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Radiation Effects in Spacecraft and Aircraft

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Overview for Assessing Impact of Space Environment on Radiation Effects

- Ionizing radiation is diverse, comprised of 3 main sources:
  - Trapped belts [electrons (10 keV-5 MeV) & protons (100 keV-500 MeV)], inner belt: e & p, outer belt-mainly electrons
  - Galactic Cosmic Rays (GCR) ~85% energy protons, ~13% alphas and 2% HZE, all at high energies (0.01-100 GeV/amu)
  - Solar energetic particle (SEP) events, mainly protons, alphas and HZE, but at much lower energies than GCR
  - 4th source, Solar wind, very low energy protons (~1-5 keV)
- Ionizing radiation can effect great variety of equipment types, i.e, devices: electronics, optics, electro-optics, photovoltaics, thermal & optical coatings, MEMs, etc.
- It can also effect biological systems, especially astronauts, but that won’t be dealt with in this presentation

Overview for Assessing Impact of Space Environment on Radiation Effects-Cont'd

- **There are orders of magnitude variations in: energy of the radiation, thickness of the devices, rad capability to penetrate materials, effects that can be induced, etc.**
- **Thus, clear need to characterize the ionizing radiation in detail at both high and low energies**
  - **accurately describe energy spectra of each rad source**
  - **better describe variation of radiation sources over time**
    - **SEP events ("solar flares") & creation of new "belts"**
    - **Enhancements in relativistic outer belt electrons**
  - **improve existing models (NASA, NRL, USAF)**
  - **predict lifetime, operability and reliability of devices being selected for space missions**
  - **understand human threats (Shuttle, ISS & further missions)**
  - **understand/correlate different effects by different types radiation in various components**

Description of Three Main Types of Radiation Effects in Microelectronics

- **Total Integrated Dose [TID]**
  - **Cumulative effect of ionization (charge buildup) in IC leading to a gradual degradation of electrical parameters**
- **Single Event Effects [SEE]**
  - **Disturbance of an active electronic device caused by a single energetic particle; 4 main categories**
    - **Upset (SEU) --change in logic state, e.g., bit flip in RAM**
    - **Latchup (SEL) --increase in current resulting from turning on parasitic *pnpn* (in CMOS devices)**
    - **Damage or burnout (SEGR & SEB) of power transistor**
    - **Functional interrupt (SEFI)- malfunctions in more complex parts sometimes as lockup, hard error, etc.**
- **Displacement Damage**
  - **Cumulative effect of displacing atoms out of their lattice**

Overview in Assessing Magnitude of Radiation Effects on ICs

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- **TID**
  - **3 main environment parameters:**
    - **daily dose rate (depends on orbit altitude and inclination)**
    - **mission time (number days); also effects flare probability**
    - **shielding (by structures, reduces dose rate)**
    - **TID = daily dose rate (rad/day) _ number days**
  - **Combine with measured response of ICs (passing dose level at which degradation is measured)**
- **SEE**
  - **GCR Heavy Ions**
    - **Composite differential particle spectrum (ion/cm_day >E) as function of E, then transformed from E→ LET**
  - **Trapped Protons**
    - **Integral or differential daily flux, p/cm_day>E**
  - **Combine with measured response of ICs (SEE vs. LET)**

Upsets in Shuttle Orbiter GPC Computers on Ground (1)

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- STS-37 (4/91) 1st flight with GPCs (general purpose computers)
  - Use IMS1601 64K SRAMs (~13Mbits/GPC)
  - Protected by EDAC (records errors) on ground and in space
- First upset in GPC memory during ground testing, 4/92
- Since then, total of 14 SEUs have been recorded in the GPCs during ground testing (13 in Orbiters, 1 in spare)
- Average ground upset rate [based on total time (ETI, elapsed time indicator) -flight time] is ~8E-12 Upset/Bit-hr
  - Higher ground rate than for other SRAMs by factor of 4-8
  - Agrees w/WNR SEU measurement
  - Factor 1.5-2 high compared to IBM measm't, Manassas, VA
- GPC data fromTami Mitchell and Kathy Milon of KSC
- Ground upsets in Shuttle Orbiter GPCs on the ground are random, therefore they are SEUs

Upsets in Shuttle Orbiter GPC Computers on Ground (2)

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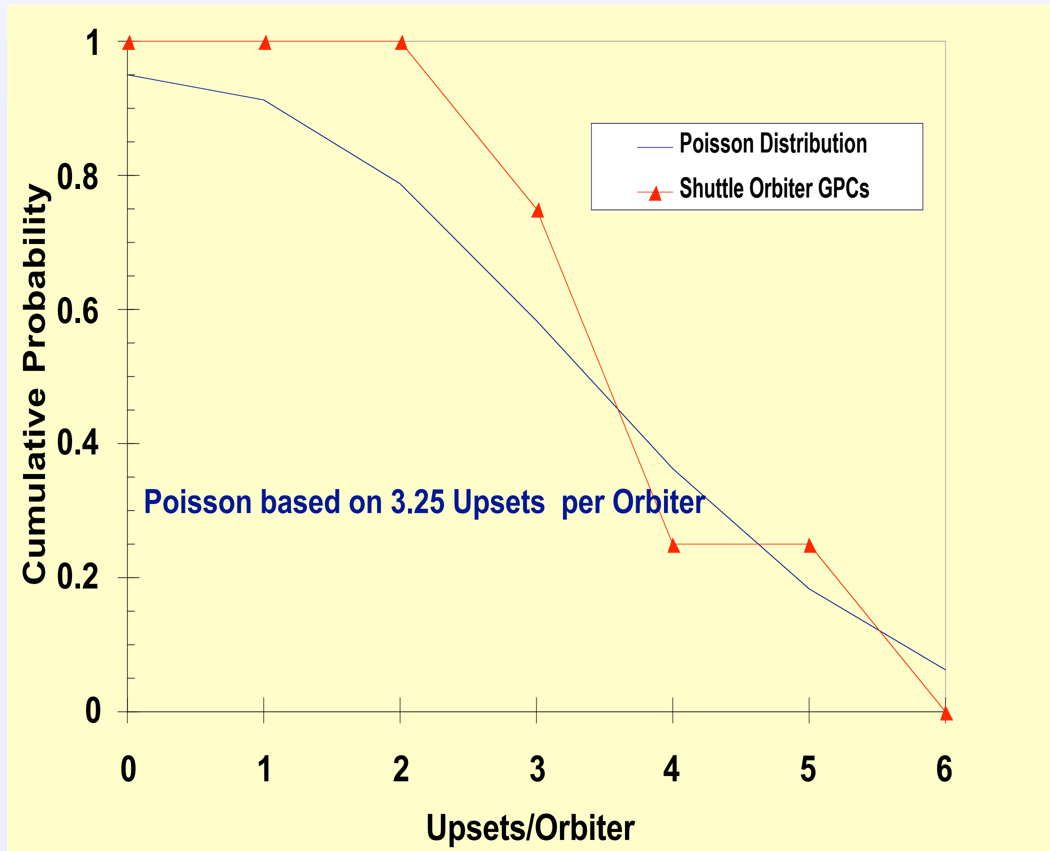
- Ground upsets in Shuttle Orbiter GPCs on the ground are random, therefore they are SEUs



SEU Observed in Autopilot in Boeing Commercial Aircraft

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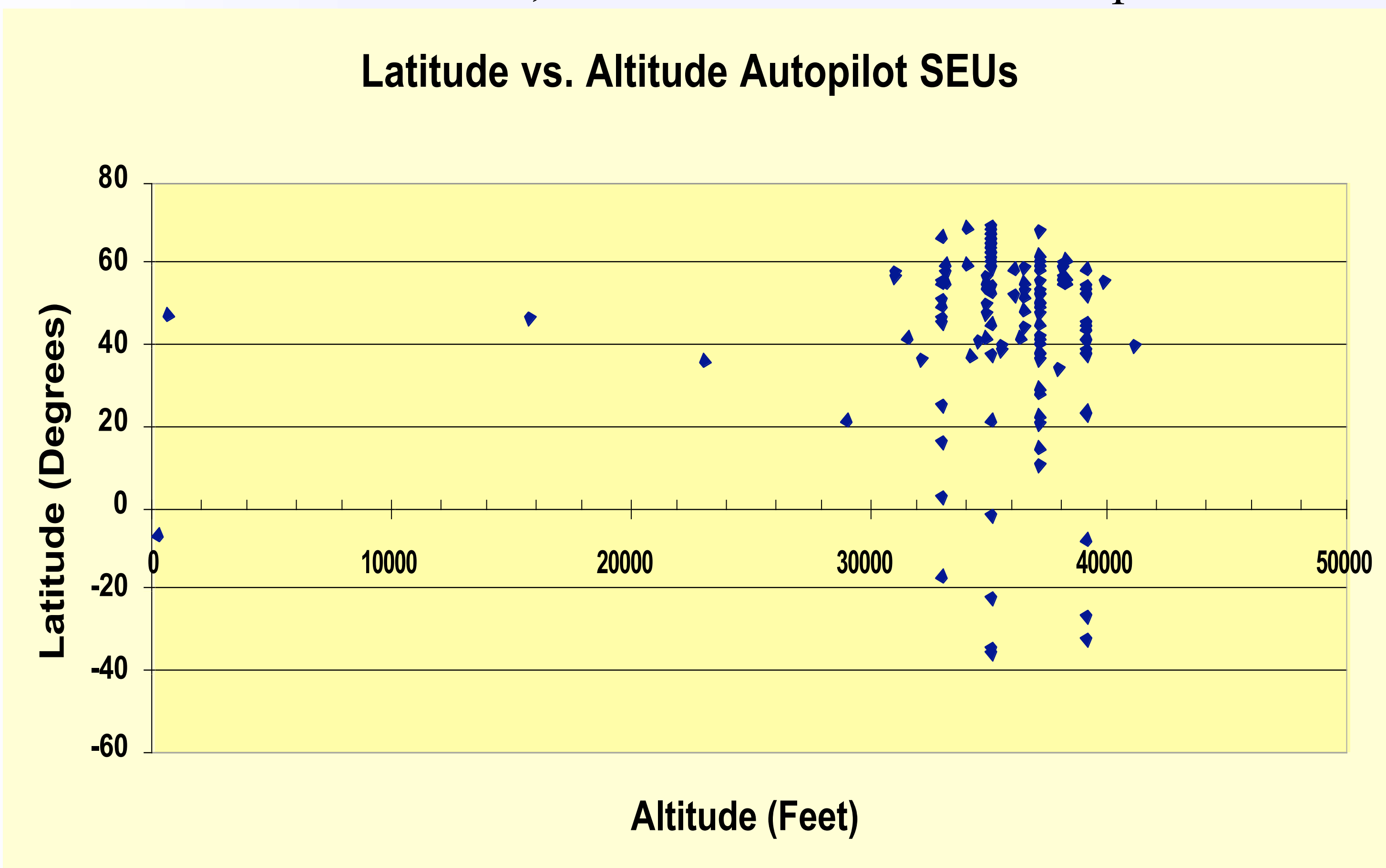
- Data obtained by Autopilot Vendor; original design had "No Bus Outputs"
- Autopilot design modified to include triple-voted RAM to allow neutron SEU to be detected and corrected; occurrence of "No Bus Outputs" eliminated



SEL Observed in ERS Satellite Led to Failed Instrument After 6 Days

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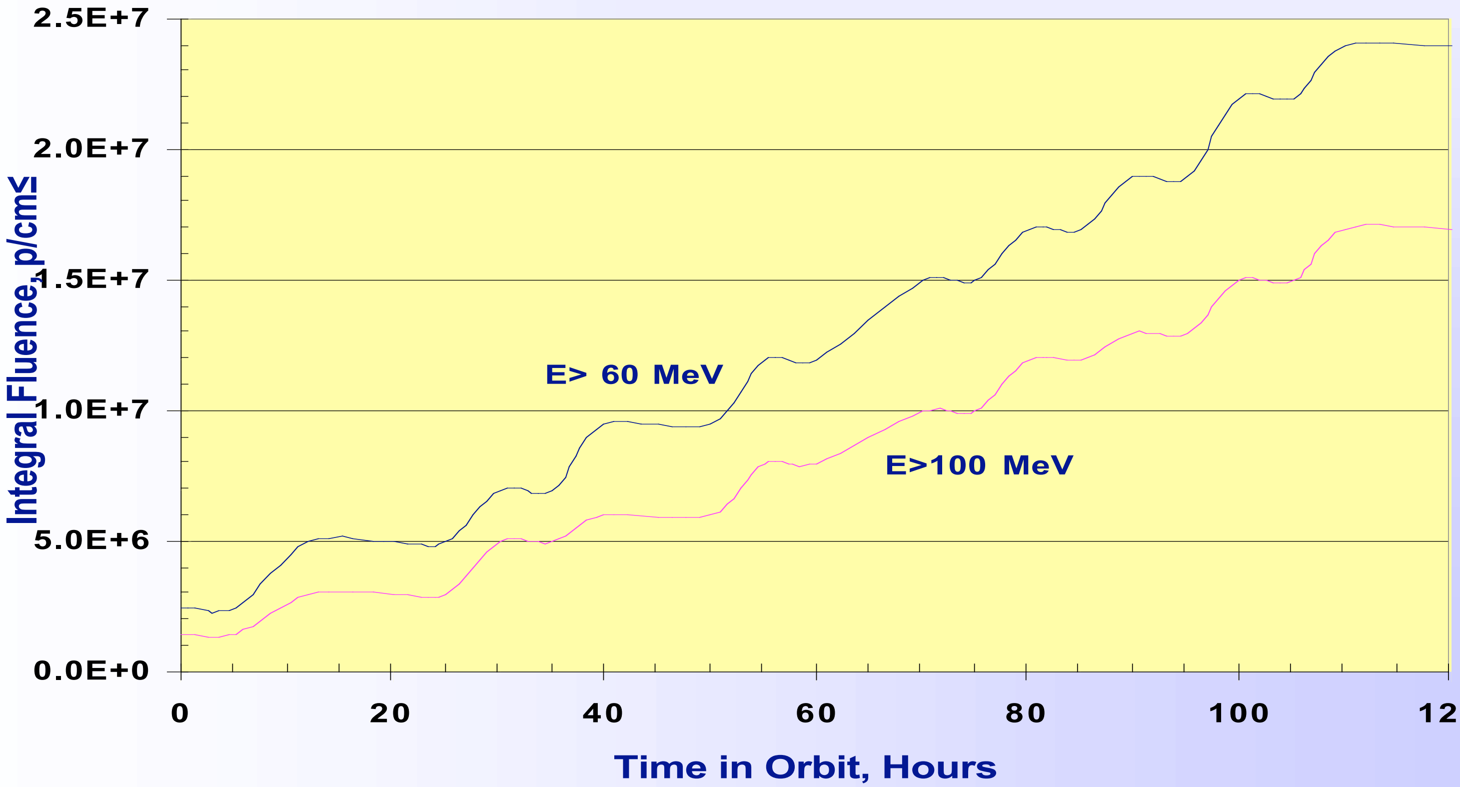
- PRARE instrument on ERS-1 Satellite (784 km, polar orbit), launched in 1991
- Failed after 6 days, problem traced to SEL in one of 22 64Kbit SRAMs
- No pre-flight testing; post-flight test indicated SRAM prone to proton-induced SEL
- SEL test (60 MeV protons) gave X-Section of ~3E-9 cm_/dev, leading to mean fluence for single SEL of ~1.5 E7 p/cm_, agrees with 6-day orbit fluence



Single Even Burnout (SEB) in Power MOSFETs Observed in Spacecraft

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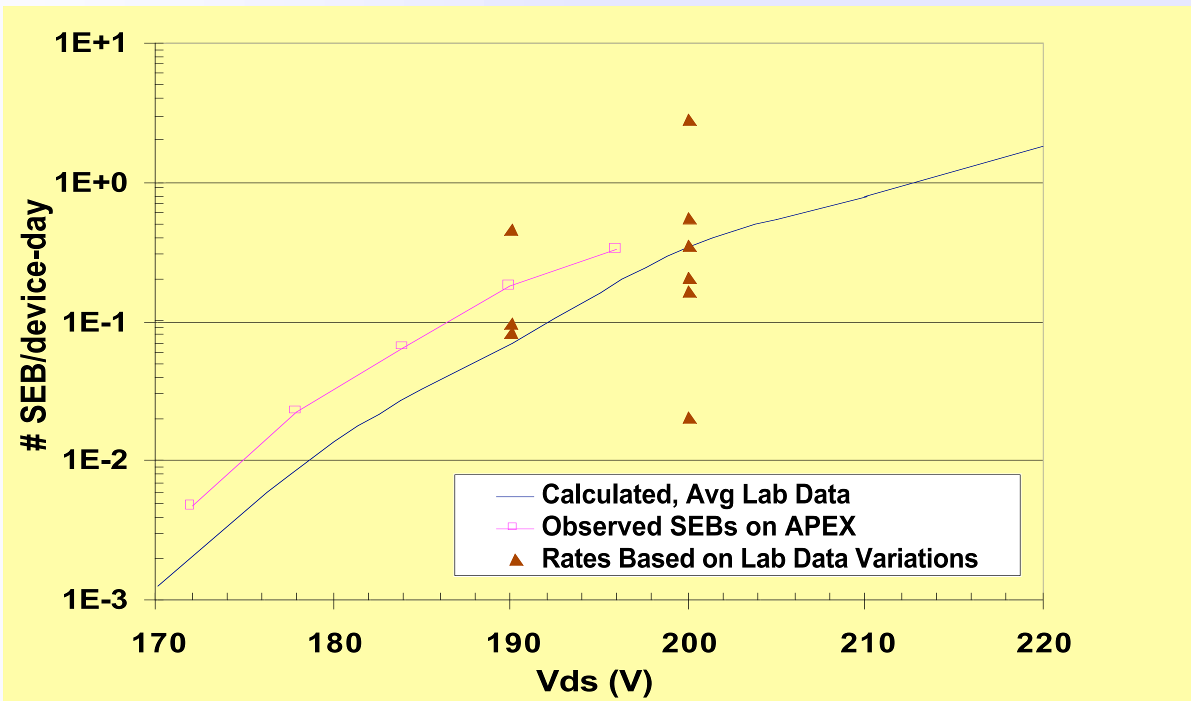
- Single event burnout (SEB) caused by GCR ions, as well as protons, has been concern; designers avoided problem by operating MOSFETs at highly reduced Vds
- CRUX experiment on APEX satellite (360_2540 km, 70° orbit) allowed 100 & 200V MOSFETs to be cycled through high voltage range, resulting SEBs were recorded
- 200V 2N6798 (flight lot) was tested by Boeing at HCL, yielding proton SEB cross sections; when combined w/ orbit environment, obtain good agreement w/flight data



Change in Solar Absorbtance of Ag/FEP Thermal Coating due to Electron Dose

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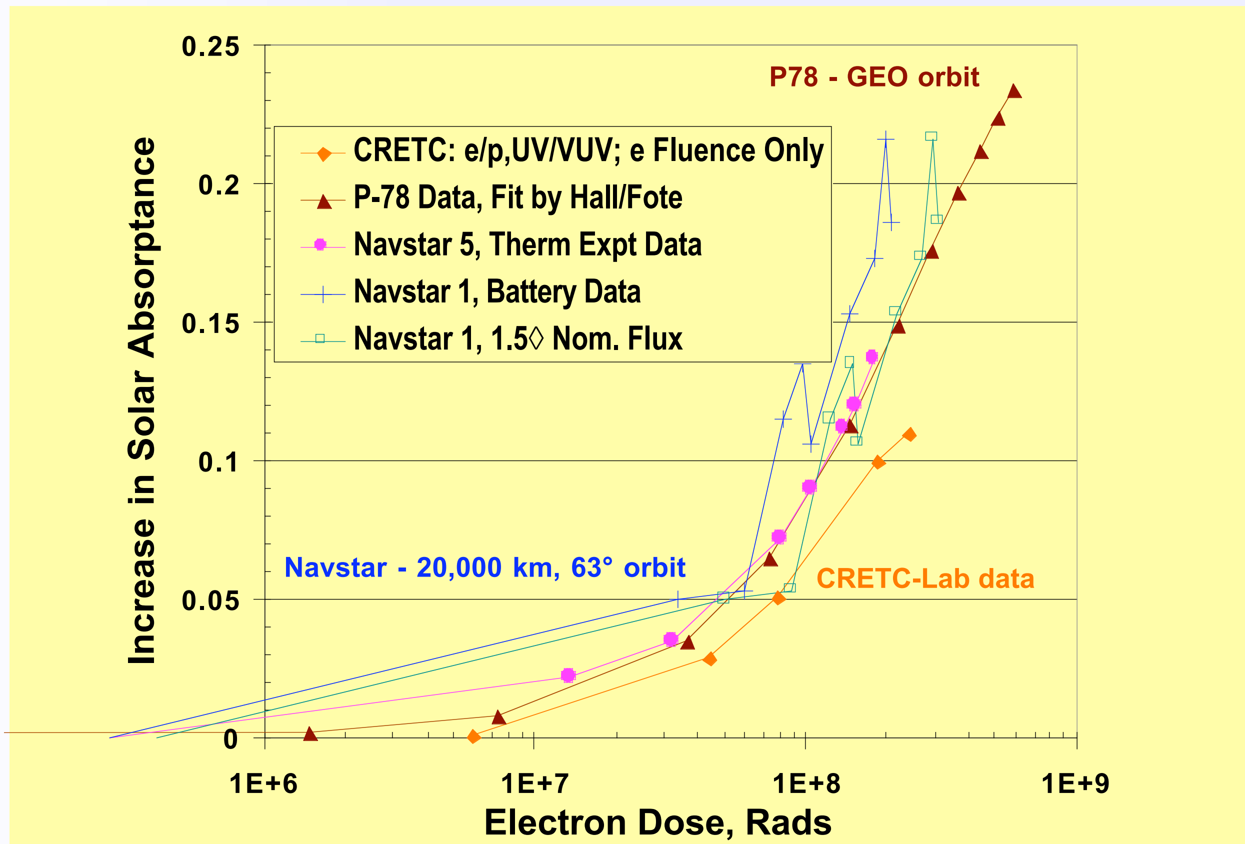
- Many satellites use very thin (few mils) thermal coatings, such as silver/teflon (Ag/FEP), to control the UV absorbed and hence the temperature of satellite
- As low energy electrons deposit energy in the coatings, absorptance increases
- Result is higher temperature; examples of data from GEO and half-GEO satellites



Conclusions

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- We have shown diverse effects measured in satellites, as well as airplanes and on ground, examples of impact ionizing radiation can have on materials
- Most effects have been in electronics, but have also shown effect in very thin materials such as thermal coating (silver/teflon, Ag/FEP)
- Many other speakers will be providing other examples of the effects of ionizing radiation and our attempts to measure it in space, and incorporate that information into useful models of the space radiation environment
- As we improve our understand the space radiation environment, the better we will be able to understand and plan for its effect on the equipment that we will be sending into space
- The Living With A Star spacecraft constellation represents a unique opportunity for basic science experts to join forces with applied science researchers to make measurements that will be useful and meaningful to both constituencies