Radiation Effects on Microelectronics: Forecasting Tomorrow's Problems

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WHAT KINDS of radiation effects problems will be reported in the pages of this journal in future years? Will new radiation environments extend the range of topics that must be considered? If technological developments continue at the rapid pace of the past few decades, will our information base be sufficient to deal with the emerging problems effectively? What other factors will play a role? To what degree are the future needs for basic radiation effects information predicatable?

Over the years, the types of radiation effects problems addressed in this journal have changed in nature and in scope. New studies were introduced, driven by scientific, technological, economic, and political forces. Originally, the radiation environments of primary concern were those associated with nuclear power sources and nuclear weapons. Effects produced by relatively short pulses of gamma rays, X-rays, and neutrons were the focus of most research activity. These radiations, and the sources used to simulate them, determined the character of the research studies undertaken. Introduction of the atomic test ban further modified the specific problems addressed.

The discovery of the van Allen belts early in the space program necessitated the consideration of effects produced by a totally different environment. In this case, long duration exposures to electrons and protons with a wide range of energies were of concern. High-altitude nuclear explosions showed that the natural radiation belts could be enhanced markedly and led to the first radiation problems encountered in satellites. Extraplanetary exploration broadened the range of space radiation exposures that had to be considered.

The galactic cosmic ray component of the space radiation environment soon added to the range of particles and energies of concern when it was identified as the source of what had been anomalous effects in high-density computer memories. It was found that the passage of a single energetic cosmic ray particle through a memory cell could cause it to switch from one state to another. Cosmic ray related effects, now known as single event upset (SEU), have been at the center of intensive investigations over the last decade. It is interesting to note that this component of the natural environment became of concern due to advances in miniaturizing devices and not because of the development of a new radiation source (e.g., nuclear power) or visits to previously unexplored regions (van Allen belts). It was the direct consequence of the increased sensitivity of the new high-density memory technology. A related problem, brought on by the changed sensitivity, was that of naturally occurring radioactive elements in device packaging materials. Fortunately, the alpha particle-induced upsets, arising from the trace amounts of uranium and thorium in package materials, can be readily shielded against, while the more energetic cosmic rays cannot. In addition to these events, the introduction of ion implantation and the possible adoption of X-ray lithography raised the issue of radiation damage to semiconductor devices even before they were installed in electronic systems.

Still another set of environments had to be considered with the emergence of the Strategic Defense Initiative (SDI) program. Pulsed particle beams introduced the possibility of additional modes of radiation-induced response in electronic devices. Related problems arising from damage to particle detectors used in present or future research at high-energy accelerators, such as the Superconducting Supercollider, provide a continuing expansion of the types and energy range of the particles that require attention.

When we consider the evolution of the radiation environments over past years, our ability to anticipate the kinds of problems they precipitated is cast in doubt. Certainly, the emergence of nuclear weapons at the end of World War II was not anticipated by the majority of the scientific and technical community. The radiation belts and the effect of weapons on them constituted additional unexpected events. Although the cosmic ray environment was recognized very early relative to the other sources of radiations, the fact that it could produce effects in advanced electronic systems was not generally recognized until the events actually occurred.

Consideration of these factors could diminish expectations with regard to identifying tomorrow's problems and the information required to deal with them. Nevertheless, there are important clues from the past that provide strong reasons for optimism. It is interesting to note that the emergence of new radiation environments did not lead to the abandonment of research on effects produced by those of earlier concern. They simply added to the range of research problems. Why?

The reason, of course, is that the electronic systems potentially or actually exposed to these environments have undergone explosive and radical development. One manifestation of this growth is the scaling down in size of individual microelectronic devices. The benefits of such size reduction—increased speed, enhanced performance, reduced power, consumption, and lower cost—have propelled technological development to this day. The reduction in size has raised questions as to the ultimate limits of miniaturization, and from the radiation effects' point-of-view, the specter of increased vulnerability.

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The issue is not a simple one, and the "vulnerability" depends upon the measure of performance used. For example, in the case of cosmic ray upset, the critical charge required to produce an upset drops approximately inversely as the square of the feature size. This would indicate a marked increase in vulnerability with size reduction. Furthermore, the energy spectrum of cosmic ray particles is such that a reduction in the critical charge effectively increases the number of particles capable of causing a memory upset. The cross section of an individual memory cell, however, drops as the feature size decreases, and when a vulnerability measure such as "events per bit day" is applied, some analyses indicate a reduction in vulnerability.

Interestingly, the problem of single particle upset was identified at least a dozen years before its actual occurrence and recognition as a significant problem. Little attention was given to that early warning, and the problem had to be rediscovered. Nevertheless, this experience suggests that in the area where we might reasonably expect the most rapid and extensive changes—microelectronics technology—forecasting problems is possible. Such forecasts are inextricably intertwined with questions of ultimate performance limits, a subject that has been addressed periodically in semiconductor device literature for many years. The novelty of the prediction previously cited, regarding the ultimate susceptibility of microelectronics to cosmic rays, is that it is perhaps the first instance where the problem of fundamental limits imposed by radiation environments was specifically addressed. What about the other radiation environments? It would seem that further studies along these lines could lead to useful guidelines for answering questions regarding the investment of future resources.

Returning to the opening theme of this editorial, it appears that it is reasonable to seriously consider the possibility of accurately forecasting the nature of future radiation effects problems by closely following ongoing studies of the ultimate limits anticipated in microelectronics. This will involve more than simply considering the consequences of scaling present day devices to smaller dimensions. The ability to microengineer materials at the nanometer level has lead to the evolution of quantum devices operating on principles totally different from those of semiconductor junction devices. The availability of high-temperature superconductors promises further radical departures from the past. Advances in instrumentation, such as the tunneling electron microscope and markedly enhanced computer capabilities, promise new insights into old problems and the identification of new ones. Furthermore, the development of interdisciplinary areas (e.g., microelectronic analogs to the biological effects of radiation) may provide valuable information regarding otherwise intractable problems.

There will clearly be more problems to explore than available resources will allow. That makes it all the more imperative, and rewarding, to identify those areas most likely to result in significant advances in our basic knowledge and capabilities. A number of examples exist where the application of the same basic engineering and scientific procedures with which we are all familiar can be applied to the problem of making quantitative assessments of future possibilities. The past is a guide to the future. Perhaps the most basic question of all is: Can we improve, or do we need to improve, upon our ability to identify significant research problem areas? The answer will determine the future directions of radiation effects research.

Editorial Note: Edward A. Burke (M'88) is a Senior Scientist at Spire Corporation and has been active in radiation effects research since the mid 1950's. He has received a number of awards at the annual IEEE Nuclear and Space Radiation Effects Conference including the Distinguished Poster Paper Award in 1986 and the Outstanding Conference Paper Award in 1987, and was the first recipient of the Radiation Effects Award in 1988. He is a member of the APS, HPS, and Sigma Xi.

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