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Expansion of Radiation Hardness Assurance Tool Suite

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NEPP Electronics Technology Workshop, 2020

This work supported by NASA NEPP Grant #80NSSC20K0424



Overview



- **Description**

- This effort proposes to expand online capabilities through integrating environment and effect models beyond CREME96 for radiation hardness assurance and to evaluate assessments of single event functional interrupts (Ogden, next presentation)

- **Approach**

- Leverage the existing tools and include probabilistic radiation environments for confidence-level assessments of reliability, displacement damage calculations, and notional tools to provide guidance to small satellite developers

- **Outcomes**

- Online tool developments will increase accessibility of tools, facilitate interoperability, and position them for model-based mission assurance



Online Resources



<https://creme.isde.vanderbilt.edu>

Welcome to the CREME site

It has been almost a decade since the introduction of CREMERS, the current state-of-the-art tool for SEE rate prediction. CREMERS uses phenomenological models to predict SEE rates. These models were based on two assumptions. First it was assumed that the ionization track left by the particle was much narrower than the minimum feature size in the microelectronic circuit. Second, it was assumed that the SEE sensitivity of individual microcircuits could be idealized as being due to a single sensitive junction. The cross section of this junction versus the linear energy transfer (LET) rate of the ionizing particle could then be measured and used to estimate the SEE rate. Since CREMERS has developed the minimum feature size has deviated by more than a factor of 100. As a result, the distinction between track microstructure and device characteristics can no longer be ignored. This assumption in CREMERS has been shown to have significant shortcomings when applied to new and emerging technologies like advanced CMOS, SiGe HBTs, photodiodes, and DR FPGAs. The solution is to replace current models in CREMERS with a physics-based model that correctly accounts for the distribution of energy deposited along the track and the possible existence of multiple sensitive junctions in each microcircuit.

The need for a comprehensive and extensible complement to CREMERS that is widely accessible is now apparent. This approach allows for this new SEE model to include, use, standardize or safely integrate computer languages, and is based on a core of open-source material, the @Gentic Libraries, for the basic radiation-computation engine. This core Monte Carlo engine can be supplemented in an extensible way with specific models relevant to new technologies, as these models are developed.

CREME-NC Technology

Overview & references to @Gentic Documentation

The site is built on @Gentic, which is a very versatile content management system written in @Python.

The graphics for the site are generated using the very nice @Gentic plotting package, which is open source, free, and very well designed. It produces high-quality PDF output. Users are encouraged to download this package as they can directly manipulate the Gentic files from the site, rather than reformatting to the CSV files, and having to reformat the plots. Note that Gentic is excellent for publication plotting, and is capable of saving style files, allowing one to format all graphics for a given @Gentic component.

We use @ReportLab to generate the pictures.

What's New?

Open the public release of this site in browser

- = an update to the model for the galactic cosmic ray multiplexer structures to evaluate the Monte Carlo radiation transport models for
- = simulate pressure, apnea, and hearing loss
- = capture the effects of high-energy particle
- = critical energy loss variation, etc.

Environments & SEE Rates (Sierawski)

<https://vanguard.isde.vanderbilt.edu/RGentic/>

Tool Guide:

This tool is meant to be used as guidance for understanding the radiation risks that apply to a specific set of circumstances, not to replace modeling one's own environment or replacing the need to test a device. When used from start to finish you can get guidelines to help mitigate radiation effects and understand where you can avoid risks, based on simplified inputs, for a parts list in question.

Each Navigation Tab is a step in the process:

- User Mission:** Begin with selecting the options that apply to you for an intended mission, each input will directly impact the output of the tool that is to follow. At any time, you can choose to begin again, or follow the path for a new mission design under question. By selecting a mission class, Helium, orbit, and architecture you are returned an environment severity with contributions and the EEE threats the tool will focus on.
- Environment Comparison:** Using the inputs from section 1, the tool displays past mission modeling efforts that have been done. It returns the details of a mission that has been calculated to be close to yours when normalized for one year. This panel allows selection of multiple missions to compare and explore. It should be noted that the Solar cycle has an impact on the dose based on the launch year, and the normalization is for approximation. This piece of the tool is to show how shielding can be used to mitigate dose levels, and how mission characteristics impact your SEE concerns. Two plots are available, the TID vs. shielding depth curve and the GCR spectra. The tool also returns data tables for all plots rendered.
- Device Response:** Using the top level selections from section 1, the device susceptibility and basic radiation concerns are called out when the user inputs the device information. Here the tool returns examples of the most prevalent radiation concerns through plots and references of similar components where possible.
- Guidelines:** The final step captures radiation line of questioning that is tailored to the user inputs, the major concerns are clarified and the user is presented with mitigation strategies. You can also see a listing of class guidelines with respect to radiation using the dropdown. In an effort to document failure modes and reduce the breakdown to the system from a radiation standpoint, a list of risk and post mitigation is returned. This output can be saved and added to a table in the Summary.

Notional RHA (Campola)

<https://modelbasedassurance.org/>

SEAM (Systems Engineering and Assurance Modeling) is a web-based collaborative modeling platform for modeling assurance cases integrated with the models of the system.

GSN Assurance Models

SEAM supports the Global Structuring Notations (GSN) standard to build assurance case models. GSN uses hierarchical models, as well as cross-referencing to manage complexity in GSN models. Additionally, GSN allows linking assurance cases to system models to provide context to the assurance case argument.

System Effects Modeling (Witulski)

<http://seutest.com>

Flux calculation

Use this calculator to determine the relative neutron flux at a particular location. The output value is relative to the sea level flux in New York City, New York, USA. This point has historically been the reference point for neutron flux measurements.

Instructions for use are here (opens a new window) and summarized at the bottom of this page.

Location

Latitude: N S equator

Longitude: E W equator

Elevation, Pressure or Depth: Enter a single value and check the appropriate box

Elevation: feet meters

Station pressure: mm Hg inches Hg millbar (mbar)

Atmospheric depth: g/cm²

Solar Modulation

Solar modulation: % (0 is minimum flux / active sun, 100 is maximum flux / quiet sun)

Terrestrial Neutron (Wilkinson)



CREME96 Tools



Tools

TRP

GTRN

FLUX

TRANS

LETSPEC

HUP

PUP

DOSE

- **Near-Earth particle environment (Sawyer & Vette '76)**
 - Extracted from tables of AP8 proton fluxes, user selects between solar minimum and solar maximum
- **Geomagnetic shielding (Nymmik '91)**
 - Precomputed vertical cutoff magnetic rigidity values, user selects between quiet and stormy conditions
- **Galactic cosmic ray environment (Nymmik '92)**
 - Relates intensity to Wolf sunspot number
- **Solar particle events (Oct. 1989 event)**
 - Provides worst-week, worst-day and peak 5 minute fluxes
- **Single event upset rate predictions**
 - Proton and RPP-based heavy ion models



Tool Development



- **Each web tool, CREME or otherwise, has backend and frontend code**
 - Access to additional or updated codes requires development of both
 - Modifying the CREME codes and output files undesirable for development, maintenance, and efficiency
 - Building or wrapping backend additions in Python takes advantage of wealth of integration, fitting, parsing modules
 - Evaluating modern, reactive web tools for updated frontends outside CREME
- **In the following slides, we will *discuss* the backend development and *show* an operational frontend**

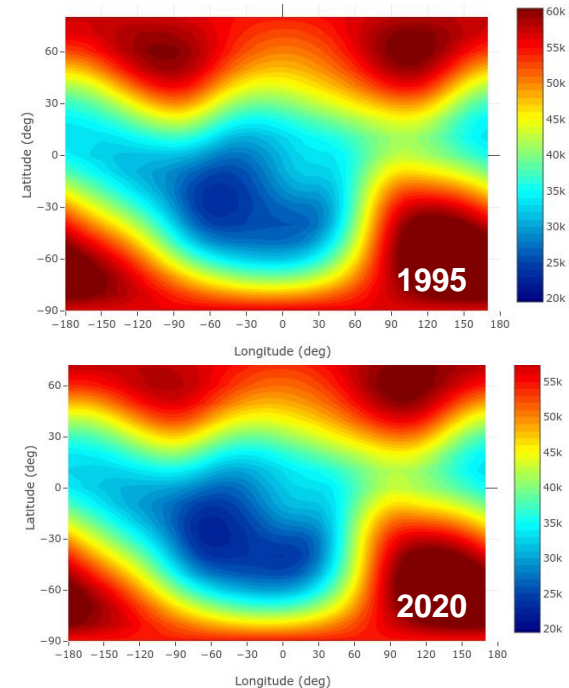


Magnetic Field Models



- **CREME96 geomagnetic model is deeply integrated and based on old IGRF fields**
 - Post 2000 calculations require new IGRF model and rigidity calculations
- **IGRF13 built for internal fields through 2025**
- **Tsyganenko models built for external fields**
 - Influenced by time, tilt, magnetic disturbance, etc.
 - Most important for orbits L shell > 4 [1]
- **Vertical cutoff rigidity calculation for geomagnetic transmission functions in development**
- **Precalculated cutoff rigidities being reviewed**

IGRF13 Magnetic Field Intensity (nT)



[1] J. Barth, "Modeling Space Radiation Environments," *IEEE NSREC Short Course*, 1997.



Solar Energetic Particles

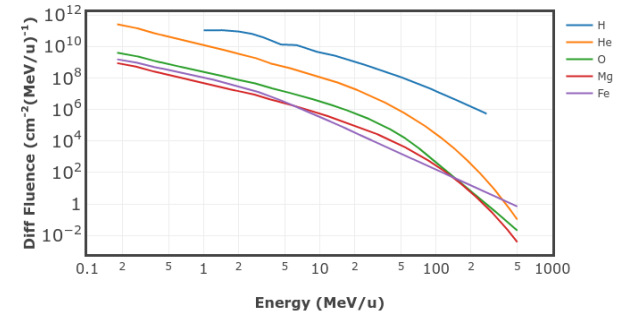


- **CREME96 solar particle events produce worst case spectra based on the October 1989 event**
 - Worst-week, worst-day and peak 5-min flux
- **ESP/PSYCHIC probabilistic environment models have been implemented to generate environments with given confidence levels**
- **Environment parameterized by years in solar maximum**
 - SILSO sunspot data are currently used to provide historical solar conditions
 - NOAA observed and predicted sunspot numbers planned for upcoming solar cycle

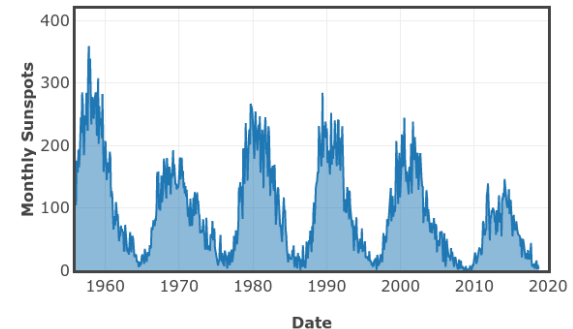
[2] M. A. Xapsos et al., "Model for cumulative solar heavy ion energy and linear energy transfer spectra," in *IEEE Trans. Nucl. Sci.*, vol. 54, no. 6, pp. 1985-1989, Dec 2007.

[3] WDC-SILSO, Royal Observatory of Belgium, Brussels

Differential Fluence (90% CL, 2 yrs)



SILSO Sunspot Numbers



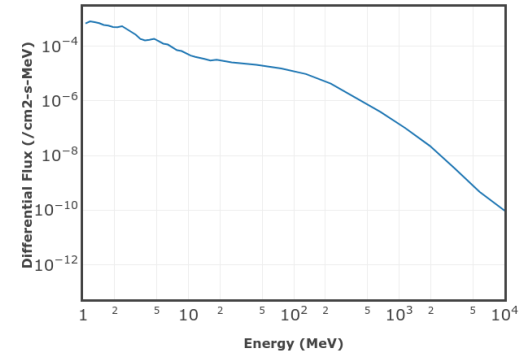


Terrestrial Neutrons



- **CREME only provides support for space environments**
- **Terrestrial electronics are affected by relative neutron environment across location and altitude**
 - Models rely on cutoff rigidities
 - Revision of JEDEC standard JESD89 [4] includes updated table cutoff rigidities
 - Calculations supported by seutest.com
- **Inclusion of neutron models can leverage commercial interest, perhaps mix communities**

Cosmic Ray Neutrons, NYC



Location and Altitude Scale Factors

Summary

Rigidity (GV) 2.337
Fa Parameter 0.99979
Fb Parameter 0.99151
Relative Flux 0.9913

[4] Measurement and Reporting of Alpha Particles and Terrestrial Cosmic Ray-Induced Soft Errors in Semiconductor Devices

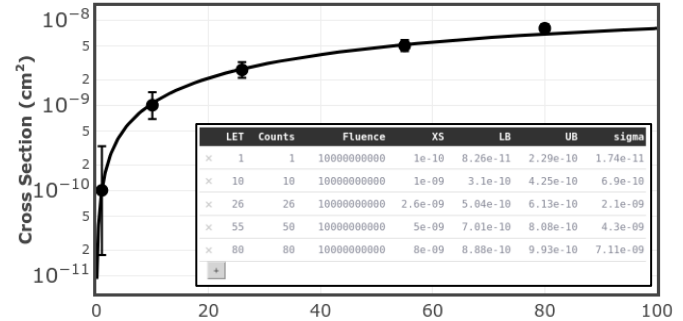


Cross Section Curves

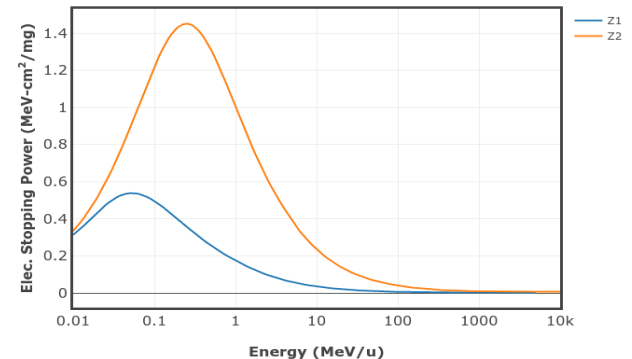


- **CREME96 upset routines accept Bendel or Weibull parameters for SEE rates**
 - Variety of fitting techniques and "eye-balling" used
 - Difficulties encountered with data near threshold
- **Fitting utility developed to calculate counting error bars and apply log-least-squares (LLS) technique [5]**
 - User data, including spreadsheets, easily entered
- **SRIM-calculated stopping power and range curves generated for reference**

Heavy Ion Cross Section Curve Fitting



Stopping Power Curves



[5] R. Ladbury and M. J. Campola, "Statistical Modeling for Radiation Hardness Assurance: Toward Bigger Data," in *IEEE Trans. Nucl. Sci.*, vol. 62, no. 5, pp. 2141-2154, Oct. 2015.

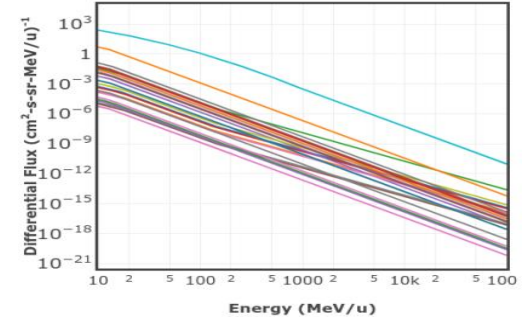


Dose Depth Curves

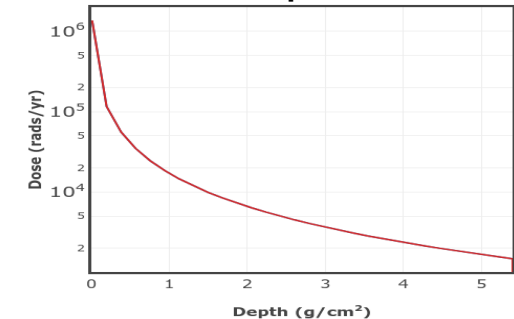


- **CREME96 total dose calculations integrate proton spectrum**
 - Only exist for non-trapped environments
 - Electron and bremsstrahlung are *not* included
 - Cumbersome evaluation of shielding
- **SHIELDOSE-2 [6] has been integrated to calculate dose depth curves**
 - CREME96 and SPENVIS files can be supplied as environments
 - Comparison of results underway

Example Particle Environment



Dose Depth Curve



[6] S. M. Seltzer, "Updated calculations for routine space-shielding radiation dose estimates: SHIELDOSE-2," *NIST Publication NISTIR 5477*, Gaithersburg, MD., December 1994.



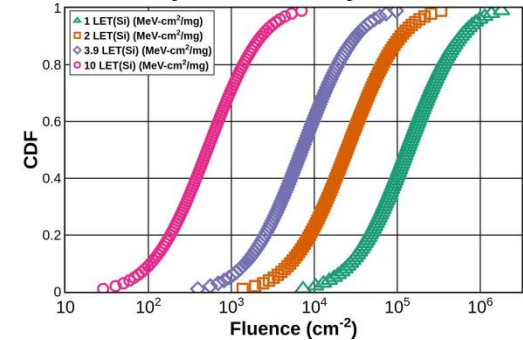
SEE Reliability



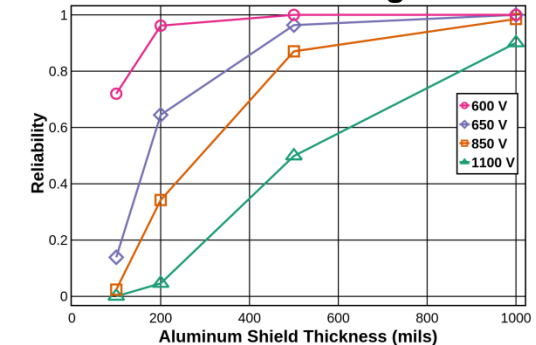
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- **CREME96 evaluates solar particle events for worst case environments**
- **Metric for SEE reliability proposed for devices with a lethal ion failure based on [7]**
 - Demonstrated for SEB in SiC power MOSFETs [8]
 - Accounts for environment variability (a la ESP/PSYCHIC)
 - Allows evaluation of shielding and derating

Probability Fluence 1yr Solar Max



Effectiveness of Shielding and Derating



[7] M. A. Xapsos et al., "Inclusion of radiation environment variability in total dose hardness assurance methodology," *IEEE Trans. Nucl. Sci.*, vol. 64, no. 1, pp. 325–331, Jan. 2017.

[8] R. A. Austin et al., "Inclusion of radiation environment variability for reliability estimates for SiC power MOSFETs," *IEEE Trans. Nucl. Sci.*, vol. 67, no. 1, pp. 353–357, Jan. 2020.



Future Work



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- **Continue development of existing tools**
 - Magnetic field models require cutoff calculation and orbit propagator to be useful
 - Solar cycle predictions for solar event and galactic cosmic ray parameters
 - Goodness of fit and poor statistics techniques for cross section fitting
- **Define and demonstrate integration between tools**
 - eg. How does output of ESP pass to SHIELDOSE?
- **Pursue integration of additional environments, models, analysis methods**
- **Include additional informational tools (eg. rigidity maps)**
- **Explore links to MBMA (eg. assumptions, context, evidence)**