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Expansion of Radiation Hardness Assurance Tool Suite

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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

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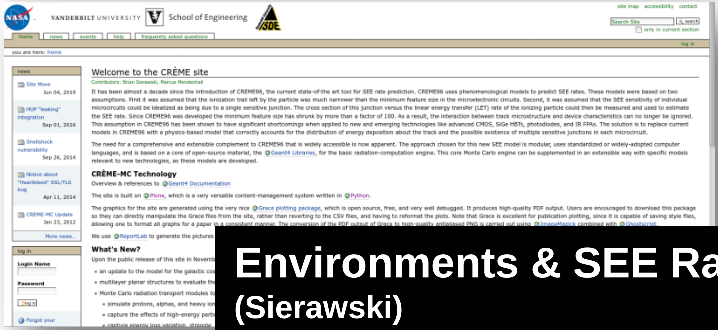
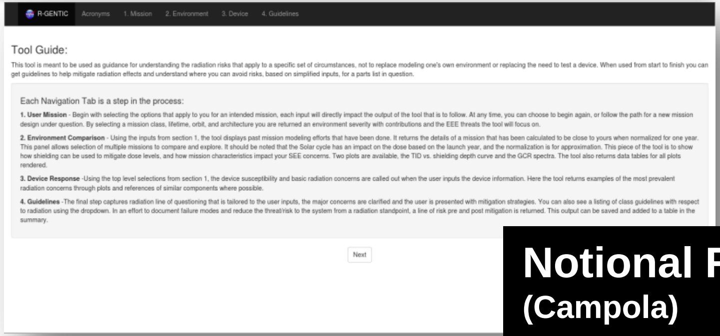
https://creme.isde.vanderbilt.edu



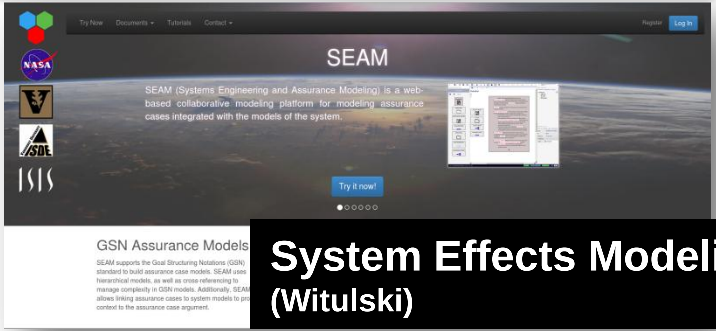
Environments & SEE Rates
(Sierawski)

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



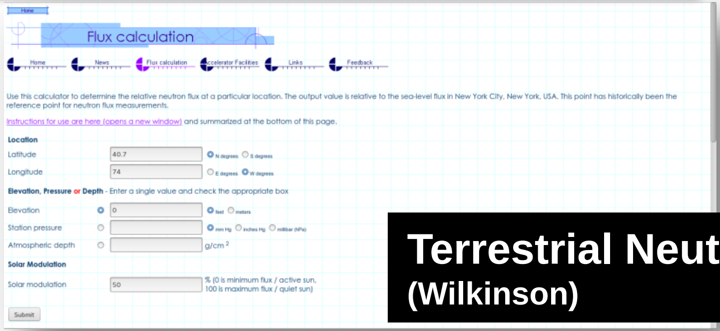
Notional RHA
(Campola)

https://modelbasedassurance.org/



System Effects Modeling
(Witulski)

http://seutest.com



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

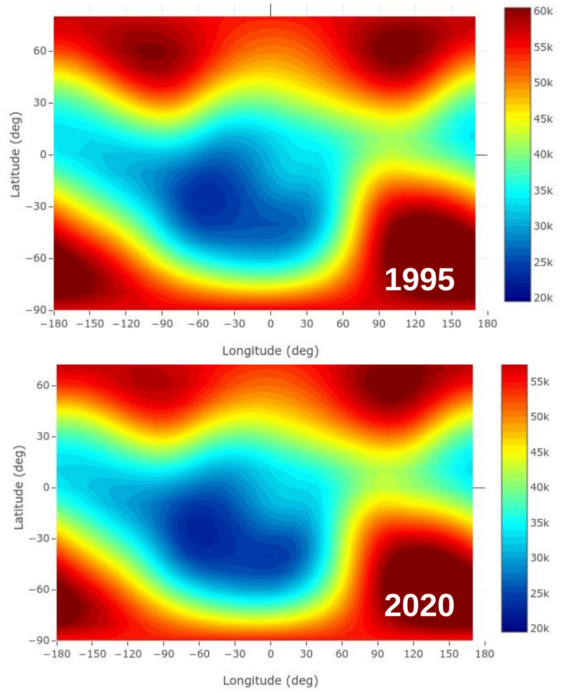
Tool Development

- **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.

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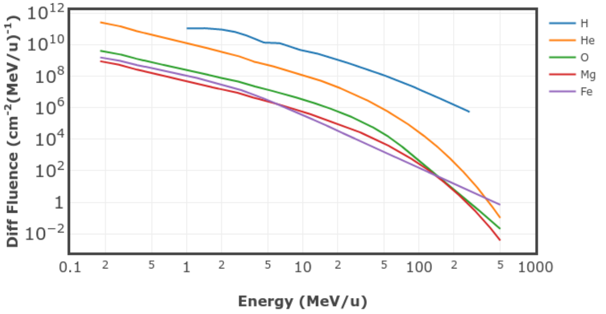
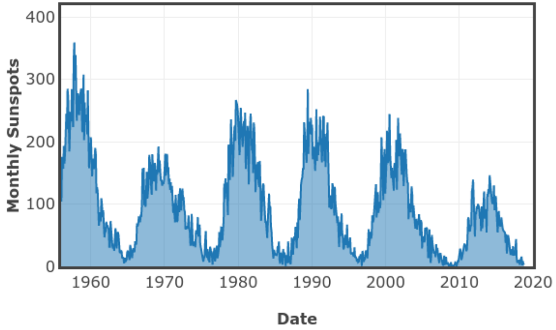
Solar Energetic Particles

- **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

Differential Fluence (90% CL, 2 yrs)



SILSO Sunspot Numbers

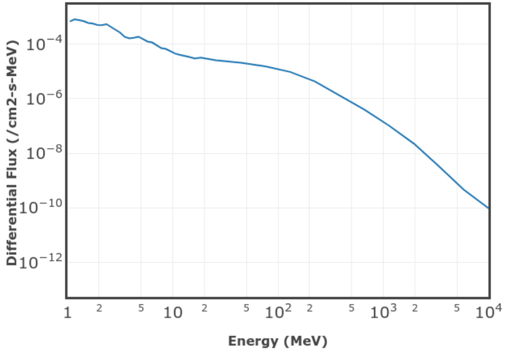


[2] M. A. Xapsos et al., "Model for cumulative solar heavy ion energy and linear energy transfer spectra," in *IEEE Trans. Nucl. Sci.*, vol. 54, no. 6, pp. 1985-1989, Dec 2007.
[3] WDC-SILSO, Royal Observatory of Belgium, Brussels

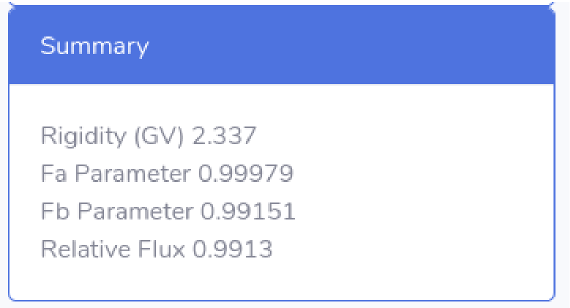
Terrestrial Neutrons

- **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



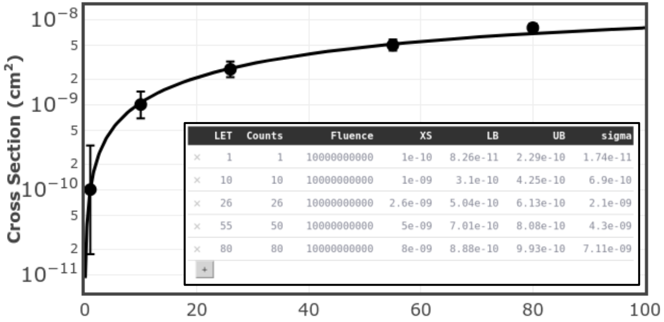
[4] Measurement and Reporting of Alpha Particles and Terrestrial Cosmic Ray-Induced Soft Errors in Semiconductor Devices

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**

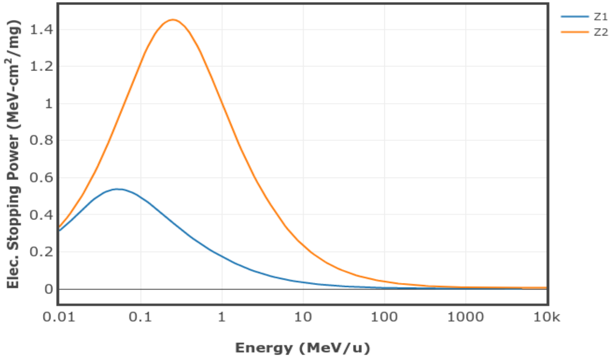
[5] R. Ladbury and M. J. Campola, "Statistical Modeling for Radiation Hardness Assurance: Toward Bigger Data," in *IEEE Trans. Nucl. Sci.*, vol. 62, no. 5, pp. 2141-2154, Oct. 2015.

Heavy Ion Cross Section Curve Fitting



	LET	Counts	Fluence	XS	LB	UB	sigma
×	1	1	10000000000	1e-10	8.26e-11	2.29e-10	1.74e-11
×	10	10	10000000000	1e-09	3.1e-10	4.25e-10	6.9e-10
×	26	26	10000000000	2.6e-09	5.04e-10	6.13e-10	2.1e-09
×	55	50	10000000000	5e-09	7.01e-10	8.08e-10	4.3e-09
×	80	80	10000000000	8e-09	8.88e-10	9.93e-10	7.11e-09

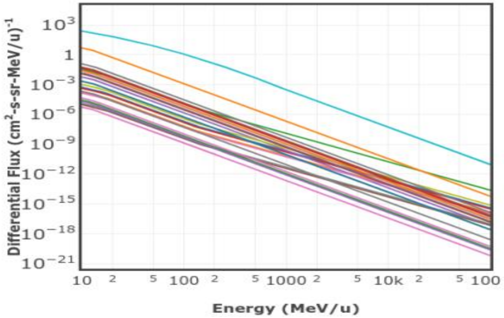
Stopping Power Curves



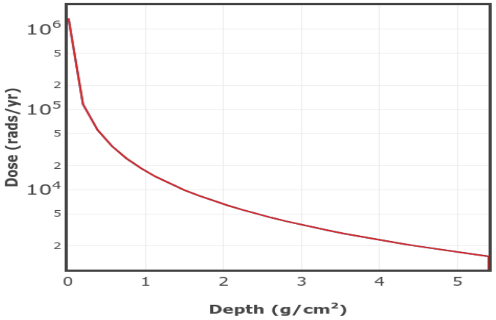
Dose Depth Curves

- **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

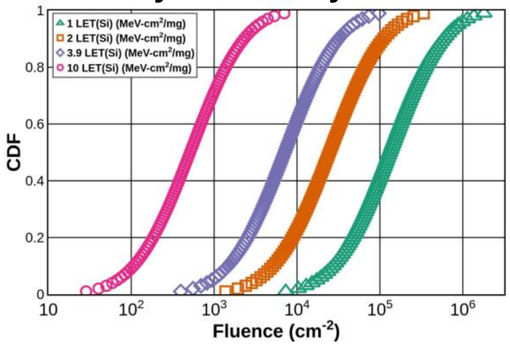


[6] S. M. Seltzer, "Updated calculations for routine space-shielding radiation dose estimates: SHIELDOSE-2," *NIST Publication NISTIR 5477*, Gaithersburg, MD., December 1994.

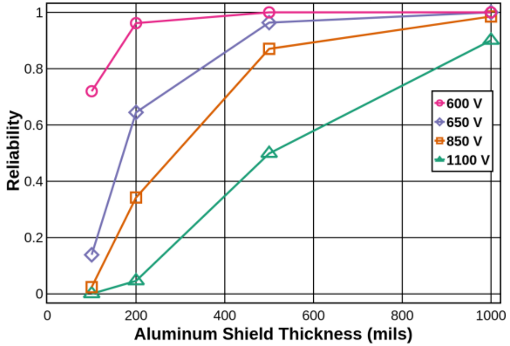
SEE Reliability

- **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

- **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)**