CREME96 Update/Replacement Efforts

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Abstract:

This talk concerns the plans to update the CREME96 model that is currently available on the WWW. The talk states the reasons for updating CRÈME. It describes the updates that are planned, including the single event prediction paradigm, the method of radiation transport through the spacecraft to the electronic component of interest and the planned updates to models for the space radiation environment. It also reviews user suggestions received do date for the update.
CREME96 Update/Replacement Efforts

presented by Jim Adams
Outline

◆ Why Update CRÈME?
  o The CRÈME paradigm and why it does not work
  o Examples
◆ The CRÈME Replacement
  o Technical Approach
    – SEE Rate Predictions using RADSAFE
    – RADSAFE Implementation Concept
    – Structure of MRED - Core of RHESE Tool
    – Modeling a Complex Stack - Nuclear Events
  o Using MRED to Predict SEE Rates
◆ Summary
Why Update CRÈME?

- The currently available models are out of date
  - Single Event Effect (SEE) rate predictions are unreliable for modern devices because:
    - Components contain features made of heavy metals
    - The combination of feature sizes are < 1 μm, low critical charge and the high packing density of microcircuits.
    - So we often do not understand why SEE's occur.
  - Improved environmental models are available
    - More accurate galactic cosmic ray models
    - Better solar energetic particle models
      - Models of recent very large events can be included
  - Monte Carlo radiation transport codes are available
    - They include transport of heavy ions
    - As well as neutron production and transport
    - And they correctly treat complex spacecraft designs
The CRÈME paradigm

Space Environment

Ground Testing

Direct Ionization: Rectangular Parallelepiped (RPP) model
Nuclear Reactions (proton only): Bendel Model
(both are circa 1980)
https://creme96.nrl.navy.mil/

On-Orbit SEE Rate

Single Event Effects Symposium, Long Beach, CA, 11 April 2007
Technical Justification (1)
Classical On-Orbit SEE Performance Predictions

Space Environment

Ground Testing

These models no longer capture the physical processes that drive the response of modern technology to ionizing radiation

On-Orbit SEE Rate?

Single Event Effects Symposium, Long Beach, CA, 11 April 2007
Examples of Breakdown of Existing SEE Models

No Model Widely Available!

RADHARD CMOS SRAM Nuclear Reactions from Heavy Ions (Z>1)

Protons Effects in Optical Links

Proton effects in SOI based memories

Heavy Ion Effects in SiGe HBTs

Heavy Ion effects CMOS SRAM


Provided by Vendor A

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This is a measurement of the SEU cross section for Radhard part developed for DOD. It was supposed to have threshold at an LET of 40, but obviously it does not. Detailed TCAD simulations of the part could not identify any lower threshold junctions in the circuit. A RADSAFE analysis showed that the subthreshold SEE were due to target fragments from heavy ion induced reactions by the 523 MeV Ne beam.

This figure shows how the data can never be explained by the RPP model in CREME. The purple curve is an attempt to use the RPP model to explain the SEU cross section versus LET. The data in black, green, pink and orange are from Kr (15 MeV), Ar (15 MeV), Ar (20 MeV) and Ne (40 MeV/nuc) beams at 0, 30, 45, 60, and 70 degrees. Ne and Ar beam measurements are not consistent with the RPP model. This is caused by the sensitive volume shape and heavy ion effects.

This shows the angular dependence of the proton-induced SEU cross section on the angle of incidence of the proton in 0.5 micron SOS. It is thought that the SEUs in this device are due to nuclear recoils and these are most likely at 0 degrees to the proton beam. When these recoils are nearly in the plane of the silicon.

These are proton-induced single event transient cross section measurements, probably on an optocoupler. Bendel will predict the purple line, but if you include direct ionization using the RPP in CREME, you can get the peak at 90 degrees from the direct ionization of the stopping protons.
The CREME Replacement

♦ The CREME96 Replacement will have:
  o Backward compatibility:
    - Provide access to the CREME96 methods
    - Include the classical SPE models from CREME86
  o Provide access to the environment data directly
  o Provide total dose estimates
  o Provide several new approaches to SEE Predictions
    - Calorimetric approach
    - Device model-dependent approach
  o WWW accessible
    - Have the possibility to be locally hosted by the user
Technical Team

- Marshall Space Flight Center Team
  - Scientists
    - James H. Adams, Subproject Lead and Cosmic Ray Team Lead at MSFC
    - Nasser Barghouty, Astrophysicist, Cosmic Ray Team at MSFC
    - Zi-Wei Lin, Nuclear Physicist, Research Professor at Univ. of Alabama in Huntsville
    - John Watts, Cosmic Ray Physicist, Cosmic Ray Team at MSFC

- Institute for Space and Defense Electronics (ISDE), Vanderbilt University
  - Principal Engineers
    - Robert A. Weller, Prof. of Electrical Engineering, Prof. of Physics
    - Robert A. Reed, Research Associate Professor of Electrical Engineering
    - Ronald D. Schrimpf, Prof. of Electrical Engineering, Director of ISDE
    - Marcus H. Mendenhall, Research Associate Professor of Physics
  - Additional Engineering Staff Participants
    - Lloyd W. Massengill, Prof. of Electrical Engineering, Director of Engineering, ISDE
    - Brian Sierawski, ISDE Engineer
    - Kevin Warren, ISDE Senior Engineer
    - Dennis Ball, ISDE Engineer
  - Graduate Students
    - Students from the Radiation Effects and Reliability Group test and use ISDE code
Technical Objectives

◆ Improve External Radiation Environment Descriptions
  o Galactic cosmic rays
  o Solar energetic particles
  o Anomalous cosmic rays
◆ Improve Radiation Transport though Spacecraft
  o Full Monte Carlo radiation transport
◆ Provide a Physics-Based Simulation Tool of Single-Event Effects
  o Correctly treat hole-electron plasma creation
  o Charge collection
  o Circuit response
◆ Use the Tool to:
  o Diagnose SEE mechanisms in selected technologies
◆ Provide a WWW site to predict total dose and SEE effects on spacecraft
Technical Approach

The External Environment

◆ Quiet-time Galactic Cosmic Ray (GCR) Environment
  o We will evaluate the available GCR models against data and choose the most accurate one.

◆ Solar Energetic Particle Environments
  o We will offer a variety of models based on real event (probably using Xapsos spectral fits)
  o We will include a probabilistic model based on the work of Joan Feynman

◆ The Anomalous Cosmic Ray Environment in the Outer Heliosphere

Radiation Transport

◆ The external environment will be propagated though the spacecraft structure to the electronic part of interest using a Monte Carlo transport code (probably GEANT or FLUKA)
  o These codes include the capability to calculate the absorbed dose in the part of interest (thus allowing the total dose to be predicted)
RADSAFE Implementation Concept

The Radiation Environment Models are used to calculate the energy deposition and partitioning. The approximate response models then use this information to determine the Poisson solver. This solver helps in making the design decision.
Description of RADSAFE

- RADSAFE will extend CREME96 models
  - Leverages ongoing NASA/DoD funded development at Vanderbilt University
- RHESE support will bring key portions of the RADSAFE concept to NASA engineers through the CREME-MC, a world wide web tool
- Examples of new on-orbit prediction capabilities
  - Heavy ion nuclear reactions
  - Realistic geometries associated with modern technologies
  - Improved charge collection models
  - Multiple Bit Upsets (i.e. FPGA based memory)
  - Proton induced effects in modern technologies
- Extensible to capture new, technology based models
SEE Rate Predictions using RADSAFE

Predictable System Error Rates

Trackable System Effects

Transistor vs. V_in

Functional Errors

Component Response Statistics

Physics of Radiation Interaction

Single Event Effects Symposium, Long Beach, CA, 11 April 2007
Structure of MRED - Core of RHESE Tool

• MRED8: a Python/Geant4 application
• Core: c++ for speed
• Interface: SWIG (simplified wrapper interface generator)
• Python: The language for software system integration
• Target machine is a Linux cluster with 1k x86 and ppc nodes
Example: MRED used to predict SE effects for two structures:
- Stylized stack to approximate an IC overlayer with and without W
- Direct and Indirect reactions computed
- Energy deposition events included from primary and secondary particles

High energy secondary particles created by nuclear reactions with W in the IC overlayer

Energy (MeV)

Relative Number of Events

\( \text{LET} \)

Nuclear Reaction Fragments

\( \text{Ne} 523 \text{ MeV} \)

\( \text{Ne} 523 \text{ MeV} - \text{W plug} \)
Product Application Example:
Using MRED to Predict SEE Rates

Charge (pC)

- CREME96
- Si only: MRED
- Si with W layer: MRED

Solar Minimum
Z = 1 to 92

Rate (events/day/SV)

-13
-12
-11
-10
-9
-8
-7
-6

0.0

0.5

1.0

Energy (MeV)

0

5

10

15

20

25

Single Event Effects Symposium, Long Beach, CA, 11 April 2007
This is a plot of energy deposition rate in a 10 by 10 by 1 micron volume within a block of silicon from the GCR environment. The blue case is pure silicon and the red case is with a tungsten layer above the sensitive volume.
Summary

- Single Event Effect (SEE) rate predictions with current models are unreliable for modern devices because:
  - Existing SEE prediction tools do not include effects found in modern devices
  - Accelerator tests cannot be interpreted by traditional methods to provide accurate SEE predictions with existing tools.
- We will use available physics-based device modeling to diagnose the causes of SEEs in selected devices.
- We will provide a WWW-based computational tool that:
  - supports real-time prediction of component reliability.
  - Includes improved environmental models that are available
  - Uses available Monte Carlo radiation transport codes
  - Uses calorimetric methods informed by physics-based charge collection and circuit response codes
- This tool will provide:
  - Estimates of mission-specific total dose and SEE rates
  - To enable the design of safe reliable space electronics.