

# **Expansion of Radiation Hardness Assurance Tool Suite**

**NASA NEPP Electronics Technology Workshop, June 2022**

**Brian Sierawski  
Vanderbilt University**

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# Expansion of RHA Tool Suite FY22



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## Objective

This effort proposes to evaluate assessments of single event functional interrupts and expand online capabilities through integrating environment and effects models developed post-CREME96 for radiation hardness assurance.

PI: Brian Sierawski  
Vanderbilt University

## Approach

- Investigate application of SEE rate prediction methods for functional interrupts in complex devices
- Expand upon existing on-orbit prediction tools through implementation of probabilistic radiation environments and effects, inclusion of displacement damage, ...
- Provide on-line guidance to designers for electronics part selection and SEE rate prediction
- Improve user access to tools and pursue interoperability with model-based, system level modeling approaches.

## Milestones

- Defined online platform for releasing additional RHA tools
- Implemented effective flux model for complex device SEE rate predictions
- Implemented ESP/PSYCHIC models for solar environment
- Proposed a probabilistic method for TID dose failure for multiple components, ETW 2021

## Tech Transfer

- "Evaluating SEE Rate Prediction Methods for Complex Devices," ETW 2021
- "Extending A Probabilistic Method for Total Ionizing Dose Failure to Multi-Component Systems," ETW, 2021.
- "Evaluating SEE Rate Prediction Methods for Complex Devices," SEE/MAPLD 2021.

# The Radiation Effects Engineer's Toolbox



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**SPENVIS** Space Environment Information System

Welcome to SPENVIS

SPENVIS is ESA's Space Environment Information System, a WWW interface to models of the space environment and its effects; including cosmic rays, natural radiation belts, solar energetic particles, plasmas, gases, and "micro-particles".

Current version: The current version of SPENVIS (4.6.1.0) was released on May 4, 2018.

System requirements: SPENVIS requires a browser with Javascript support (tested with Firefox 73 and MS-IE 11). Some outputs require a VBMLX32 plugin (tested with Octagra Viewer 2.3.1.3).

The SPENVIS system is developed by a consortium led by the Royal Belgian Institute for Space Aeronomy (BIRA-IASB) for ESA's Space Environments and Effects Section through its General Support Technology Programme (GSTP). The system is maintained by the development team at BIRA-IASB.

Current development team: Erwin De Donder (project manager), Neophytos Messias, Sigh Caldera, Antoine Calogero & Sami Mezhdour.

ESA Technical Officer: S. Clucas (ESA/ESTEC/TEC-EPS)

Welcome to the CREME site

It has been almost a decade since the introduction of CREME, the current state-of-the-art tool for SEE calculations. CREME uses phenomenological models to predict SEE rates. These models were based on test data. It is now assumed that the description left to the particles was much narrower than the previous feature set in the measurements. CREME is now based on the Monte Carlo simulation of the particle transport and interaction with matter. This approach is more general and can be used for a wider range of applications. The new version of CREME is now available for download. The new version of CREME is now available for download. The new version of CREME is now available for download.

What's New?
 

- added the model for the particle size distribution
- improved the model for the particle size distribution
- improved the model for the particle size distribution

Ion Stopping and Range Tables

Ion: H Hydrogen, Number: 1, 1.000, 10, 10000

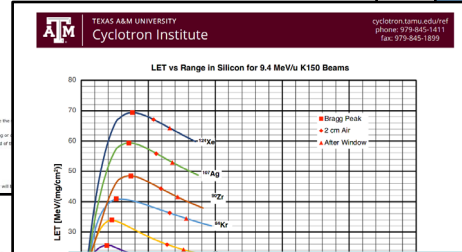
Target: Target

Calculate Table

Clear All

Main Menu

Help



IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 64, NO. 1, JANUARY 2017

## Inclusion of Radiation Environment Variability Total Dose Hardness Assurance Methodology

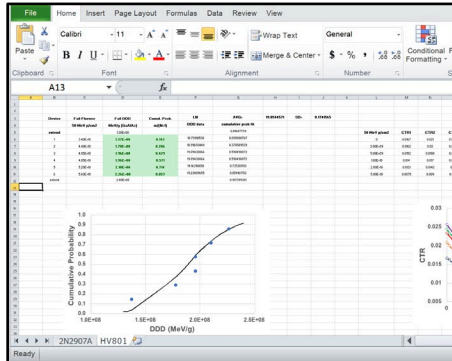
M.A. Xapous, Senior Member, IEEE, C. Stauffer, A. Phan, S.S. McClure, Member, IEEE, R.L. Ladbury, Member, IEEE, J.A. Pellish, Member, IEEE, M.J. Campola, Member, IEEE, and K.A. LaBel, Member, IEEE

**Abstract**—Variability of the space radiation environment is investigated with regard to categorization for total dose hardness assurance methods. It is shown that it can have a significant impact. A modified approach is developed that uses current environment models more consistently and replaces the radiation design margin concept with one of failure probability during a mission.

**Index Terms**—Displacement damage dose, radiation design margin, radiation hardness assurance, total ionizing dose.

**I. INTRODUCTION**

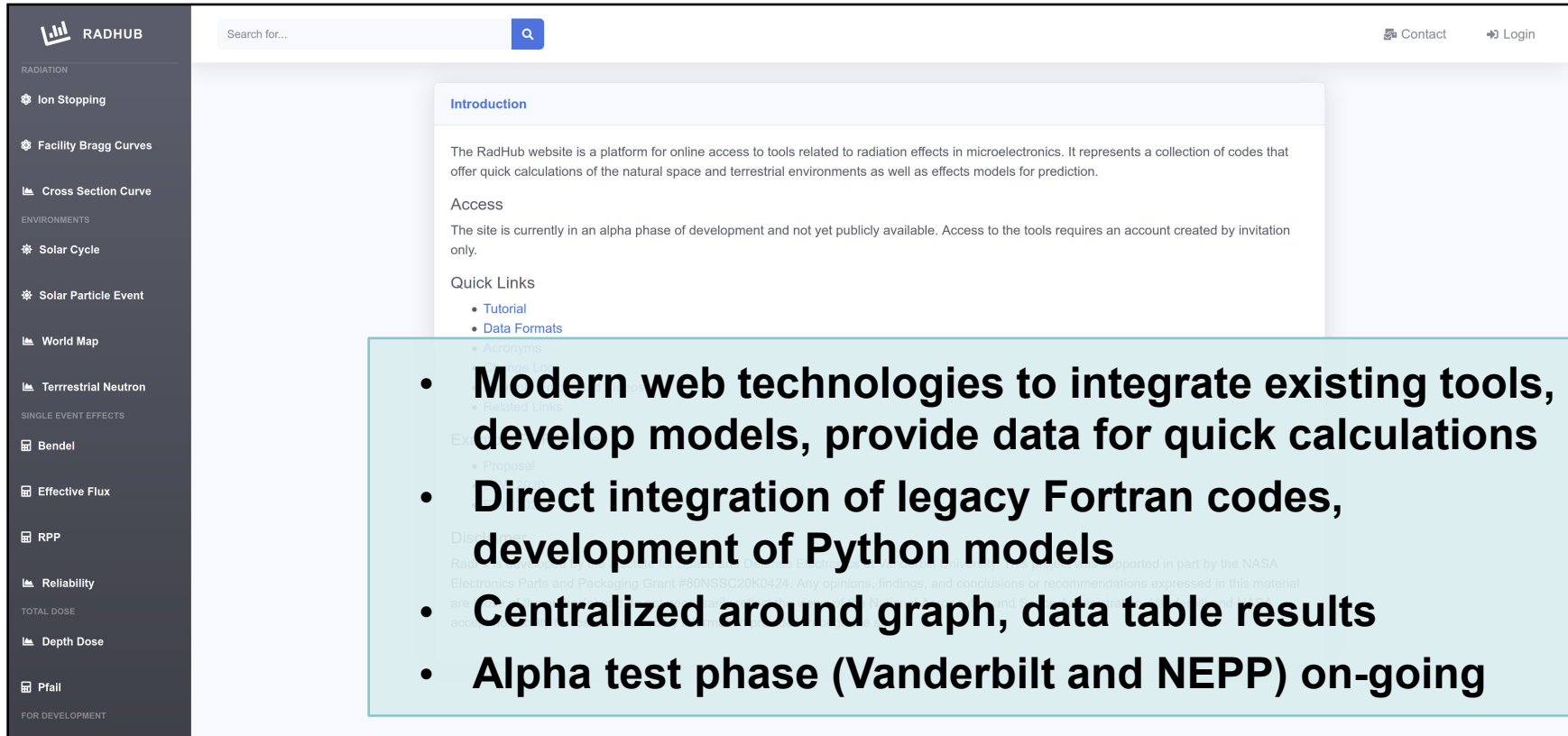
HARDNESS assurance (HA) methodology should ensure that electronic piece parts in a space system perform to design specifications after exposure to the space environment. Detailed descriptions of radiation HA methodology have been shown in the "2017 IEEE Nuclear Science & Radiation mission design. The reason behind this is largely technical. It results from the deterministic nature of the long-time standard Aerospace Proton Model-8/Aerospace Electron Model-8 (AP8/AE8) trapped particle models that are used to evaluate the total dose environment within the Earth's magnetosphere [4], [5]. In contrast, the new AP9/AE9 models are probabilistic in nature. They allow full Monte Carlo calculations for evaluating the dynamics of the trapped particle environment [6]. This is consistent with widely used solar proton models, which take the probabilistic approach [7]–[9]. Making use of probabilistic models for both trapped particles and solar protons allows the complete probability distribution of total dose values for any orbit to be evaluated for the first time. This provides additional useful information to designers because the environment variability is fully quantified. The new information can be inserted into the flow of the radiation



- Accelerated test planning
- Data analysis
- Environment characterization
- Shielding evaluation
- SEE predictions, TID analysis
- Reliability assessment

- **Goal – companion platform to complement CRÈME and serve as host for rapid dissemination of analytical models in a common, accessible, and referenced location**
  - Open-access, maintain path for licensing / distribution, closed programs
  - Split from CRÈME, enable bleeding edge tools
  - Home for published analyses to disseminate to community
  - Improved links between test planning, data collection, and effects prediction
- **CRÈME Status**
  - Supports over 3000 users, still adding 37 users / month
  - Considered stable, legacy codes
  - cursory treatment of proton dose, ignores electron contribution
  - CREME96 was never designed to include electron environments
  - Heavy ion analysis limited to RPP-based models for SEU
  - Storage bloat – 50GB+ user data
  - Performance, extendibility, maintainability issues hinder expansion

http://



The screenshot shows the RADHUB website interface. On the left is a dark sidebar with a 'RADHUB' logo and a navigation menu. The main content area has a search bar at the top and a central text block. The sidebar menu includes categories like RADIATION, ENVIRONMENTS, SINGLE EVENT EFFECTS, TOTAL DOSE, and FOR DEVELOPMENT, with specific items like Ion Stopping, Facility Bragg Curves, Cross Section Curve, Solar Cycle, Solar Particle Event, World Map, Terrestrial Neutron, Bondel, Effective Flux, RPP, Reliability, Depth Dose, and Pfall. The main content area features a search bar, 'Contact' and 'Login' links, and an 'Introduction' section. The introduction text states: 'The RadHub website is a platform for online access to tools related to radiation effects in microelectronics. It represents a collection of codes that offer quick calculations of the natural space and terrestrial environments as well as effects models for prediction.' Below this is an 'Access' section stating the site is in an alpha phase and requires an invitation. A 'Quick Links' section lists 'Tutorial' and 'Data Formats'. A large light blue box is overlaid on the bottom right of the screenshot, containing a bulleted list of key features and status.

- Modern web technologies to integrate existing tools, develop models, provide data for quick calculations
- Direct integration of legacy Fortran codes, development of Python models
- Centralized around graph, data table results
- Alpha test phase (Vanderbilt and NEPP) on-going

# RADHUB Developments



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Popular Python web framework

Compatibility with CRÈME and SPENVIS environments

Model selections

Database driven markdown content, searching

Responsive graphs

Parameter checking

Authentication

Calculated values

Options to import and export

Editable datatables

The screenshot displays the RADHUB web application interface. On the left is a dark sidebar with navigation options: RADFX, RADIATION, Ion Stopping, Solar Cycle, Solar, Work, Ter, SINGLE E, Ben, Effective Flux, TOTAL DOSE, Depth Dose, Pfail, and FOR DEVELOPMENT. The main content area features a search bar at the top, a 'Cross Section' graph, a 'Settings' panel, a 'Fit Parameters' table, and a 'Cross Section Data' table.

**Cross Section Graph:** A log-log plot of Cross Section (cm<sup>2</sup>) vs LET (MeV-cm<sup>2</sup>/mg). The y-axis ranges from 10<sup>-11</sup> to 10<sup>-8</sup>, and the x-axis ranges from 0 to 100. Data points are shown as black dots with error bars, and a blue Weibull fit curve is overlaid.

**Fit Parameters Table:**

Parameter	Value	Unit
A	2.8e-8	cm <sup>2</sup>
x0	0.0020	MeV-cm <sup>2</sup> /mg
W	2.4e+2	MeV-cm <sup>2</sup> /mg
s	1.0	

**Cross Section Data Table:**

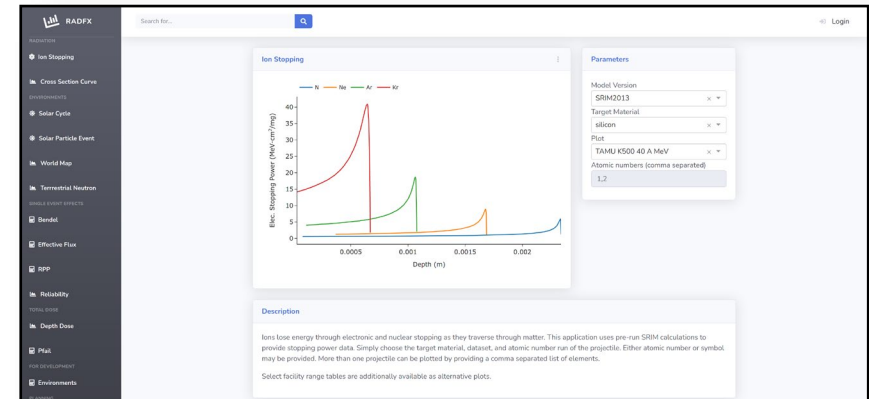
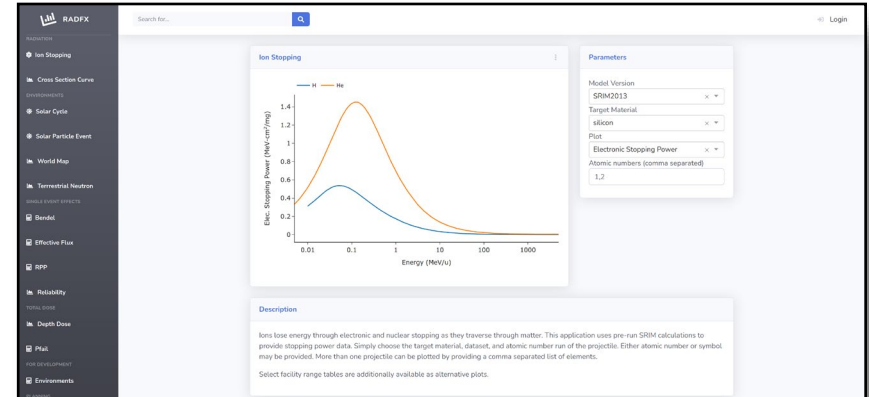
	LET	Counts	Fluence	XS	
×	1	1	10000000000	1e-10	1e-10
×	10	10	10000000000	1e-09	3.16e-10
×	26	26	10000000000	2.6e-09	5.1e-10
×	55	50	10000000000	5e-09	7.07e-10

# RADHUB for Accelerated Test Planning

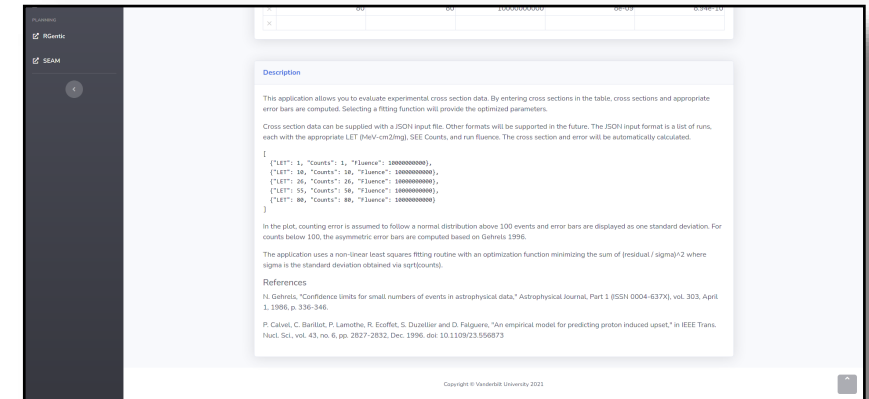
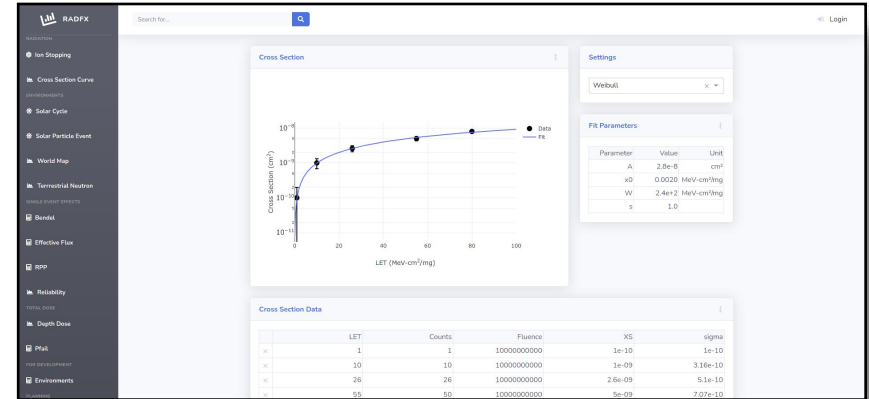


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- **Proton and ion stopping**
  - Used to investigate LET, range
  - Stopping power and range for ions in silicon and aluminum targets
  - Based on SRIM data (currently)
- **Facility Bragg curves**
  - Used to select ions with sufficient range, appropriate LET
  - Elec. stopping power vs depth (Si)
  - LBNL 88", TAMU K150 & K500
- **Responsive graphs adjust to user selections and parameters, easily export json, csv, xlsx, pdf**

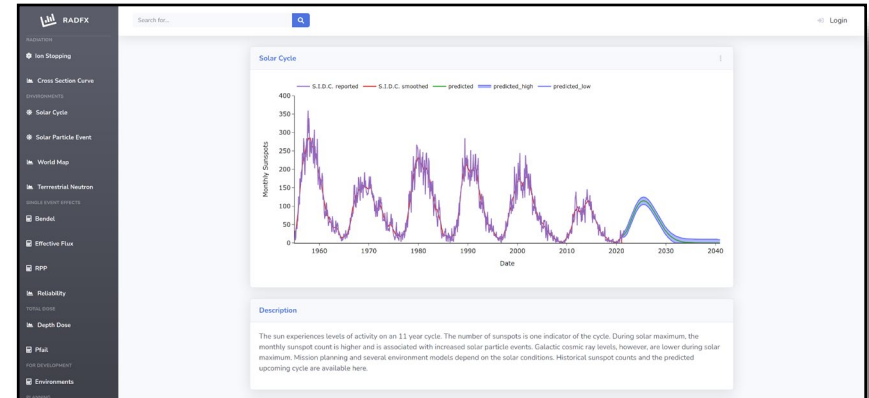


- **Cross section data fitting**
  - Provides consistent parameter fits
  - Performs MLE fits to Weibull, Bendel cross sections, suggests parameters
  - Accounts for statistical error in data
  - Calculates Petersen figure of merit
- **Editable data table allows entry of event data, calculates error bars**
  - $1\sigma$ , 90% CI, asymmetric low counts
- **Data and graphs export for reports and journals (eg. *IEEE TNS*)**





- **Solar cycles and sunspots**
  - Used for mission planning, parameterizing particle environment models
  - Historical and predicted sunspot counts from SIDC
  - Reporting changed in 2015, providing adjusted Wolf numbers based on input from Royal Observatory
- **Solar protons and heavy ions**
  - Used for worst case CI calculations
  - Implemented ESP/PSYCHIC, integrated SOLPRO

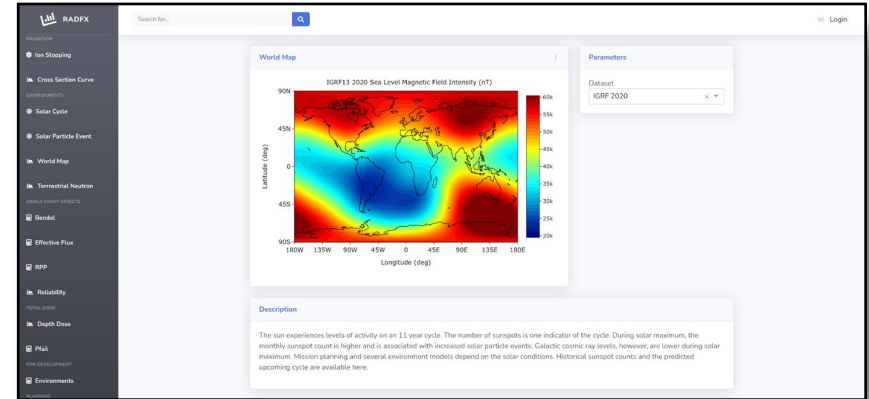


# RADHUB for Terrestrial Environments



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- **IGRF13 world magnetic intensity maps – 1995-2030**
  - Used to explore impact of mission profile on near-Earth environment
- **Terrestrial neutron spectrum**
  - Used to scale neutron flux with lat. long. and altitude
  - Based on JESD89B and seutest.com



# RADHUB for On-Orbit SEE Predictions



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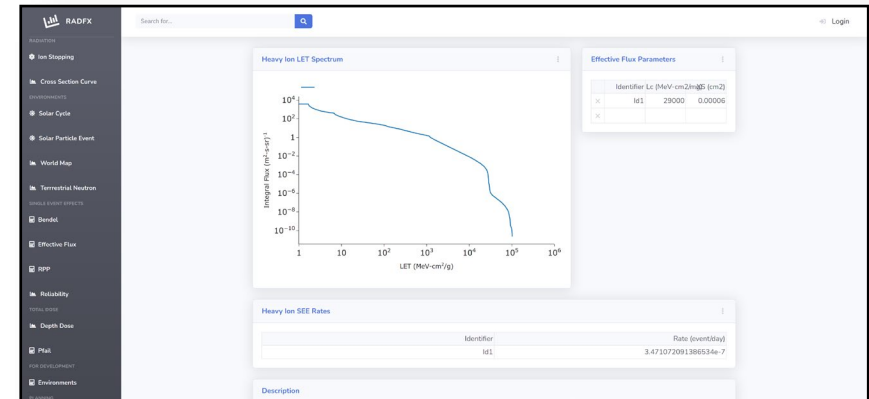
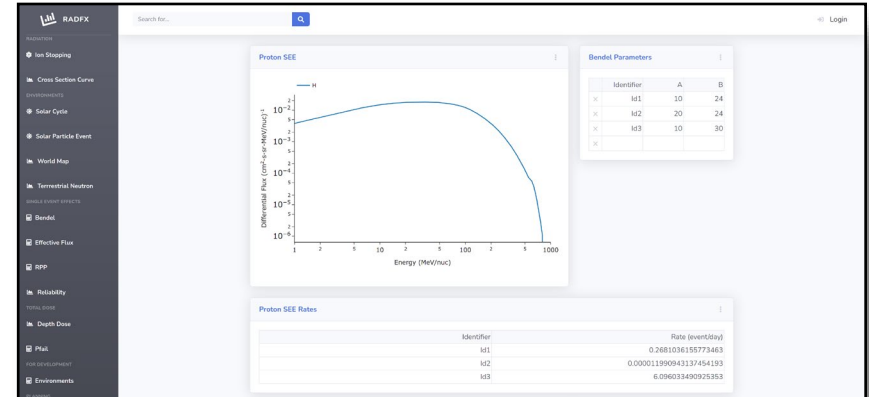
- **Bendel model**

- Used for proton SEE rates
- Imports proton spectra in CRÈME, SPENVIS formats
- Accepts parameters for multiple parts
- Rate predictions export to json, csv, xlsx

- **RPP and effective flux models**

- Used for heavy ion SEE rates
- Imports LET spectrum in CRÈME, SPENVIS formats

- **Reliability calculations for single bit, multiple bit errors**



# RADHUB for On-Orbit TID Predictions



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- **Depth dose**
  - Used as first pass evaluation of shielding effectiveness
  - Evaluates proton, electron, brem dose rates
  - Implemented with SHIELDOSE-2
- **TID failure probability**
  - Used to evaluate part-to-part and environment variability
  - Implemented Xapsos TNS 2017
  - Built in environment definitions
  - Research into probabilistic analyses on-going



# RADHUB Modules Currently Developed



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- **Ion stopping based on SRIM – stopping power and range for ions in silicon and aluminum**
- **Range plots – LBNL 88”, TAMU K150 & K500**
- **Weibull fitting to heavy ion cross sections**
- **Solar cycle data – historical and predicted from on S.I.D.C**
- **ESP, PSYCHIC, SOLPRO – solar protons and heavy ions**
- **IGRF13 world magnetic intensity maps – 1995-2030**
- **Terrestrial neutron spectrum – JESD89B**
- **CREME96 and SPENVIS environment parsers**
- **Bendel predictions for on-orbit proton SEE rates**
- **RPP predictions for on-orbit heavy-ion SEE rates**
- **Peterson Figure of Merit for on-orbit heavy-ion SEE rates**
- **Effective flux predictions for on-orbit heavy-ion SEE rates**
- **Reliability calculations for single bit, multiple bit errors**
- **Depth dose based on SHIELDOSE2**
- **TID failure probability for part and environment variability – Xapsos**

# Summary



http://

**• RADHUB is undergoing alpha test and additional module development, plan to expand user base in 2023**

**• Looking to collaborate with accelerator facilities, bootcamps, and workforce development programs**

**• Feature requests are welcome, contact [brian.sierawski@vanderbilt.edu](mailto:brian.sierawski@vanderbilt.edu)**

# Acknowledgments

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*Vanderbilt Engineering*

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- **Thomas Wu**
- **Alexander Fullerton**
- **Kensington Huber**
- **Jack Evans**