

National Aeronautics and Space Administration



Impact of Spacecraft Shielding on Direct Ionization Soft Error Rates

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Introduction



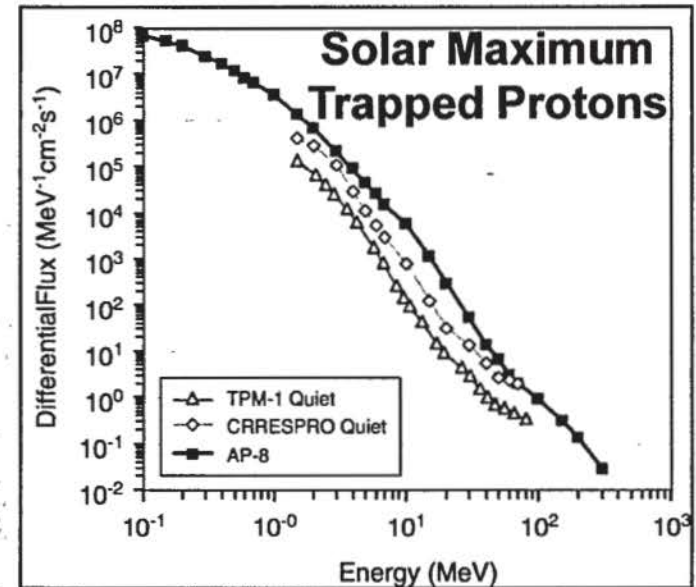
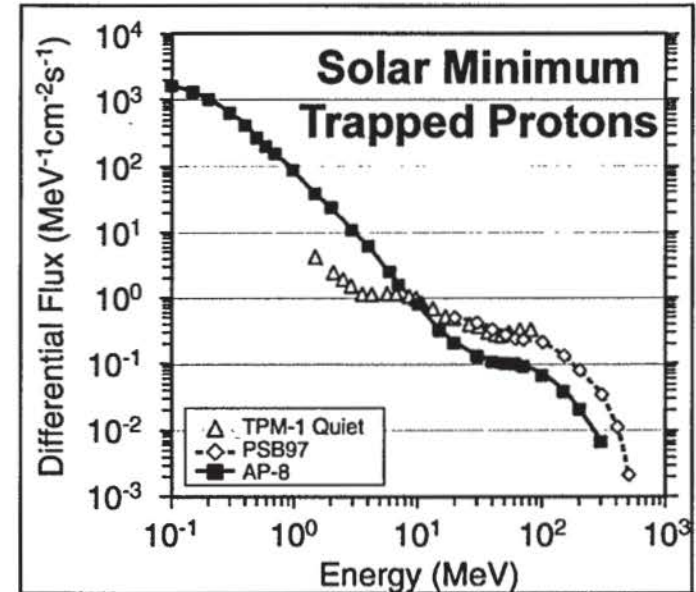
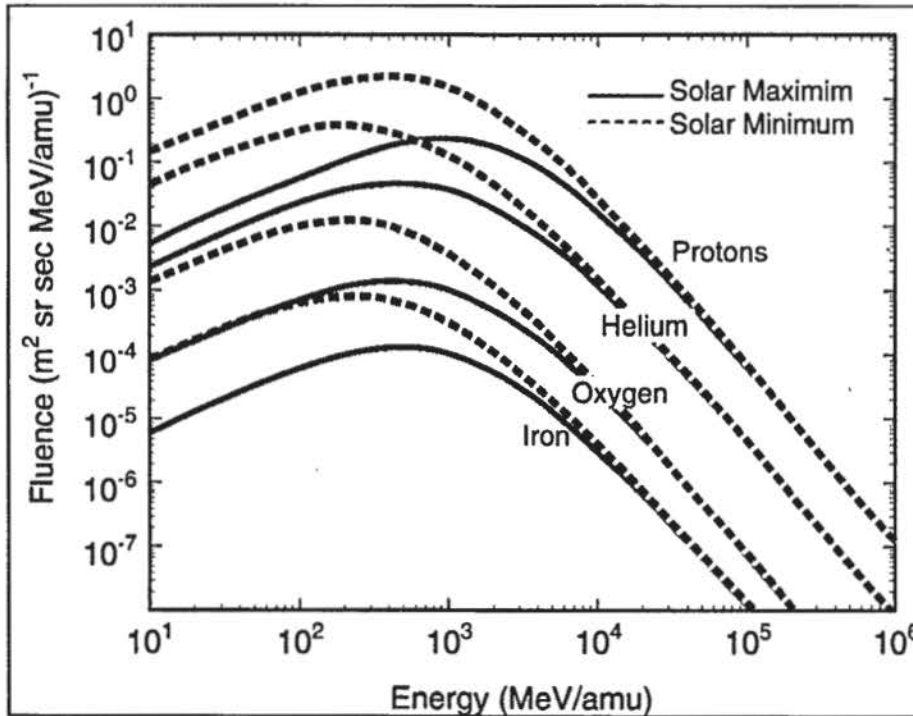
- **Describe how solar activity affects space weather and subsequent single-event effects (SEEs)**
- **Demonstrate effect of shielding distributions on different environments**
 - **GCR**
 - Solar minimum and maximum
 - **Solar particle events**
 - CREME96
 - PSYCHIC
- **Predict SEE rates for a volatile and non-volatile memory**
 - **Simple solid sphere shielding assumptions**
 - **3-D ray trace of different geometries**



Solar Activity Impacts Space Weather

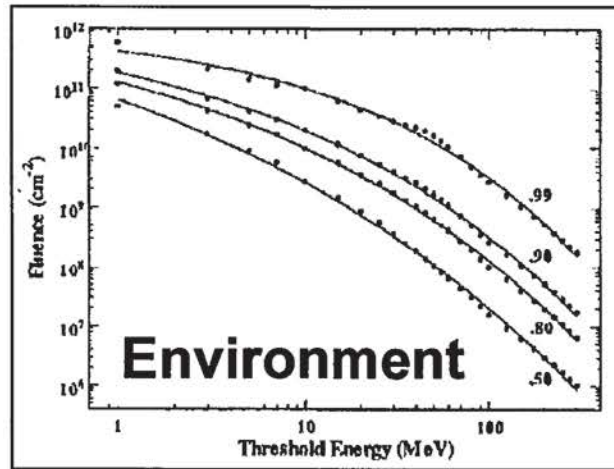


GCR Heavy Ions from CREME96

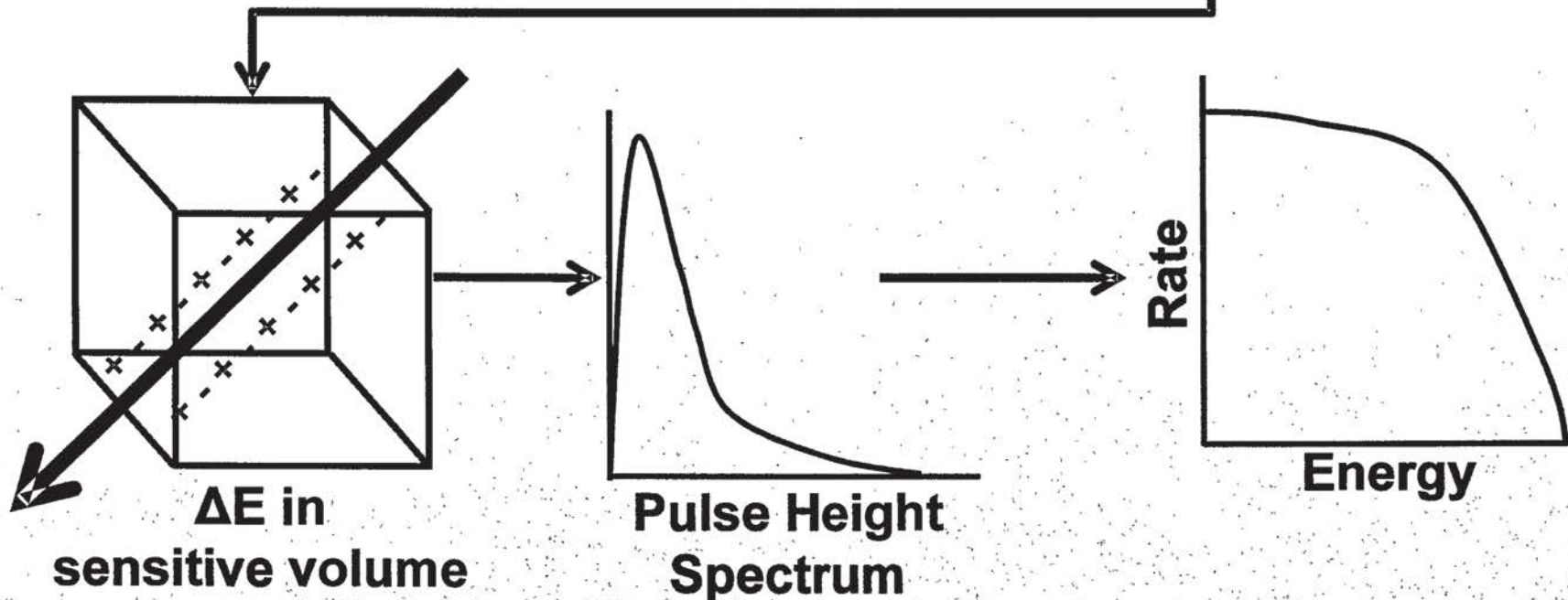
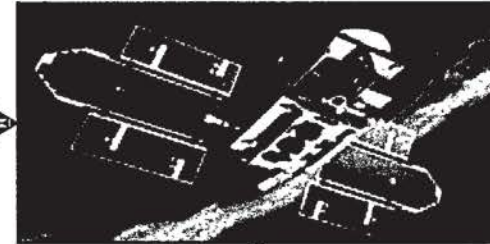


- Solar activity also affects electrons
- All images from M. A. Xapsos, *IEEE NSREC Short Course, 2006.*

NOVICE Machinery for Rate Calculations



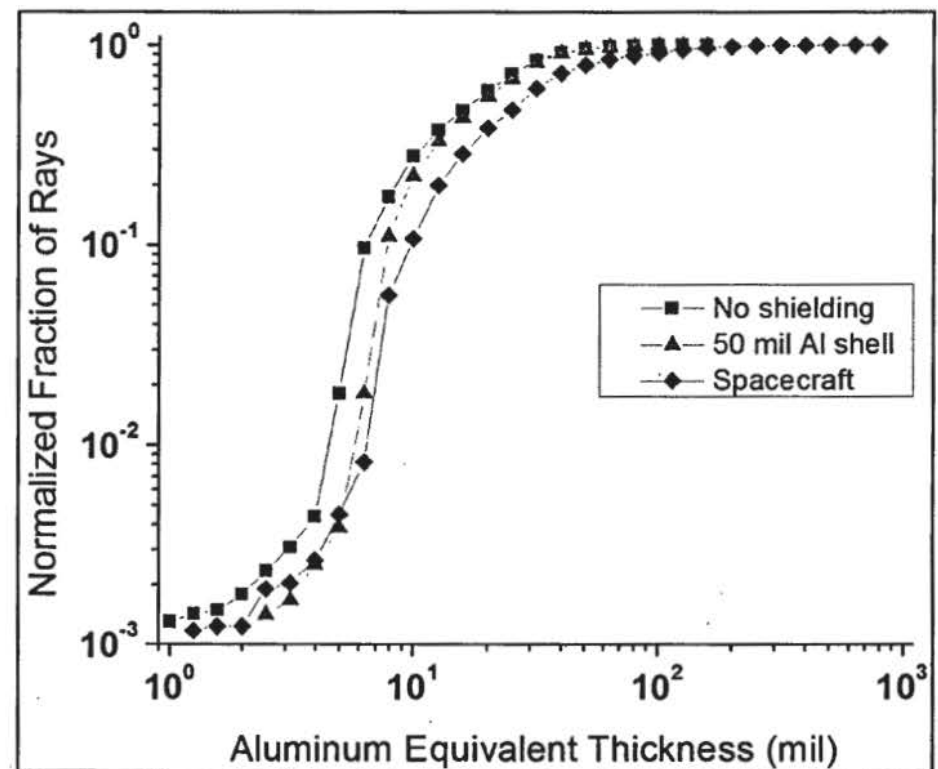
Accurate Shielding



Different Types of Shielding



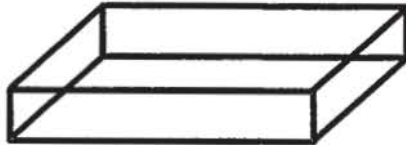
- **Semi-infinite and infinite slabs**
- **Solid sphere**
- **Spherical shell**
- **Isolated electronics box**
- **Fully-integrated spacecraft**



Sensitive Volumes

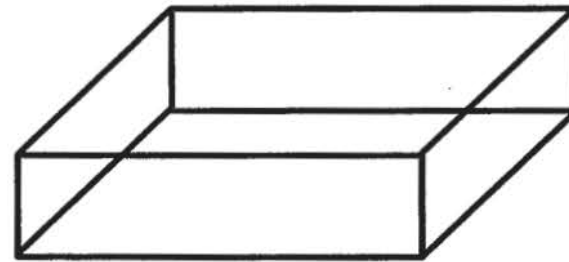


SV1
NAND Flash



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

SV2
45 nm SOI SRAM



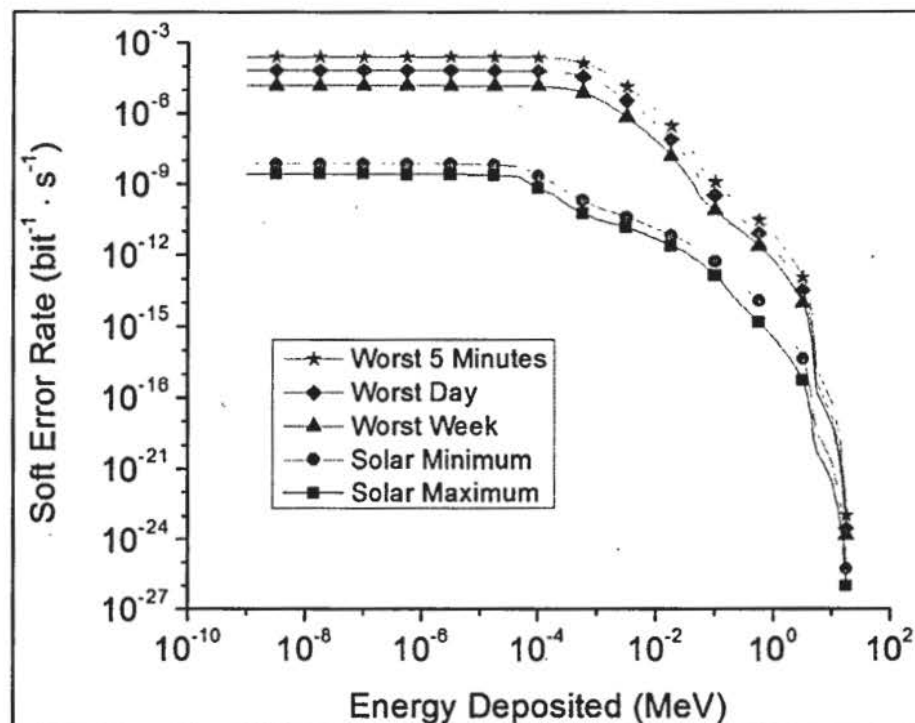
- Material: Si
- Width: 450 nm
- Length: 450 nm
- Thickness: 100 nm
- $Q_{\text{crit}} = 0.5 \text{ fC}$
- $E_{\text{crit}} = 11 \text{ keV}$

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**

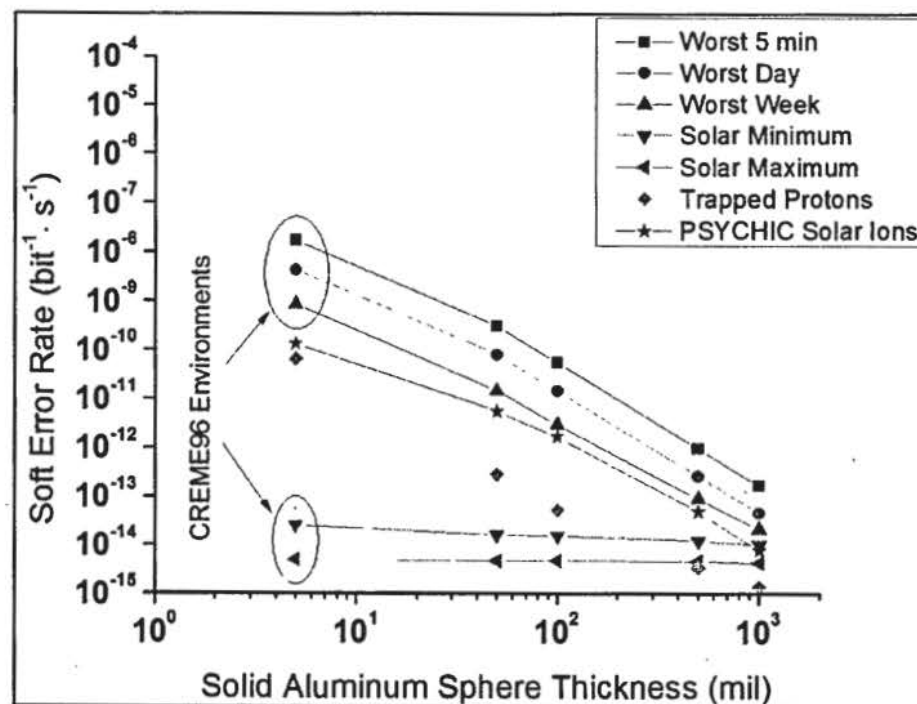
SV1 ONLY – Silicon



SV1 Soft Error Rates



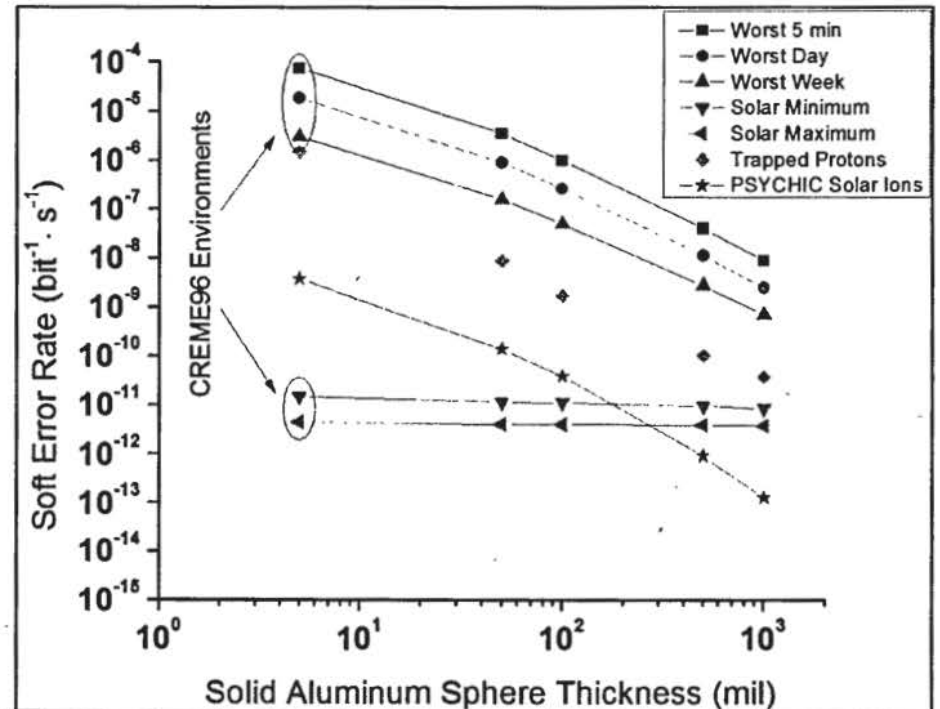
- Silicon dioxide sensitive volume
 - Can't do this in CREME96
- Shielding impacts solar event, protons, and solar heavy ions
- Trapped proton environment includes nuclear elastic scattering
- Significant contributions from protons and solar heavy ions



SV2 Soft Error Rates



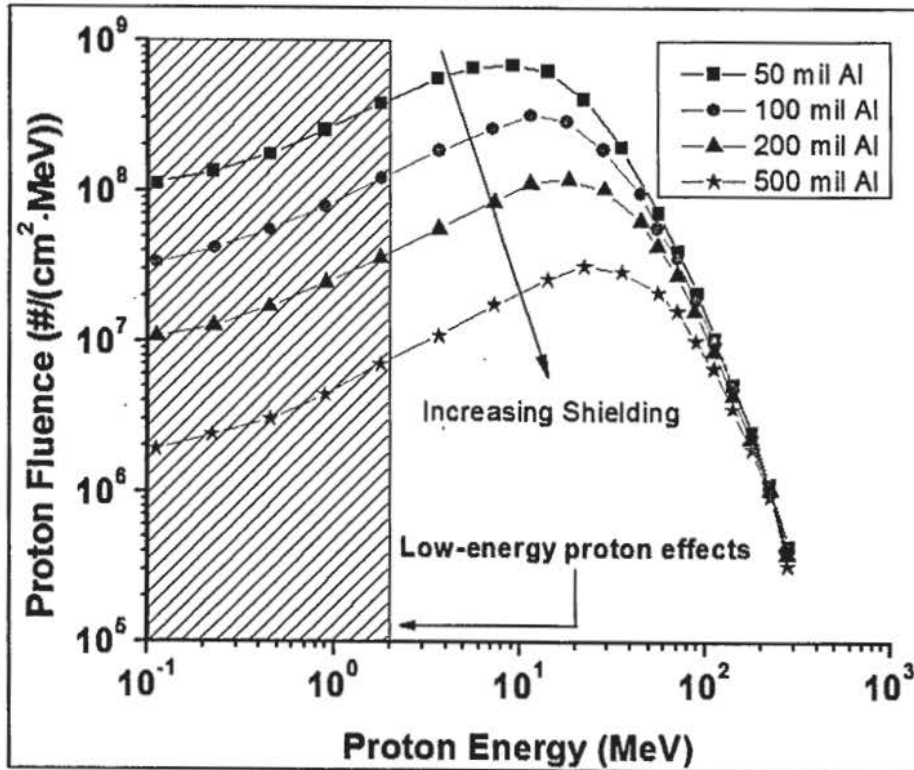
- Silicon dioxide sensitive volume
 - Can't do this in CREME96
- Shielding impacts solar event, protons, and solar heavy ions
- Trapped proton environment includes nuclear elastic scattering
- Significant contributions from protons and solar heavy ions
 - Protons dominate rate – reverse from SV1



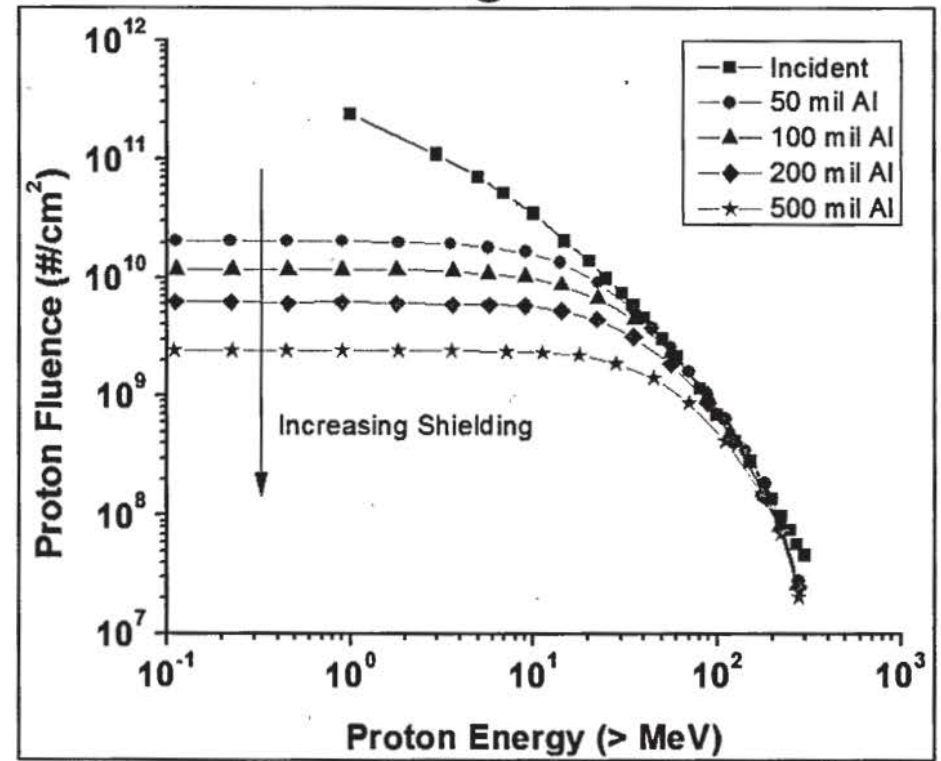
Low-Energy Protons Affect Rates



Differential



Integral



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)**