National Aeronautics and Space Administration

Impact of Spacecraft Shielding on Direct Ionization Soft Error Rates

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To be presented by M. A. Xapsos at the 19th Annual Single-Event Effects (SEE) Symposium, San Diego, CA USA 12-14 April 2010
and published on http://radhome.gsfc.nasa.gov and http://www.nepp.gov.

Introduction

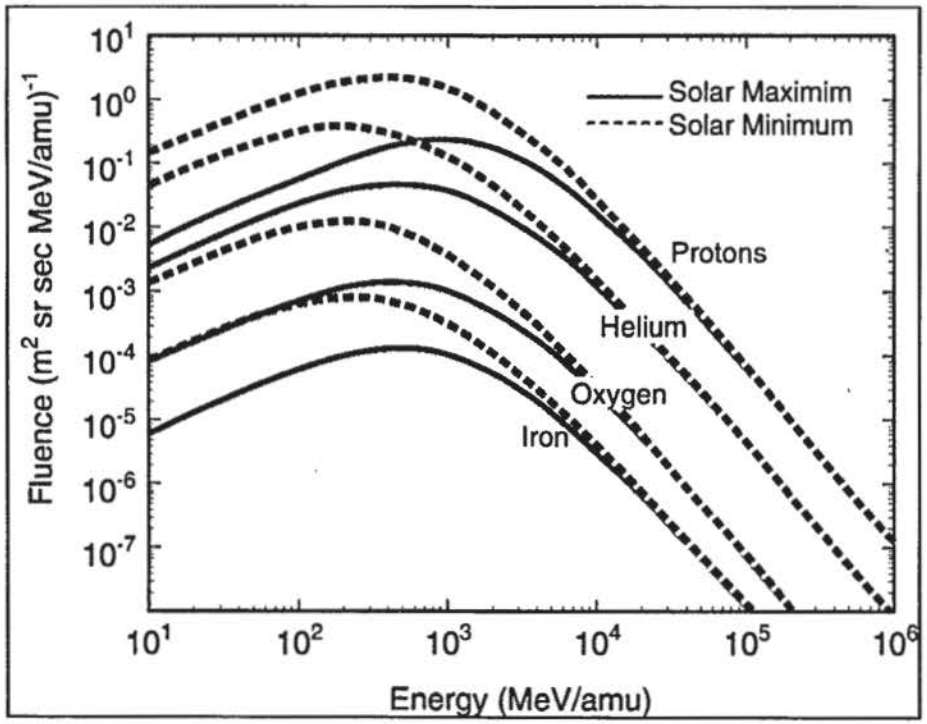
- Describe how solar activity affects space weather and subsequent single-event effects (SEEs)
- Demonstrate effect of shielding distributions on different environments
  - GCR
    - Solar minimum and maximum
  - Solar particle events
    - CREME96
    - PSYCHIC

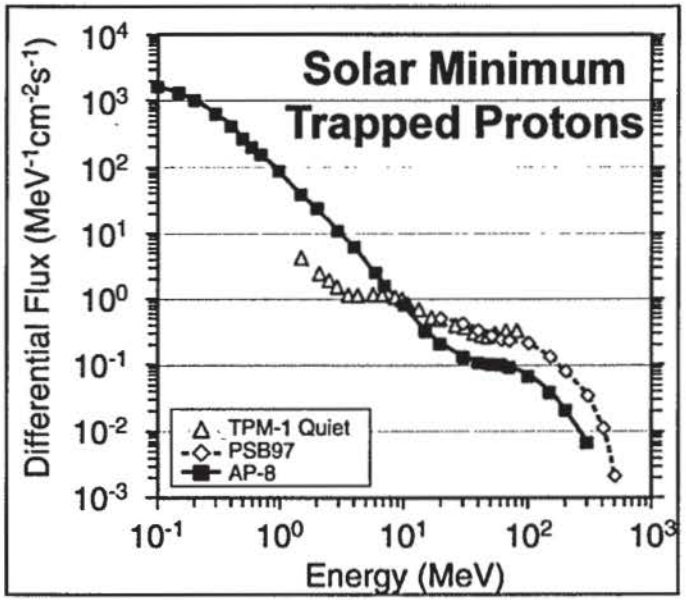

SOHO/LASCO (ESA & NASA)

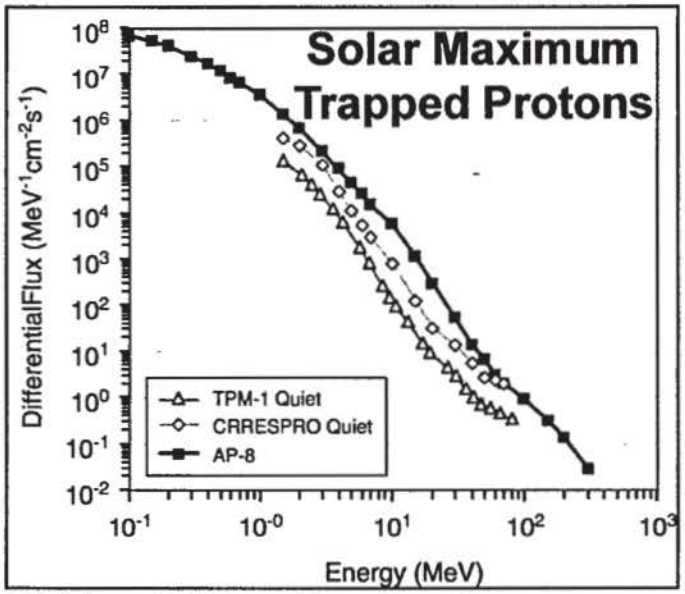
- Predict SEE rates for a volatile and non-volatile memory
  - Simple solid sphere shielding assumptions
  - 3-D ray trace of different geometries

Solar Activity Impacts Space Weather

GCR Heavy Ions from CREME96



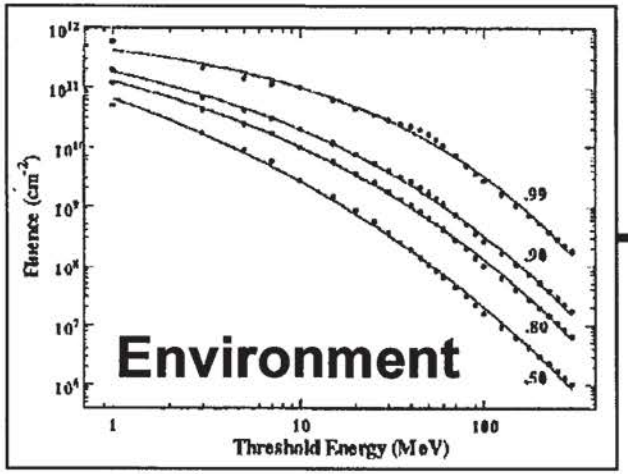




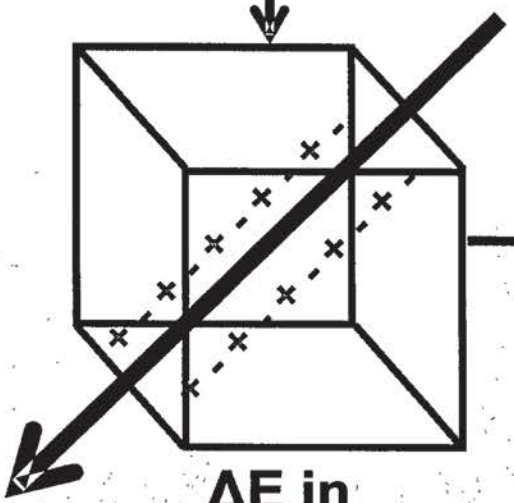
- Solar activity also affects electrons
- All images from M. A. Xapsos, *IEEE NSREC Short Course*, 2006.

To be presented by J. A. Pellish at the 2010 Nuclear and Space Radiation Effects Conference (NSREC), Denver, CO USA 19-23 July 2010
and published on http://radhome.gsfc.nasa.gov and http://www.nepp.gov.

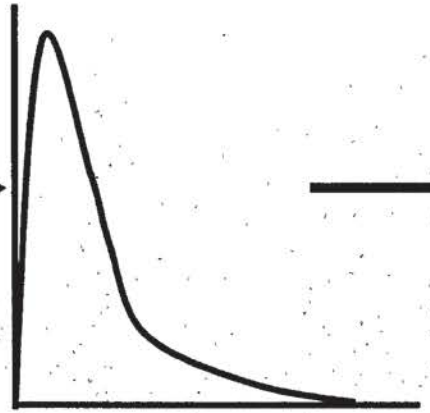
NOVICE Machinery for Rate Calculations



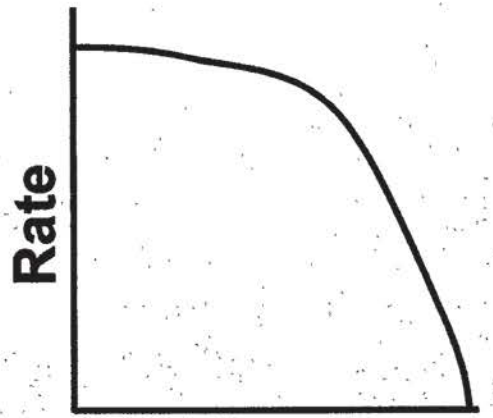
Accurate Shielding



ΔE in sensitive volume

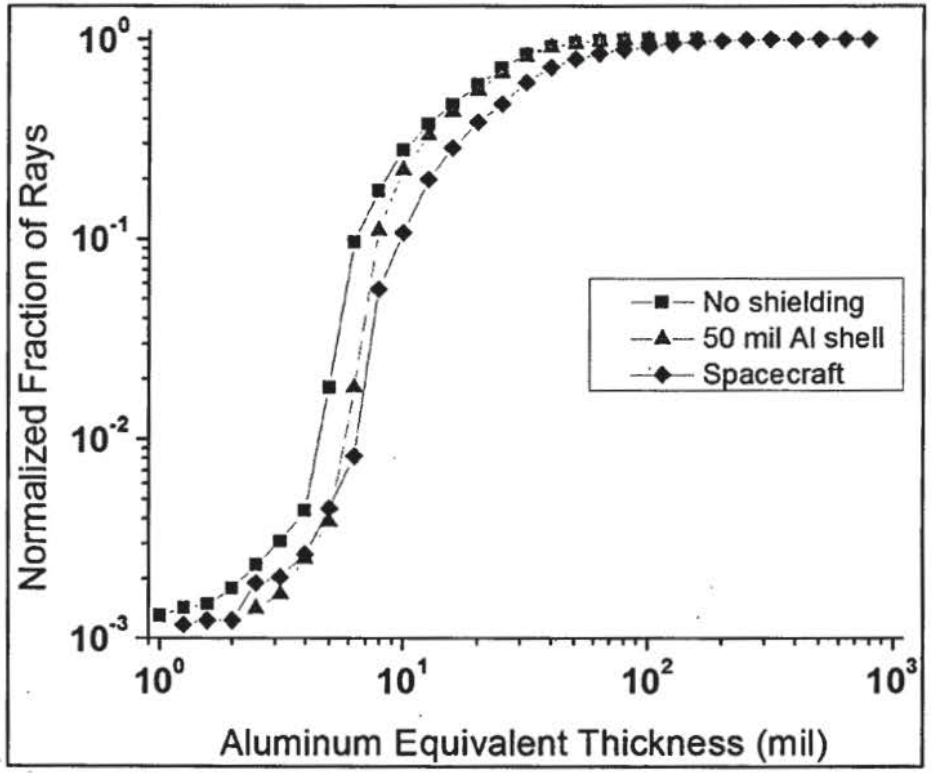


Pulse Height Spectrum



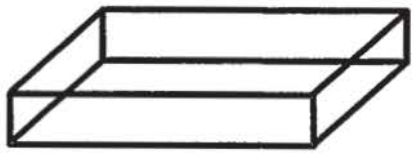
Different Types of Shielding

- Semi-infinite and infinite slabs
- Solid sphere
- Spherical shell
- Isolated electronics box
- Fully-integrated spacecraft



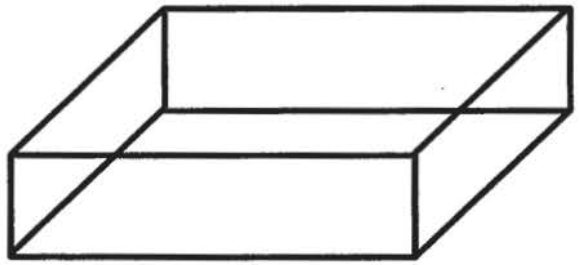
Sensitive Volumes

SV1
NAND Flash



- Material: SiO_2
- Width: 63 nm
- Length: 50 nm
- Thickness: 10 nm
- Q_{crit} = 0.06 fC
- E_{crit} = 6.6 keV

SV2
45 nm SOI SRAM

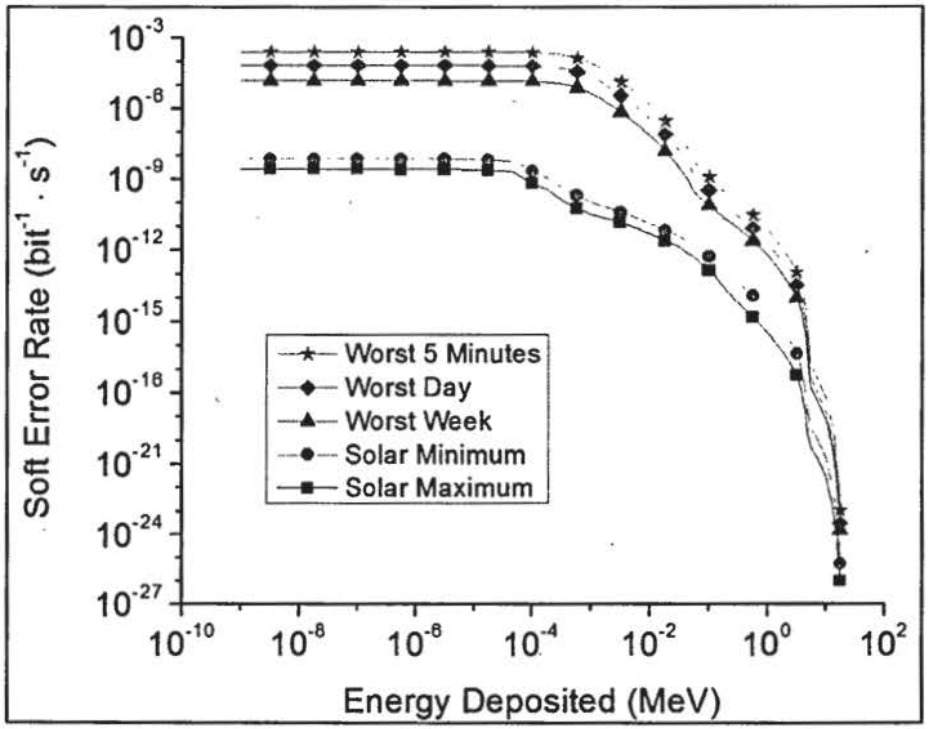


- Material: Si
- Width: 450 nm
- Length: 450 nm
- Thickness: 100 nm
- Q_{crit} = 0.5 fC
- E_{crit} = 11 keV

Solid Sphere Error Rates

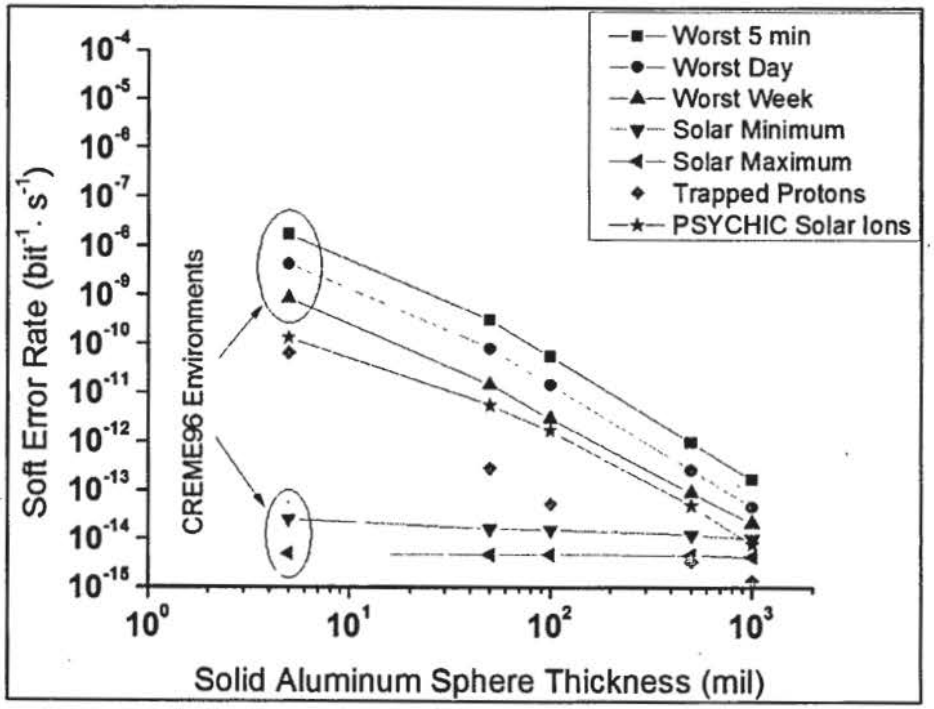
- Galactic cosmic ray (GCR) and October 1989 event spectra
  - Behind 2.54 mm (100 mil) aluminum shielding
- Direct ionization
  - Does not include nuclear elastic or inelastic reactions
- Gives reverse-integrated rate as a function of energy deposited

SV1 ONLY – Silicon



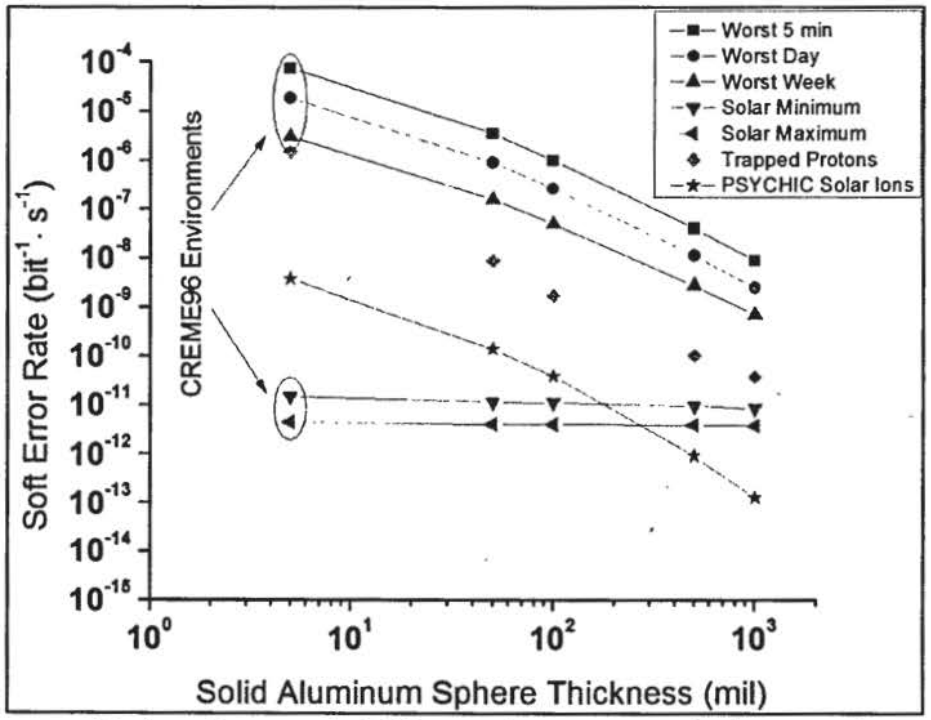
SV1 Soft Error Rates

- Silicon dioxide sensitive volume
  - Can't do this in CREME96
- Shielding impacts solar event, protons, and solar heavy ions
- Trapped proton environment includes nuclear elastic scattering
- Significant contributions from protons and solar heavy ions

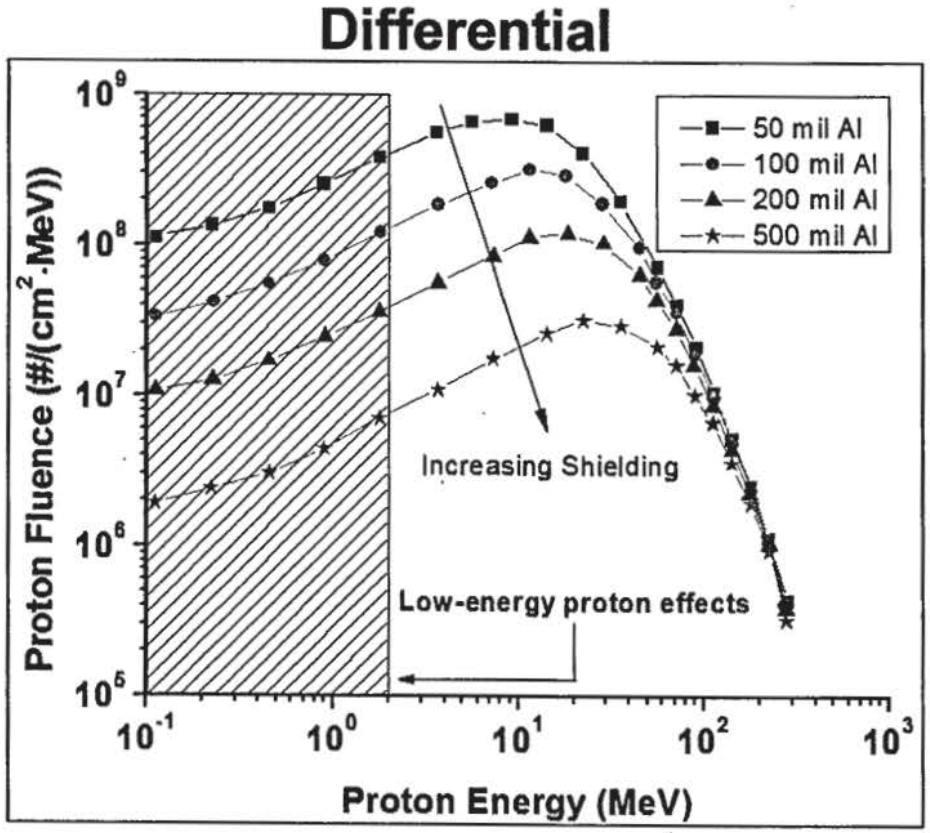


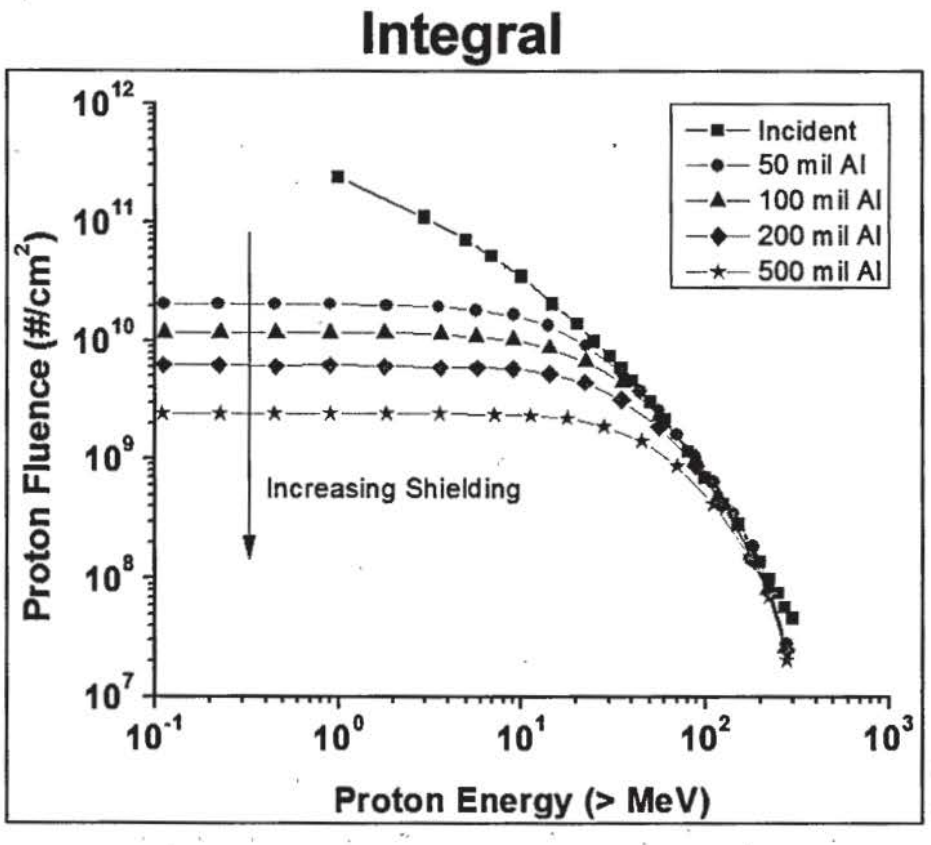
SV2 Soft Error Rates

- Silicon dioxide sensitive volume
  - Can't do this in CREME96
- Shielding impacts solar event, protons, and solar heavy ions
- Trapped proton environment includes nuclear elastic scattering
- Significant contributions from protons and solar heavy ions
  - Protons dominate rate – reverse from SV1



Low-Energy Protons Affect Rates





Both charts adapted from D. F. Heidel, *et al.*, *IEEE TNS*, Dec. 2008.

- **Both charts employ 4π sr solid spherical shielding**

Cannot shield low-energy protons – shielding hardens spectra

Conclusions

- Simplified, solid sphere shielding can overestimate soft error rates
  - This is usually true for total dose estimates too
- Contribution of trapped proton and solar heavy ion environments can dominate soft error rate
  - Equivalent to October 1989 worst week
- Direct ionization from protons is a critical effect
  - Cannot shield low-energy protons and spacecraft geometry will determine the final environment
- Future mission studies will need to rely more on tools like NOVICE and Geant4-based applications (CREME-MC and SPENVIS/MULASSIS)