation Model and Its Applications," Advances in Space Research, Vol. 17, No. 2, 1996 and P. M. O'Neill, "Badhwar-O'Neill Galactic Cosmic Ray Model Update Based on Advanced Composition Explorer (ACE) Energy Spectra from 1997 to Present," Advances in Space Research, (COSPAR04) Vol. 37, pp. 1727-1733, 2006.

[12] E. Normand, and L. Dominik, "Cross Comparison Guide for Results of Neutron SEE Testing of Microelectronics Applicable to Avionics" *IEEE Trans. Nucl. Sci*. vol. 53, pp. 3494, 2006.

[13] TBD