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Aging and Radiation Effects in Stockpile Electronics

E. F. Hartman
Sandia National Laboratories

Introduction

Modern nuclear weapons are hard to radiation environments. Often these nuclear weapon systems were hardened to; 1) theoretical enemy defense radiation environments and fratricide environments from our nuclear weapons, 2) space environments that occur during short-duration high-altitude flight, and 3) intrinsic radiation environments produced by special nuclear material within weapons that occur during stockpile storage.

The electronics within nuclear bombs and warheads perform important functions that are critical to the reliable operation of the weapon. Electronic malfunctions may cause inaccuracies in targeting and potential weapon duds. Although both bomb and warhead electronics are both hardened to radiation, the electronics in the warheads are hardened to higher radiation levels than for bombs.

Nuclear weapons in stockpile apparently will be required to remain reliable while weapon longevity is extended beyond the original design lifetimes. Identifying aging effects that impact the radiation hardness of microelectronics is increasingly important as military weapon systems are kept in stockpile beyond their originally intended use period. This additional time in stockpile can affect radiation hardness and weapon reliability in two general ways:

1. At least theoretically, aging in electronic components can affect the radiation hardness of weapon systems. Several physical phenomena where aging could affect radiation hardness are suggested in this paper. Very little data exists on aging of electronics related to retention of radiation hardness. Recently, discovery experiments have revealed some cases of aging apparently affecting radiation hardness. These discoveries are discussed briefly in this paper.
2. A problem could occur in the stockpile because of the fairly recent discovery that very low-level radiation can cause increased damage in bipolar electronic parts than higher level radiation for the same accumulated radiation dose. Since the entire nuclear weapon stockpile receives a continuous low-level dose rate of radiation from the special nuclear materials, it will be imperative to examine whether extending stockpile lifetimes incurs any risk of reduction in system hardness caused by low-level intrinsic radiation.

There are likely differences in how aging and radiation might affect bomb and warhead electronics. The first general problem (previously described) where aging lowers or negates radiation hardness of electronics could affect either bomb or warhead electronics. Problems would likely be first encountered during use when the weapon is exposed to an enemy defensive burst, a fratricide burst from one of our weapons, or a space radiation environment during reentry body flight. The normal stockpile surveillance program could uncover some problems. The problem of low level dose rate from intrinsic radiation would most likely affect only bomb electronics, since bomb electronics are less hard to total dose environments. Low level radiation could eventually damage electronics within the bomb, either degrading or causing the electronics to fail. This failure mechanism might be discovered in the future by normal stockpile surveillance, although degradation might not be discovered until exacerbated by a use environment such as radiation or temperature. There are radiation-testing methods that could determine how this low dose rate effect degrades stockpile electronics.

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Aging Effects on Stockpile Electronics

In the past, very little radiation testing of stockpile electronic components has been performed. In fact, very little data has been accumulated on aging as related to radiation hardness.[1-3] Theoretically, aging could affect radiation hardness. For example, stress relaxation of base metal in electrical contacts or corrosion of electrical contacts would increase resistance and therefore the probability that radiation dose rate would cause electronic upset due to voltage drops from photocurrents. Electromigration in metal interconnects can cause a change in resistance and excess noise that can result in a decrease in electronic upset thresholds due to reduced rail span.

Multifactor aging in insulators from thermal, chemical, or other effects can produce an accumulation of defects in insulators which increase the probability of failure in high radiation dose rate environments and from total dose.

Delaminations or separations within cables or printed wiring boards (PWBs) could dramatically enhance radiation-driven currents within cables or on PWBs. These enhanced electrical currents can damage electronics by causing burnout or dielectric punch through.[4]

Low-Level Radiation Dose Rate

Recent work has shown that total dose effects in some bipolar analog electronics depend on dose rate, exhibiting substantially greater damage under low dose-rate conditions compared to the damage that occurs at higher dose rates.[5] Since testing during weapon development was performed at higher dose rates compared to the lower dose rates that can cause increased damage, we don't have an adequate assessment of possible future damage to stockpile electronics from intrinsic radiation at this time.

As an example of enhanced damage at low dose rate compared to high dose rate, refer to Figure 1.[5] This figure shows that the measured saturation damage at a low dose rate (.005 rad/(Si)/s) is about 10 times greater than at a higher dose rate (50 rad(Si)/s).

Recent Results From Discovery Experiments

A total of 13 electronic types (naturally aged 20 years) were tested in 1997 through 1999 at a linac to high dose rate environments. The part types included transistors, op amps, RAMs, small scale and medium scale TTL logic, and other part types. All of these aged part types are identical to part types tested approximately 20 years ago. High-dose rate radiation response differences were seen for several part types between new and aged parts. The following physical analyses were performed on the electronic parts: broad beam Rutherford Backscattering Spectroscopy of whole die, ^{15}N hydrogen profiling, laser beam induced charge collection of selected devices on die, and proton induced x-ray emission to determine diffusion of metallization under Schottky diodes.

The radiation tests were performed at the Boeing Physical Science Research Center. Our tests and the earlier tests (20 years previous) were performed on similar 10-MeV linacs. We duplicated the original tests and we successfully correlated the original dosimetry to present dosimetry. In some electronic devices such as the 54LS221 multivibrator, no significant difference in photocurrent response was seen for early tests (performed in 1978) versus the 1998 tests. This data is shown in Figure 2. However, some electronic parts showed significant differences in radiation response between the 1978 test data and the 1998 test data. For example, tests performed on the 54LS14 hex

Schmitt inverter reveal a shift in photocurrent response of approximately a factor of three. This data is shown in Figure 3.

Total dose radiation testing using Co-60 to obtain low dose rates was performed on naturally aged (~ 20 years old) parts during 1997 and 1998. The five part types tested were transistors, op amps, and a TTL NAND gate. All parts were purchased at approximately the same time (1979-1981) and were either stored in nitrogen air bath environment or saw actual field use in weapon systems. No significant enhanced sensitivity to low dose rate irradiation was observed in any of the aged part types. There was also no significant difference in radiation response for any of the five part types between the stored devices and those used in fielded system for the total dose testing.

Conclusions

It is likely that aging is affecting the radiation hardness of stockpile electronics, and we have seen apparent examples of aging that affects the electronic radiation hardness. It is also possible that low-level intrinsic radiation that is inherent during stockpile life will damage or in a sense "age" electronic components. Both aging and low level radiation effects on radiation hardness and stockpile reliability need to be further investigated by using both test and modeling strategies that include appropriate testing of electronic components withdrawn from the stockpile.

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[2] J. R. Laghari, "Complex Electrical, Thermal and Radiation Aging of Dielectric Films," IEEE Trans. on Elect. Insul., Vol. 28, Issue 5.
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[4] E. F. Hartman and D. C. Evans, "Electrical Pulse Burnout of Transistors in Intense Ionizing Radiation," IEEE Trans. On Nucl. Sci., Vol. NS-22, No. 6, 1975.
[5] A. H. Johnson, et. al., "Enhanced Damage in Linear Bipolar Integrated Circuits at Low Dose Rate," IEEE Trans. on Nucl. Sci., Vol. 42, No. 6, December 1995.

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Saturation Characteristics of LM111 Comparator Input Current at Low and High Dose Rate

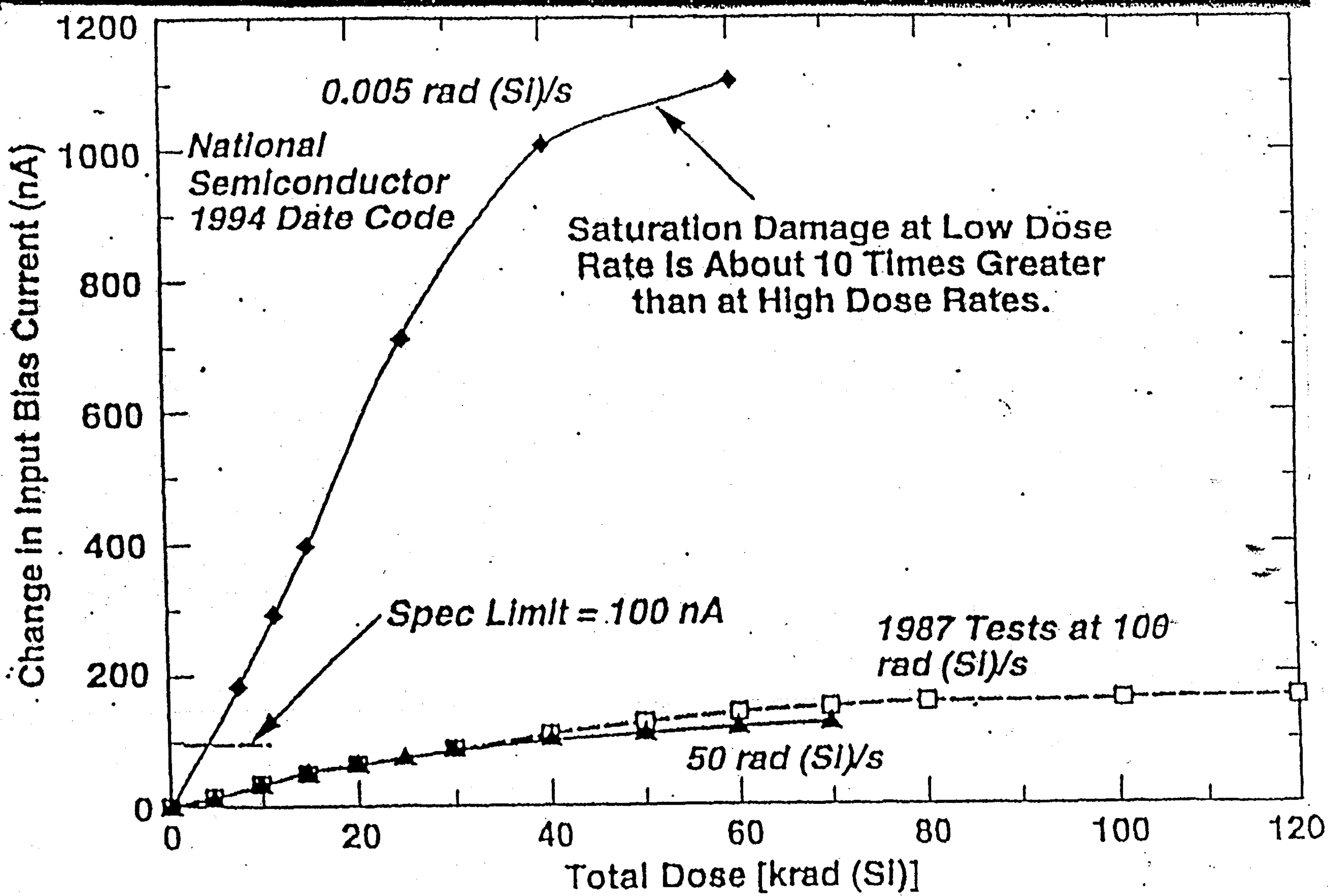

Figure 1