Overview: Physically-Based Simulation of Single-Event Effects

Robert A. Weller
Institute for Space & Defense Electronics
Vanderbilt University

R. A. Reed
J. A. Pellish
L. W. Massengill
A. L. Sternberg
M. A. Xapsos, GSFC
M. H. Mendenhall
K. M. Warren
B. D. Sierawski
R. D. Schrimpf
A. F. Witulski
D. R. Ball
C. L. Howe
M. Alles
A. D. Tipton
K. A. LaBel, GSFC

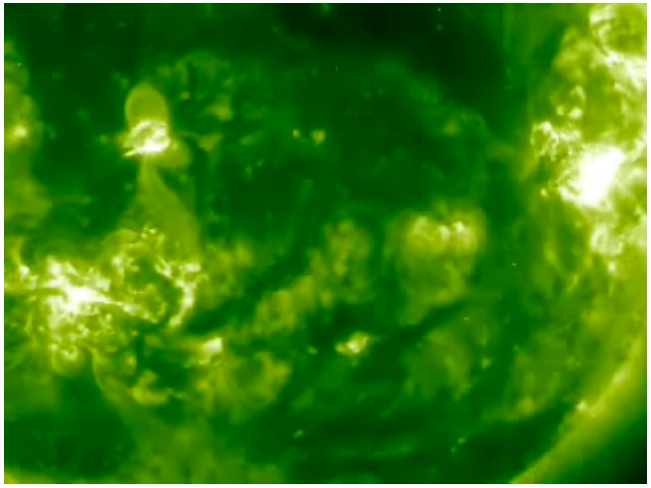
Sponsoring Agencies: NASA, DTRA, AFOSR, AEDC

MURI Review - Vanderbilt - 13-14/Jun/2006

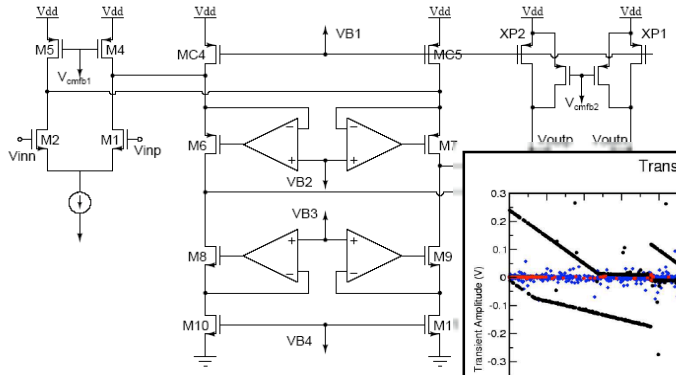
Overview

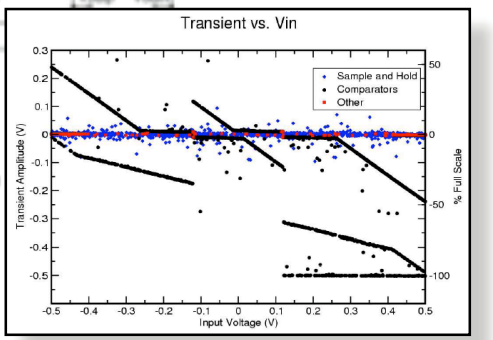
- RADSAFE - What is it?
- MRED - A Geant4 application.
- MRED - An example.
- Applications
  - Displacement damage.
  - Complex environments.
  - Neutrons.
- Summary.

RADSAFE – The Vision

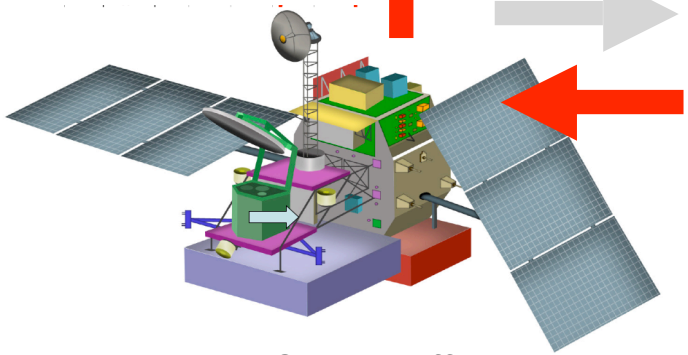


Predictable System Error Rates

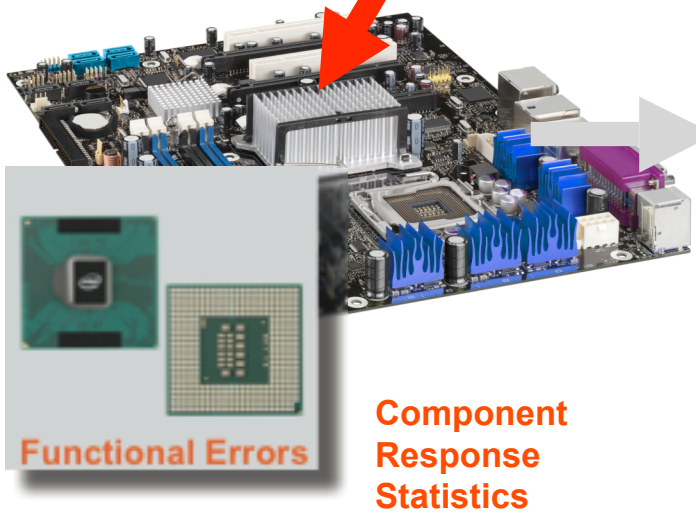




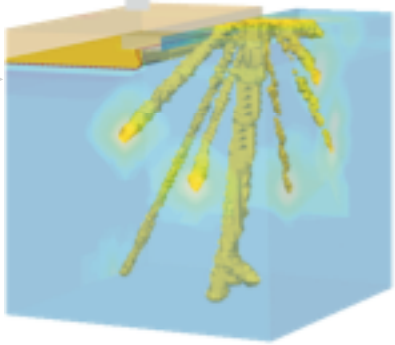
Statistical Circuit Response



Trackable System Effects

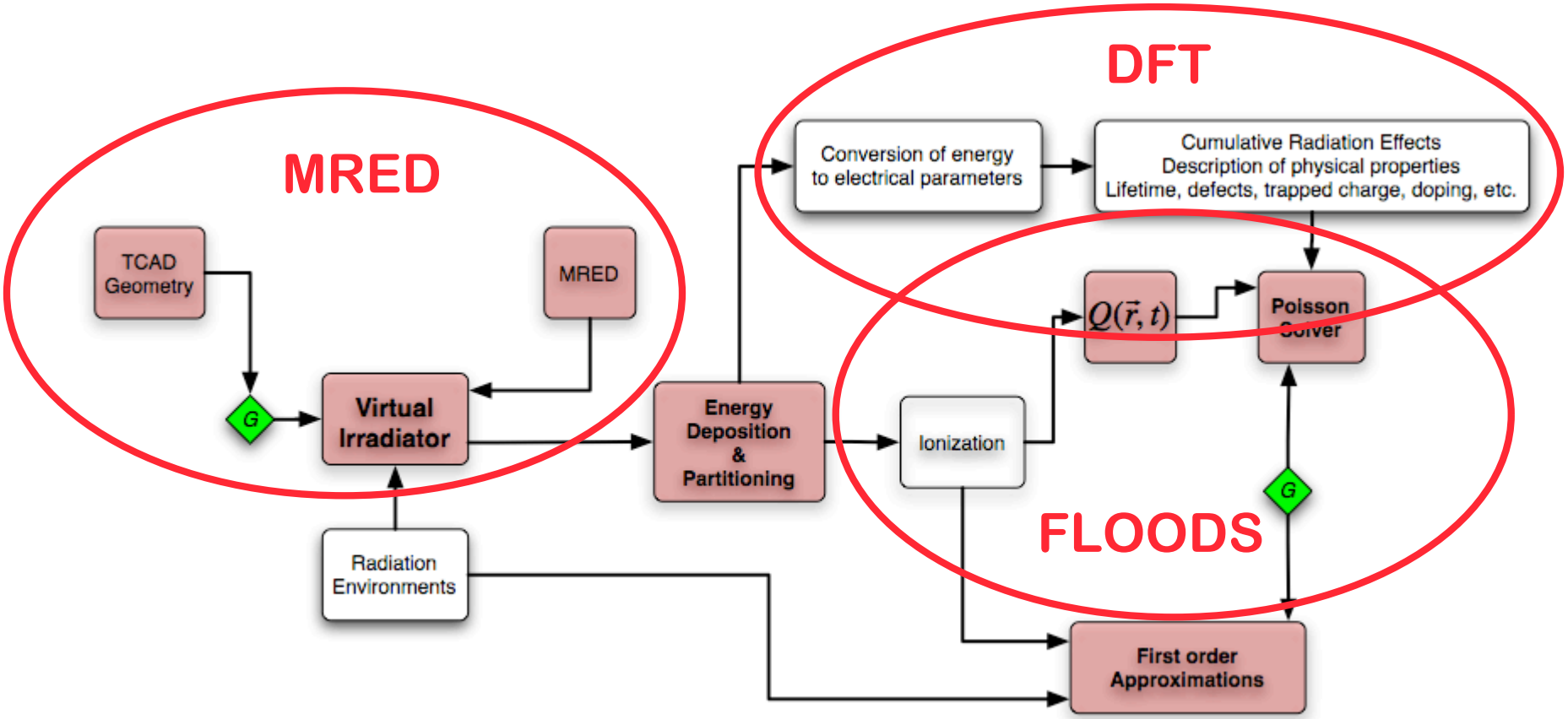


Component Response Statistics



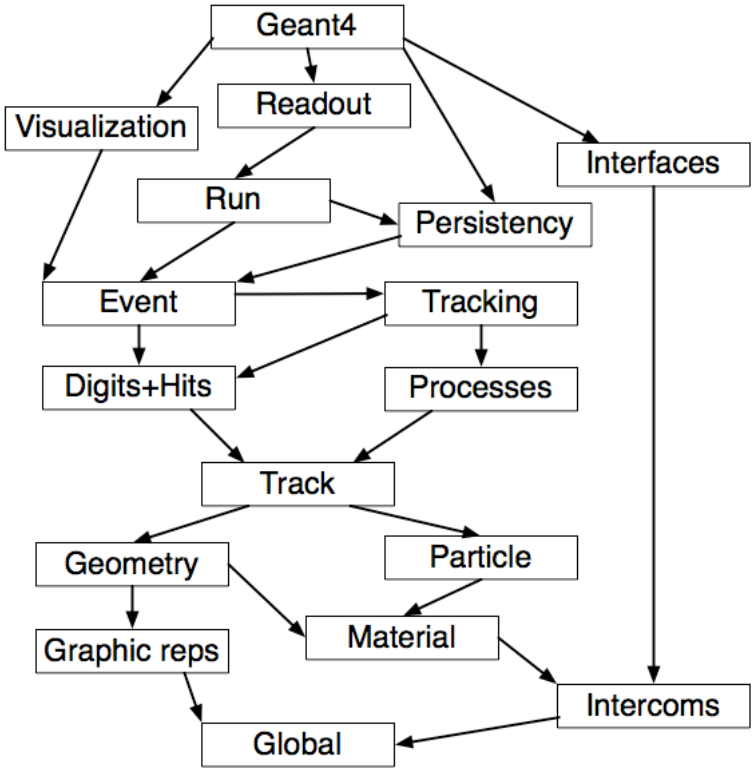
Physics of Radiation Interaction

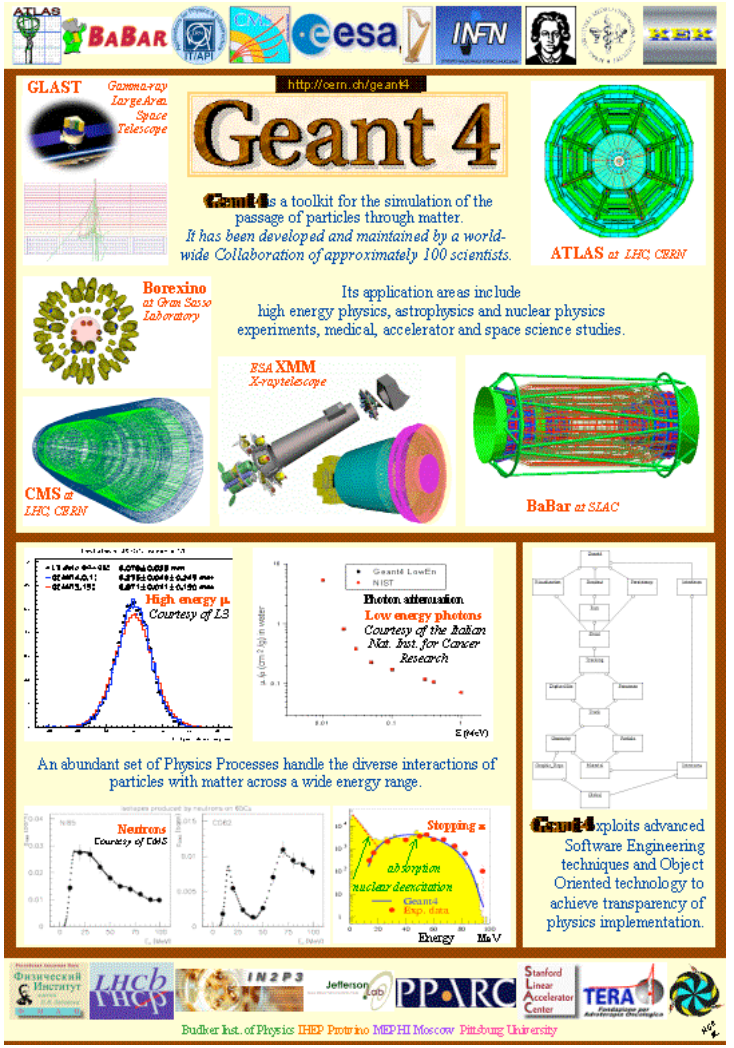
RADSAFE


DFT
MRED
TCAD Geometry
MRED
G
Virtual Irradiator
Radiation Environments
Energy Deposition & Partitioning
Conversion of energy to electrical parameters
Cumulative Radiation Effects
Description of physical properties
Lifetime, defects, trapped charge, doping, etc.
Ionization
$Q(\vec{r},t)$
Poisson Solver
G
FLOODS
First order Approximations

What is Geant4?

- Geant4 is ***NOT*** a computer program!
- Geant4 ***IS*** a collection of c++ class libraries for building Monte Carlo radiation simulation programs.

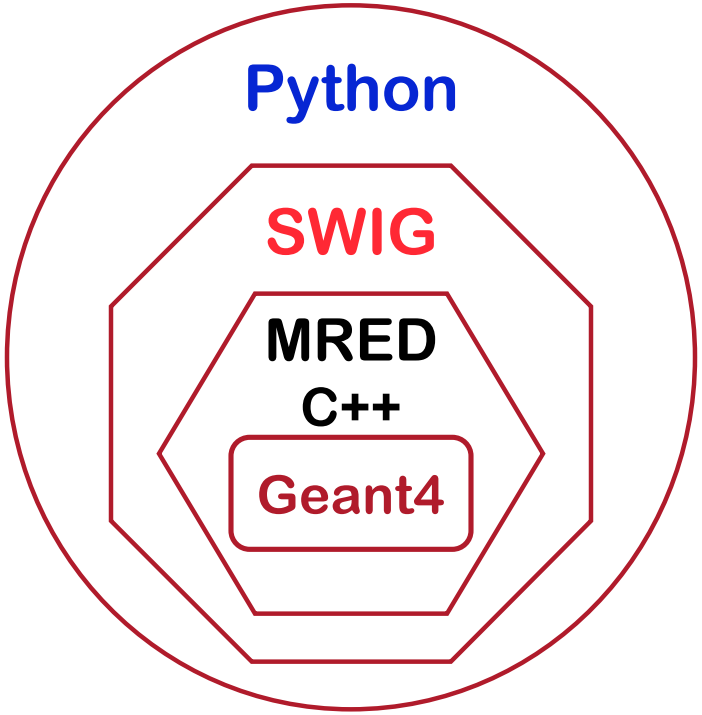




Graphics: Makoto Asai, SLAC

Structure of MRED

- MRED7 is a conventional c++ Geant4 application
- MRED8 is the first generation Python/Geant4 application
- Physics list is custom for space applications
- Target machine is a Linux cluster with ~1k x86 and ppc nodes
- Development is with Xcode under Darwin (Mac OS 10.4)
- Presently using gcc 3.3



MRED8 Physics

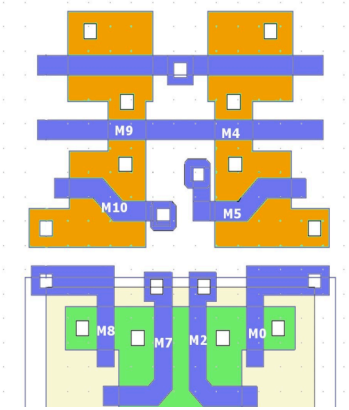
- Coulomb scattering of nuclei and tracking of recoils
- Hadronic cross section biasing with automatic track weighting
- Custom particle gun
  - Derived from G4ParticleGun class
  - Supports random planar and isotropic flux simulation
  - Uses C2Functions class to implement random energy from arbitrary input distributions
  - Random energy selection from the integral distribution -or- uniform or logarithmic selection and track weighting
- Mechanism for run-time selection of custom MRED physics or any Geant4 physics list

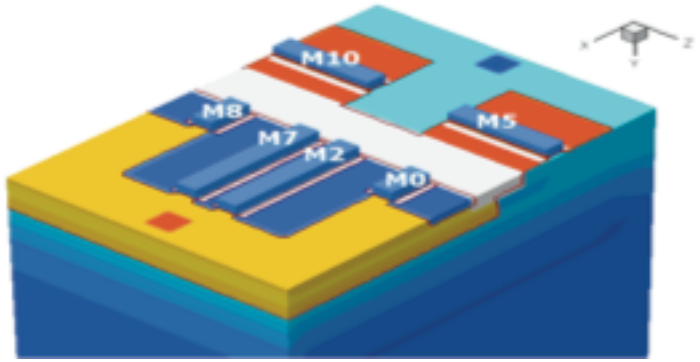
MRED8 Unique Features

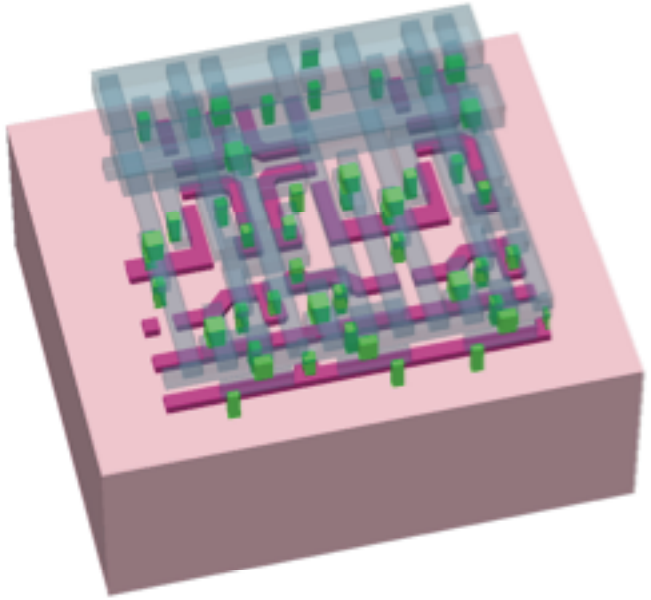
- Python control shell
- TCAD structure file parsing
- General voxel array input mechanism
- Constructive solid tetrahedron Now G4Tet!
- Screened Coulomb scattering and recoil tracking
- Hadronic cross section biasing
- Custom particle gun derived from G4ParticleGun
- Interpolating function or C2Function tool
- Detector class with multiple sensitive volumes
- Custom histogram class with Python and *Mathematica®* analogs
- *Mathematica®* output files with a compatible Python processing tool

RADSAFE simulation of detail SRAM Cell

- TCAD simulation of SRAM cell that includes details of overlayer
  - Tungsten plug locations
  - Metal lines
  - Oxides
- Detailed geometry of device structure and overlayers were obtained from GDSII and technology information provided by vendor

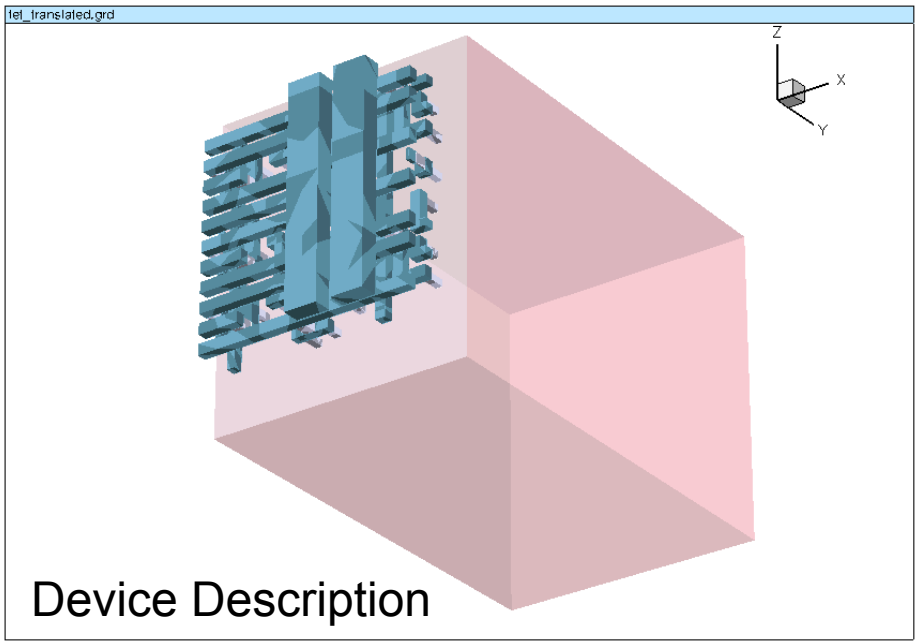


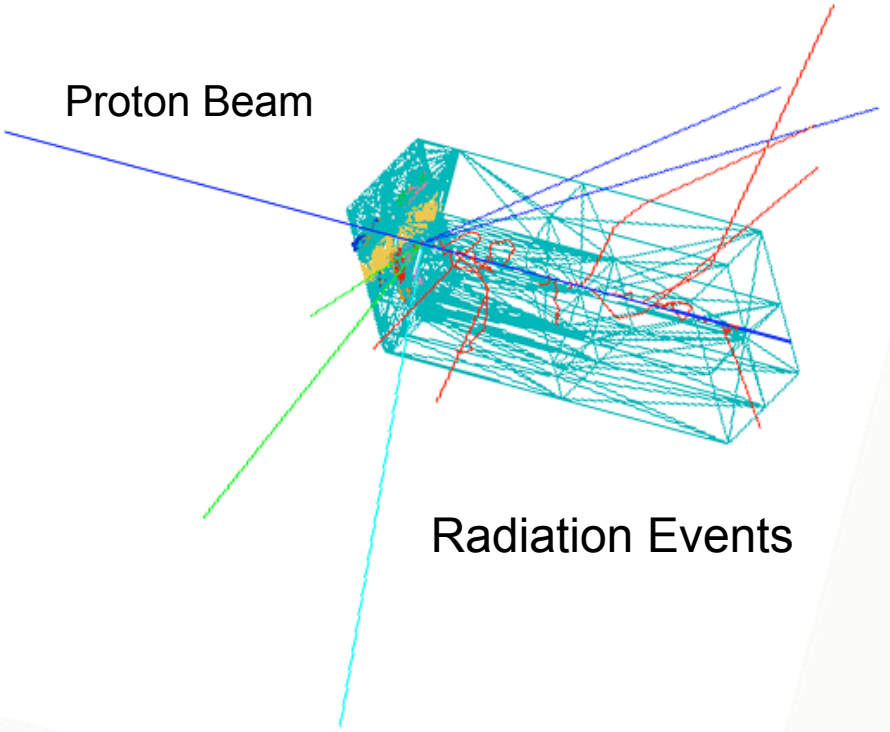




MRED8-TCAD Interface

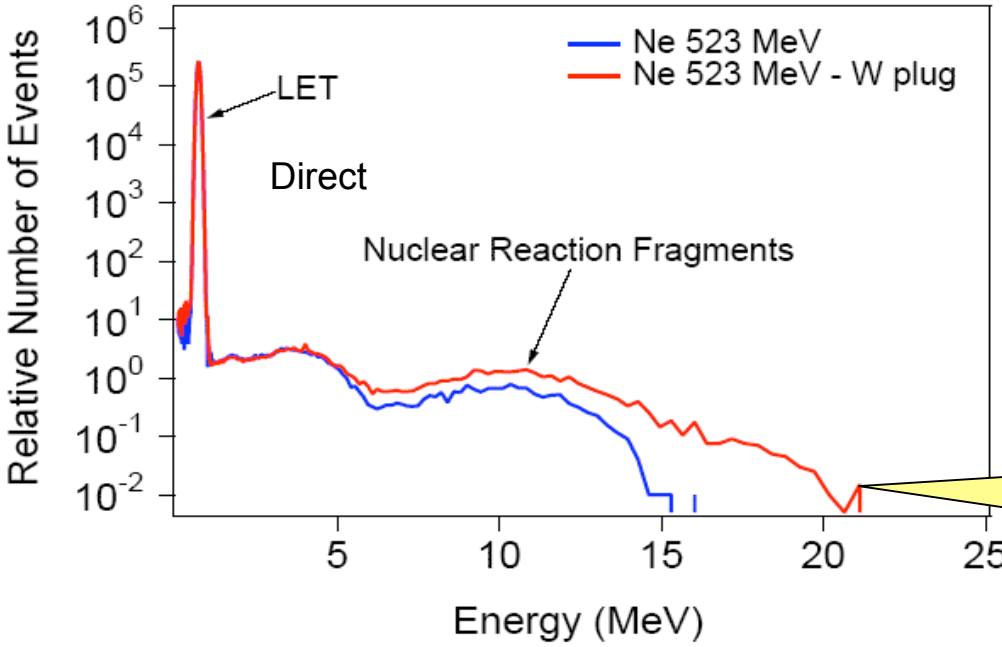
- Protons incident on an advanced CMOS integrated circuit
- Reactions in the metal layers increase energy deposition

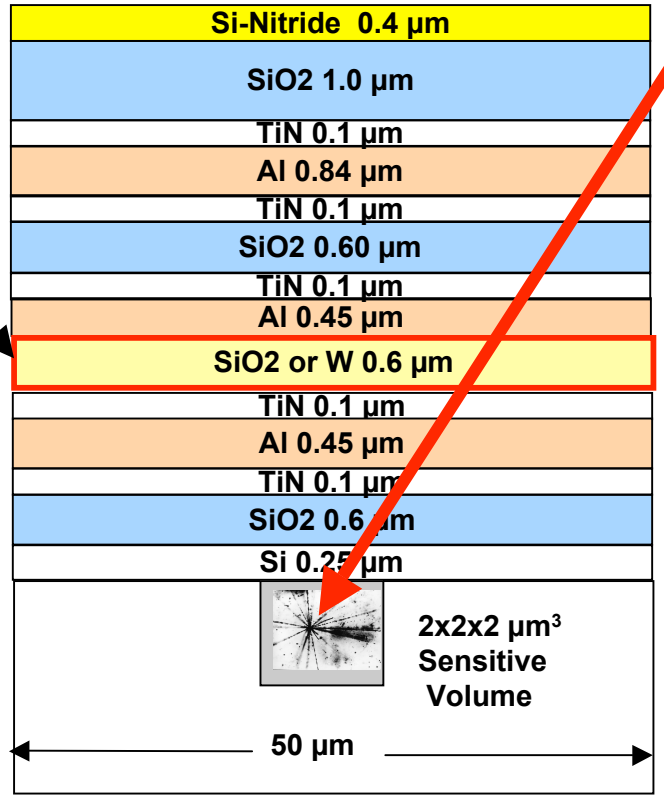




Modeling detailed structures

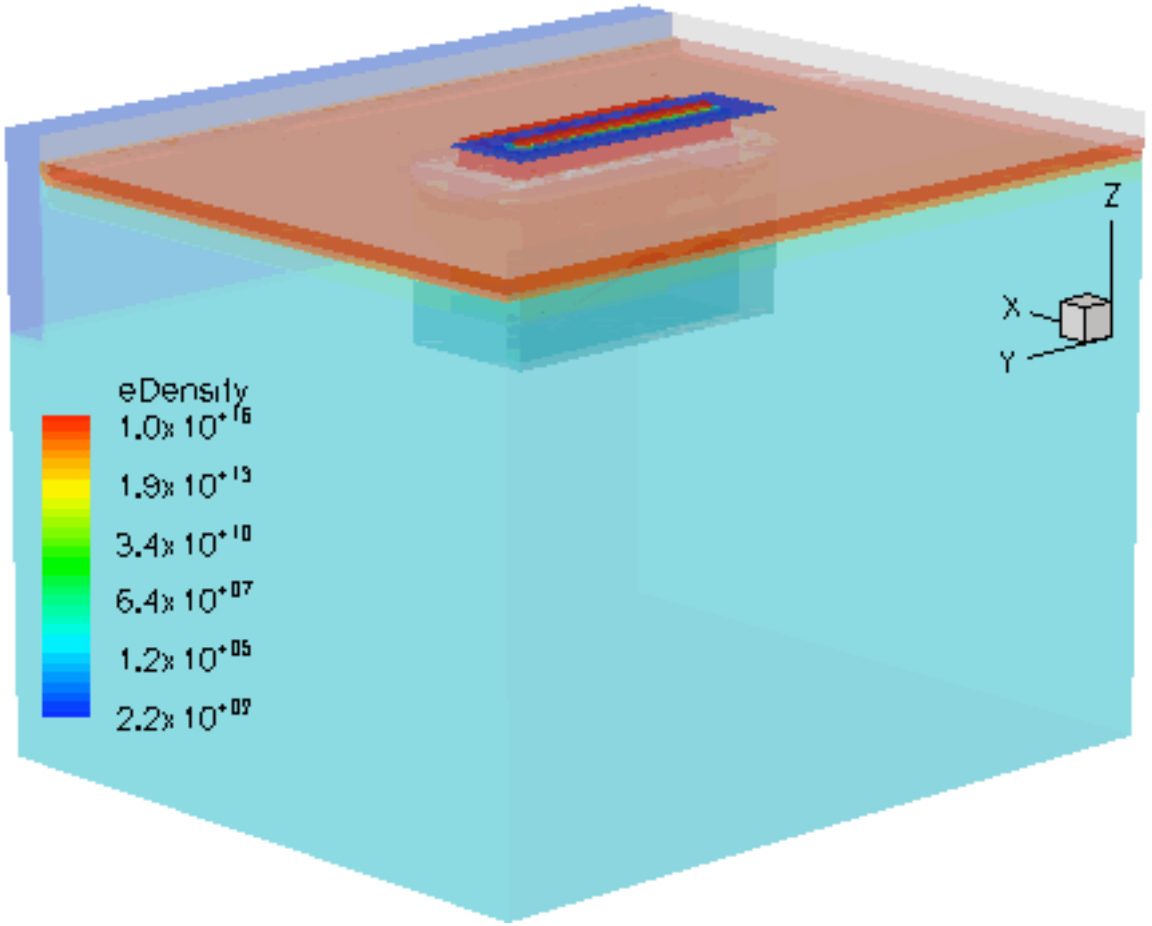
- Example: MRED used to predict SE effects for two structures:
  - Stylized stack to approximate an IC overlayer with and without W
- Direct and Indirect reactions computed
- Energy deposition events included from primary and secondary particles



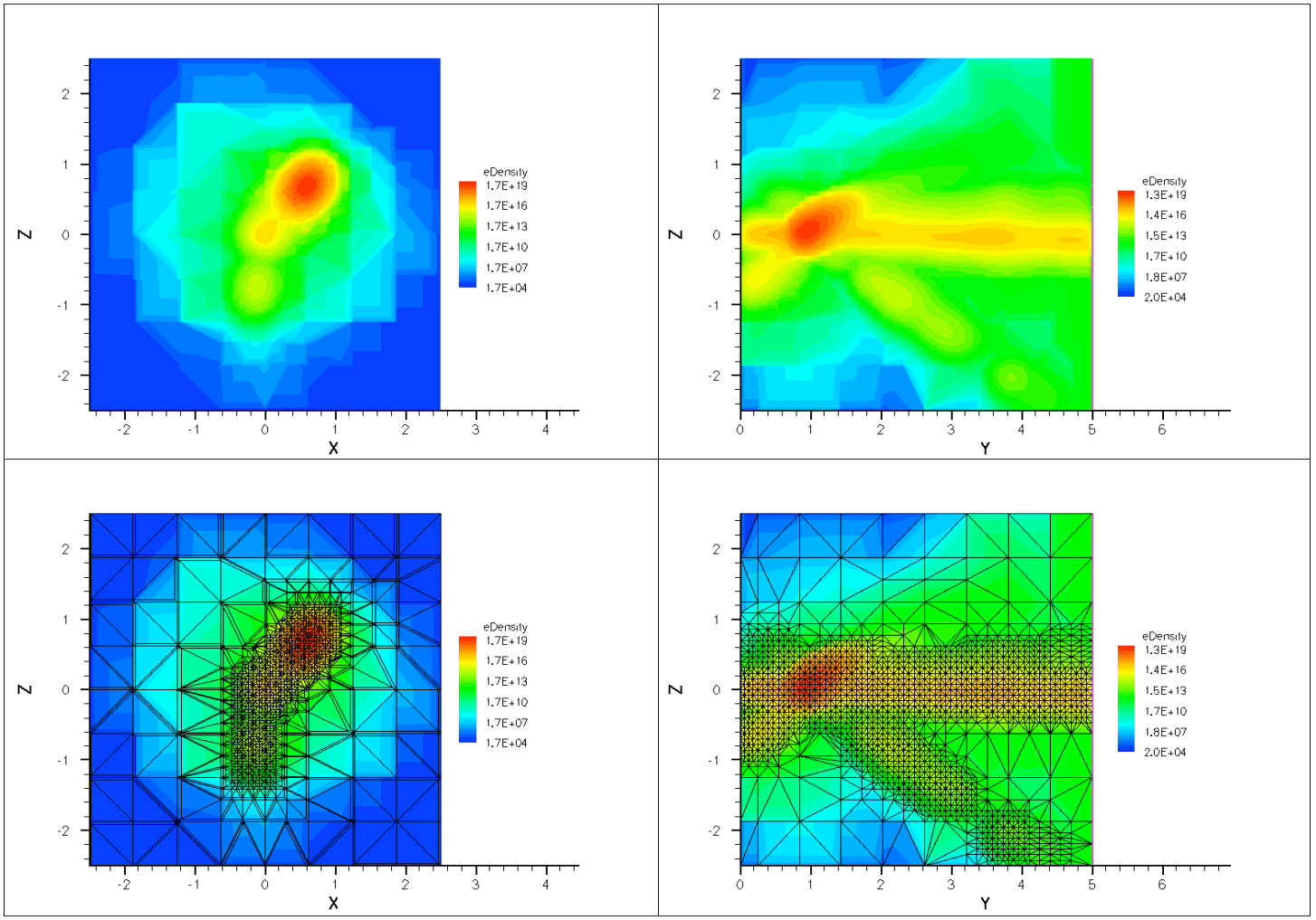


High energy secondary particles created by nuclear reactions with W in the IC overlayer

Structure of an Event



Evolution of an Event in TCAD



Event 267

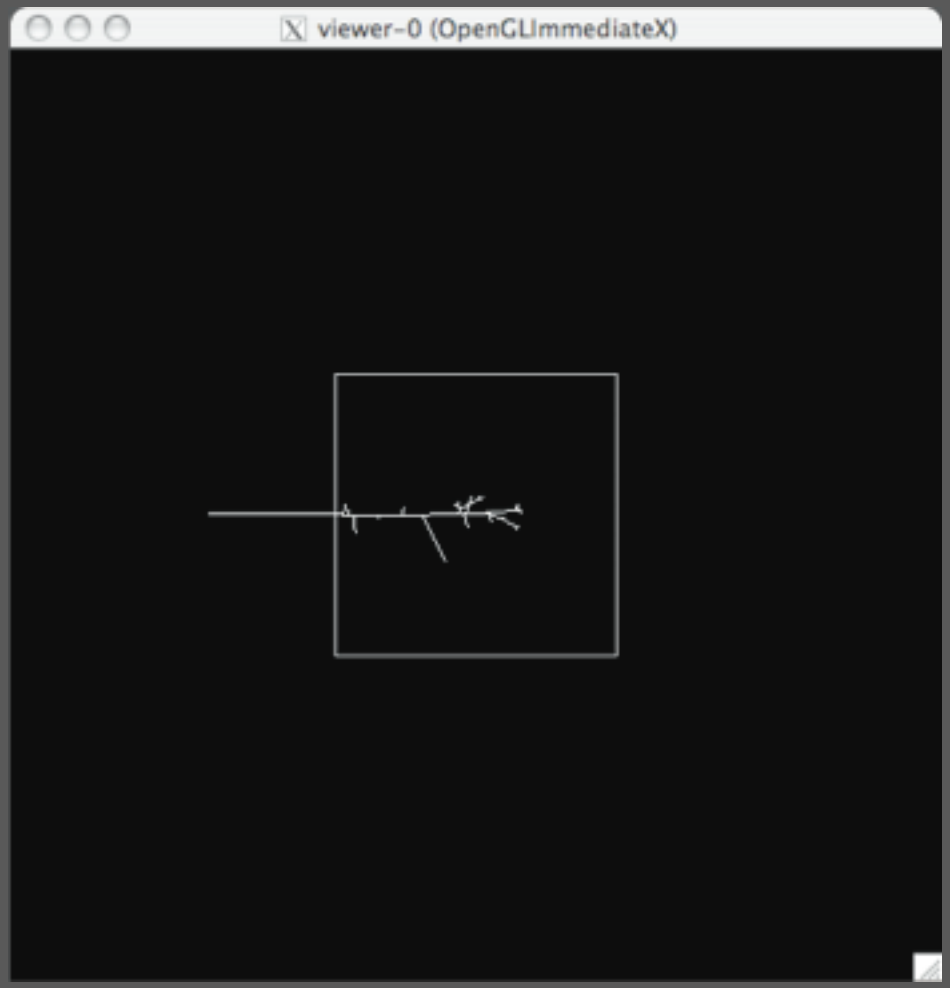
Slice at y = 1.0 μm

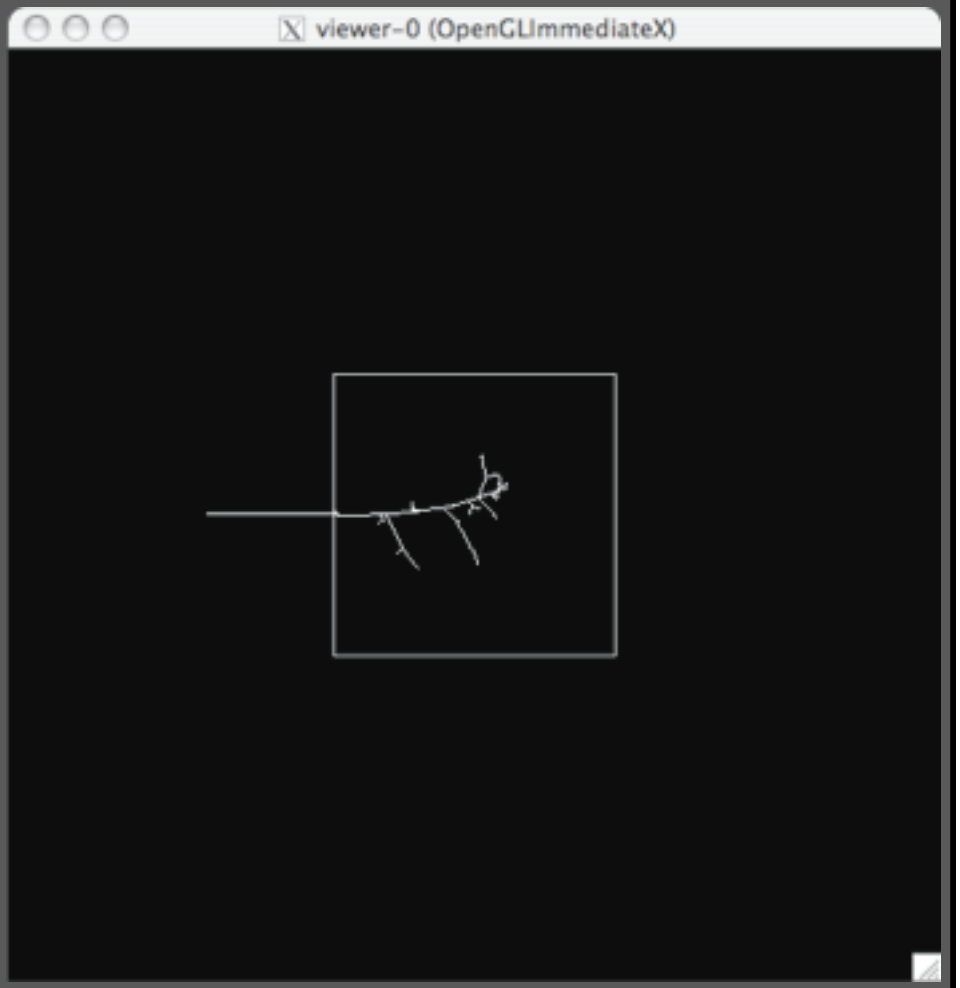
Slice at x = 0 μm

Current Applications of RADSAFE

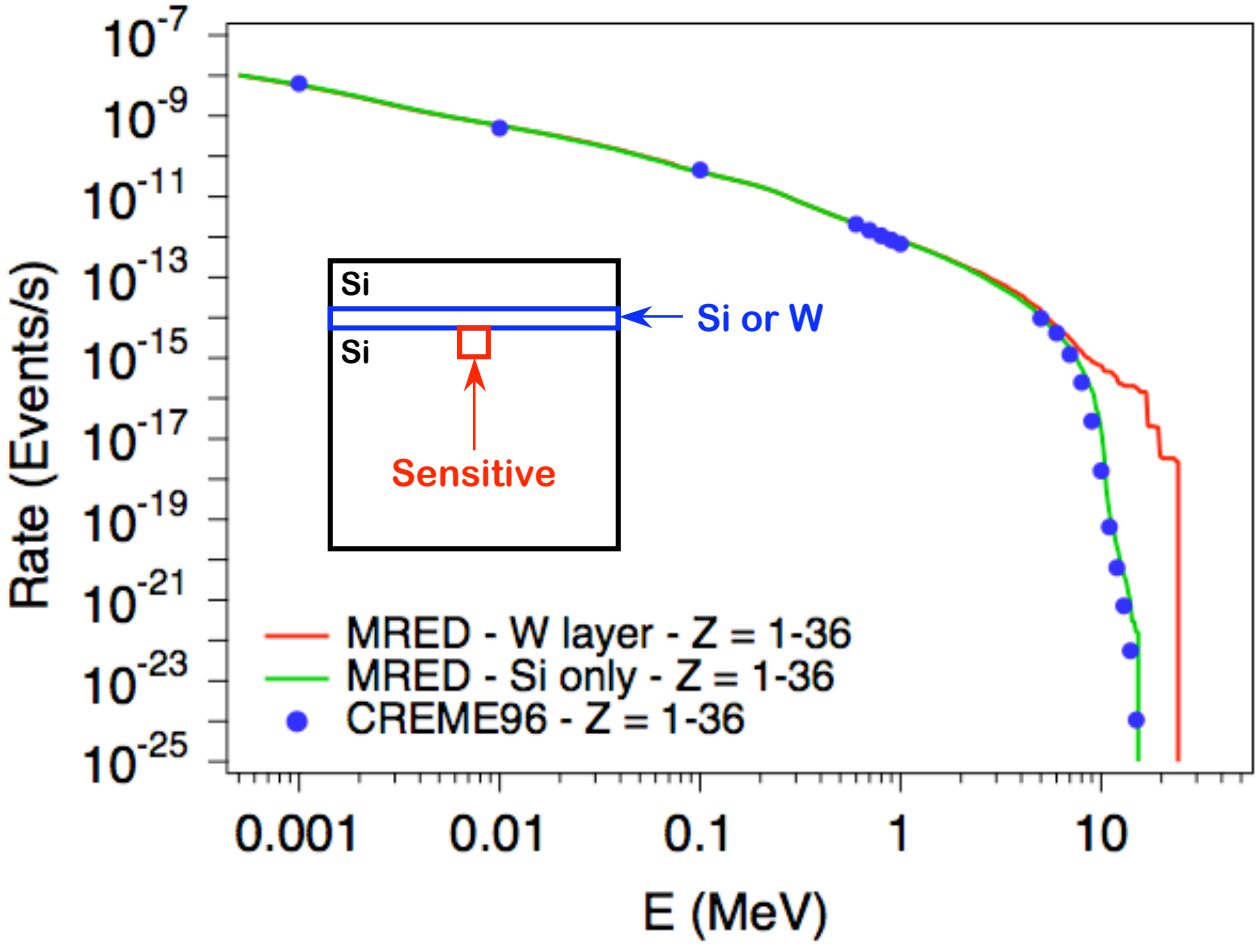
- Full RADSAFE (MRED+TCAD) on-orbit predictions of SEU rate
  - 0.25 μm and 0.15 μm CMOS SRAM
  - IBM 5HP SiGe HBT Flip Flop
- Single-event, multiple-bit upsets in 130 nm CMOS SRAM
- SEE in 130 nm, 90 nm, and 65 nm CMOS devices
- Neutron-induced SEU in CMOS SRAM
- Proton-induced SEU in SiGe HBTs
- SEGR in MOS devices
- Transient effects in HgCdTe IR-FPAs
- Displacement damage in Si, III-V, HgCdTe, and other semiconductors
- TID dose enhancement effects

MRED8 Displacement Single Event

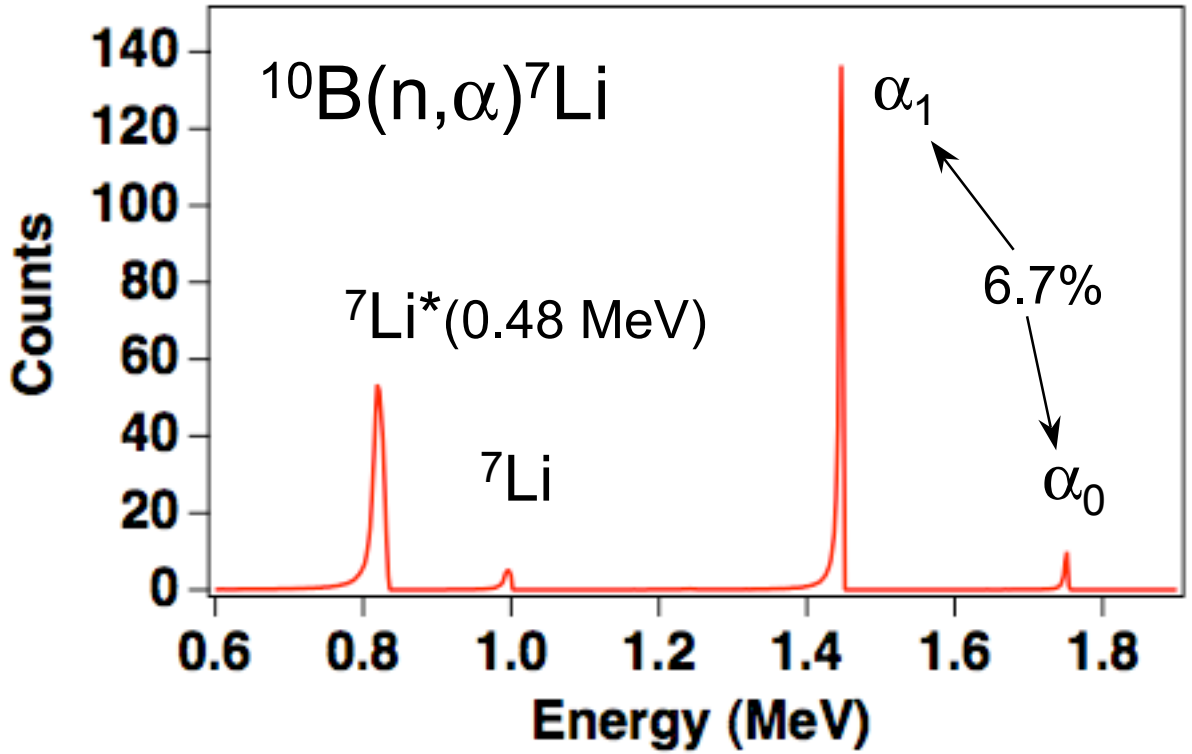




Simulating the Space Environment



Thermal Neutrons on Boron



Summary

- RADSAFE development continues as applications progress
- The core of the MRED tool is reaching maturity
- Current emphasis: TCAD interface and event selection
- Collateral applications: Instrumentation modeling & medical dosimetry
- Future: Exploring options for a tool for the community