Preface

Modern electronic circuits are highly complex systems and, as such, are susceptible to occasional errors or failures. In addition to permanent hardware failures, electronic components are subject to random transient errors which originate from various electronic noise sources. In digital electronics, errors which are not caused by permanent damage to the circuits are referred to as *soft errors*, *soft fails*, or *single-event upsets*.

IBM scientists have long known that electronic noise capable of causing soft errors in electronic components could also be created by energetic nuclear particles originating from either of two sources: extraterrestrial cosmic ray particles, which constantly bombard the earth, and the decay of radioactive atoms. The soft errors generated in digital electronics by particle bombardment are produced at localized sites and involve single memory bits or single Boolean logic steps. Although digital circuits in computers are constantly exposed to these particles, their effects do not necessarily translate into operational mistakes. For example, a changed memory bit may be overwritten before it is read. There are two common approaches for combating soft errors. Chips may be selected or designed with components that have reduced sensitivity to cosmic ray particles. Alternatively, methods such as parity checking and error correction codes, in use since the 1960s, may be employed to prevent soft fails from causing system errors. Analyses of error propagation and correction techniques in digital circuits have been extensively reviewed elsewhere and are not treated in this issue.

This issue of the *IBM Journal of Research and Development* focuses on studies of soft errors in computer chips caused by cosmic rays at terrestrial altitudes. Soft errors caused by radioactive contaminants are also considered, but emphasis is placed on the experimental, theoretical, and modeling aspects of cosmic-ray-induced soft errors in computer chips. Details of procedures used at IBM to improve chip reliability by minimizing chip sensitivity to cosmic radiation are outside the scope of this issue.

The issue is divided into two sections: experimental and theoretical. In the first paper, Ziegler et al. trace IBM's experimental studies of cosmic-ray-induced chip errors. Ziegler's second paper reviews the physics of terrestrial cosmic ray flux. O'Gorman et al. then describe field-testing measurements of soft errors in computer chips caused by naturally occurring terrestrial cosmic rays at various altitudes. Accelerated testing of computer chips with particle beams to provide a rapid and accurate evaluation of the sensitivity of newly fabricated chips to cosmic rays is discussed in a review by Ziegler et al. This is followed by a short paper by Ziegler et al. which describes the design of a portable nonvacuum Faraday cup used in accelerated-testing studies.

In the first theoretical paper, Srinivasan presents an overview of the basic physical principles and methodologies which have been incorporated into a software tool called SEMM (Soft Error Monte Carlo Modeling). SEMM is used extensively in IBM during computer chip design to meet reliability goals by predicting soft-error rates. Next, Tang reviews the theory of high-energy particle bombardment of microelectronic devices which is used in the nuclear spallation model to generate the database required by SEMM. The following paper, by Murley and Srinivasan, describes how SEMM takes information on circuit design and layout, on processing design details, and on circuit critical charge (i.e., the collected charge necessary to switch a signal in an integrated circuit) to predict soft-error rates. Freeman provides an important contribution to soft-error modeling in the final paper, in which he examines the concept and calculation of critical charge. Although critical charge is typically introduced into soft-error simulation models as a single-valued parameter, Freeman shows that normal manufacturing and operational tolerances can cause a significant variation in critical charge and give rise to a range in simulated soft-error values.

IBM scientists have been actively engaged in research on cosmic ray particle bombardment of computer chips for nearly two decades. Their purpose has been to understand and to quantify the probability of chip soft errors and to provide means to contain these errors within specified standards of system reliability. The papers presented in this issue of the *IBM Journal of Research and Development* describe their achievements and illustrate IBM's continuing efforts to enhance the reliability of its products.

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Guest Editors