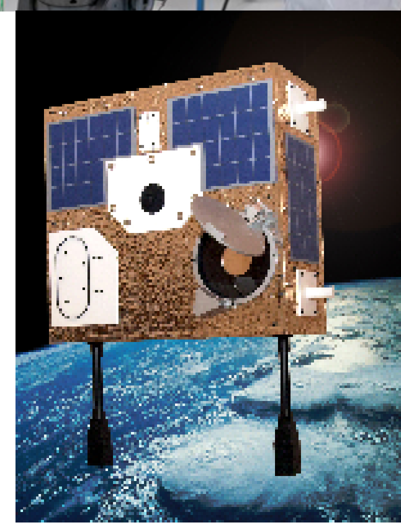
Radiation Effects and COTS Parts in Smallsats

SSC13-IV-3 August 13 2013

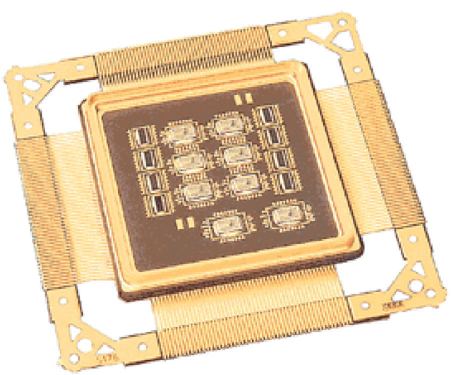
Who We Are and Why You Should Listen

- Jonny Dyer, Chief Engineer, Skybox Imaging
  - Commercial missions that are cost-constrained, but must be reliable and long-lived to produce revenue
- Doug Sinclair, Owner, Sinclair Interplanetary
  - 19 LEO missions launched to date
  - Hardware launched in 2003 still working
  - Some educational failures too

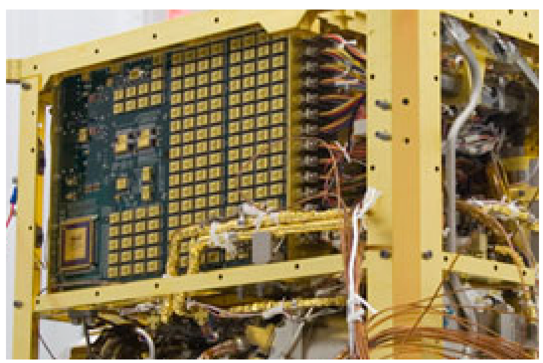


Rad Hard Approach

- Guaranteed high-dose performance
  - High radiation deep space missions
  - “Failure is not an option” crewed missions
- Old technology, custom fab process, low integration, part-level testing/screening
  - Expensive, long lead times, high part counts



Hermetic / Hybrid = $$$



Many discretes on a deep space board

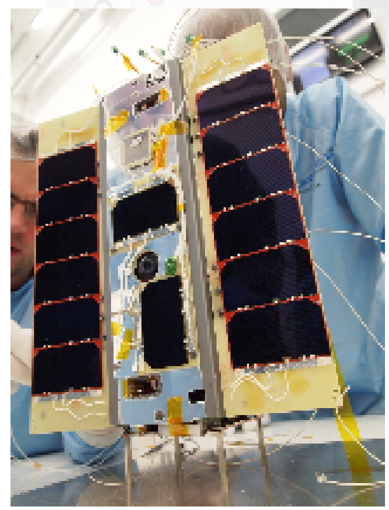
Juno’s “Now that’s some radiation” vault

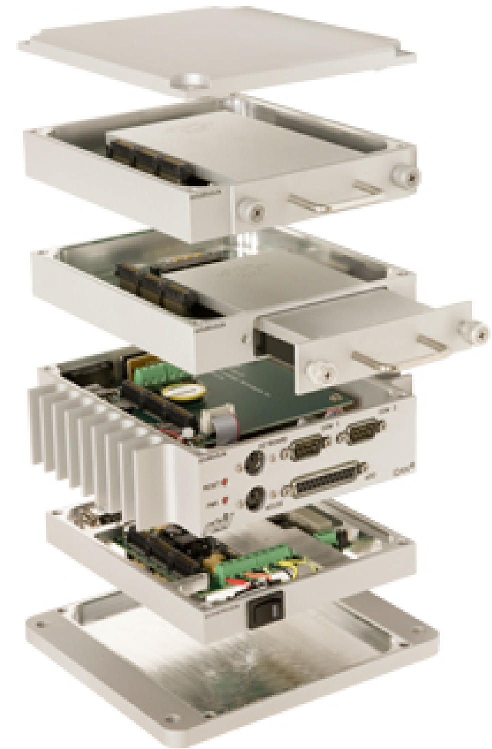
Buy and Fly Approach

- Industrial and consumer products
- Very low cost, high performance
- Little knowledge of design details
- Suitable for educational missions, or very short duration flights

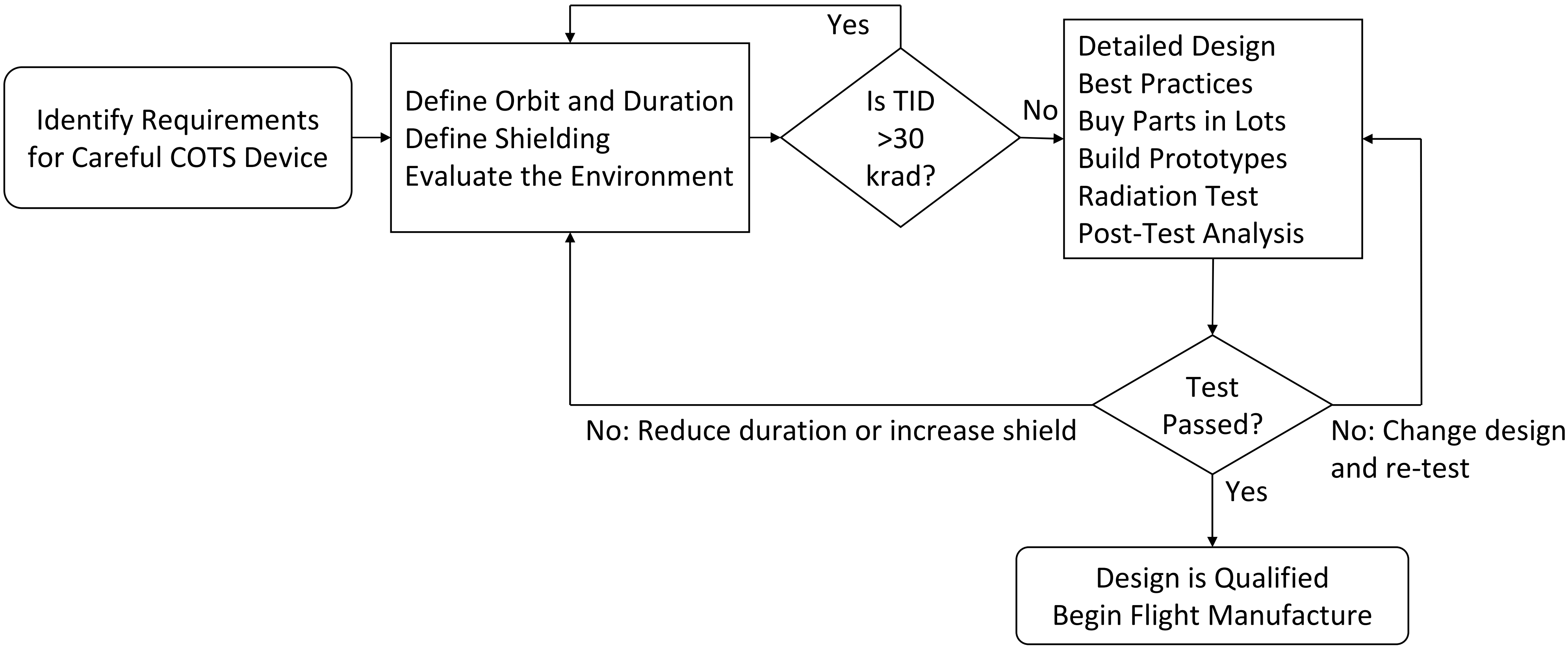
- If 90% of commercial ICs will tolerate an environment, and a device has 10 ICs, probability of mission success is only 35%.

GoPro Camera


SSTL STRaND-1 Satellite
Carries Nexus One Cell Phone

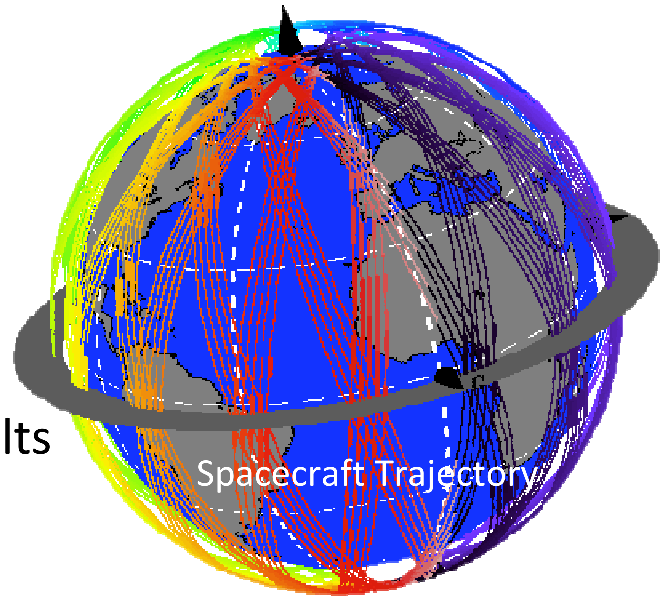

RTD PC/104
Computer Stack

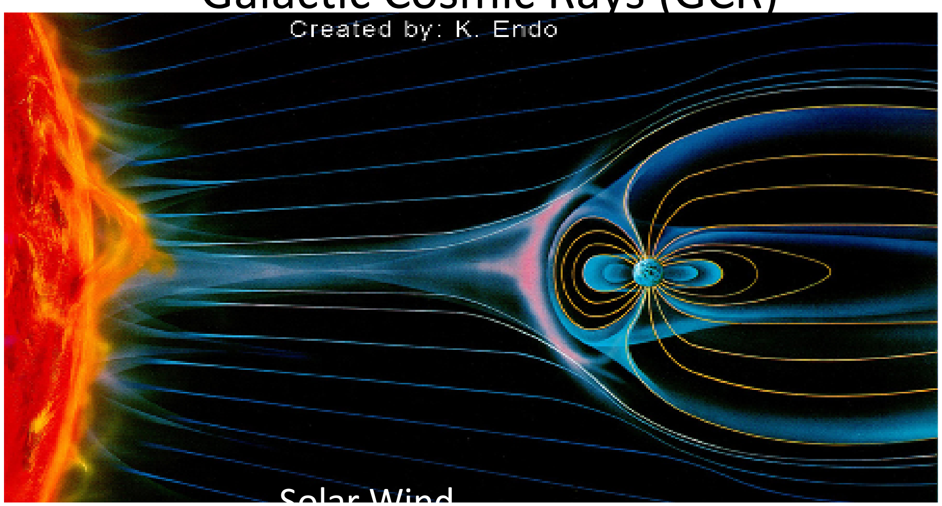
Careful COTS

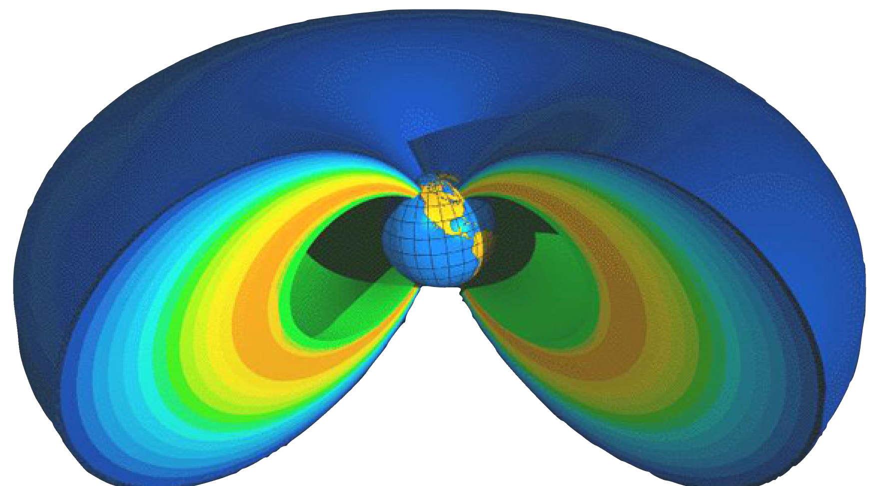


Environment - Input

- Orbit parameters, target lifetime, solar cycle
- Radiation sources:
  - Trapped particles (protons + electrons) – van Allen belts
  - Solar particles
  - Galactic Cosmic Rays (GCR)

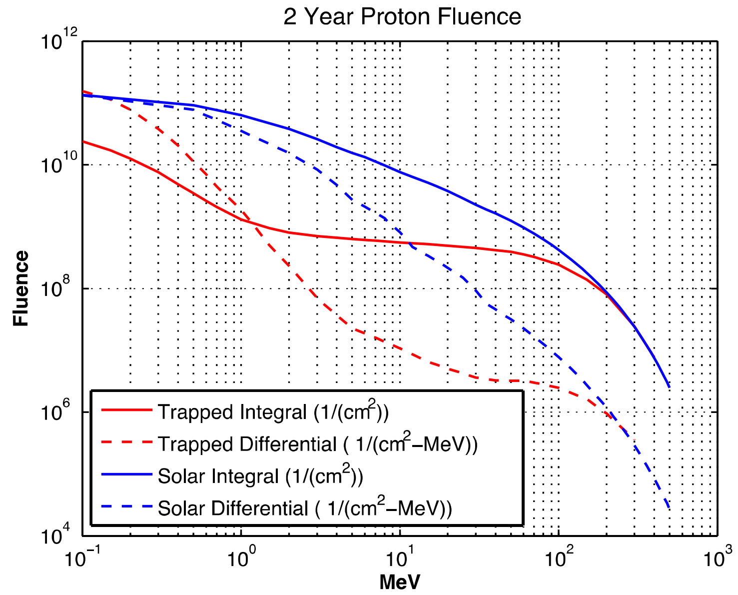


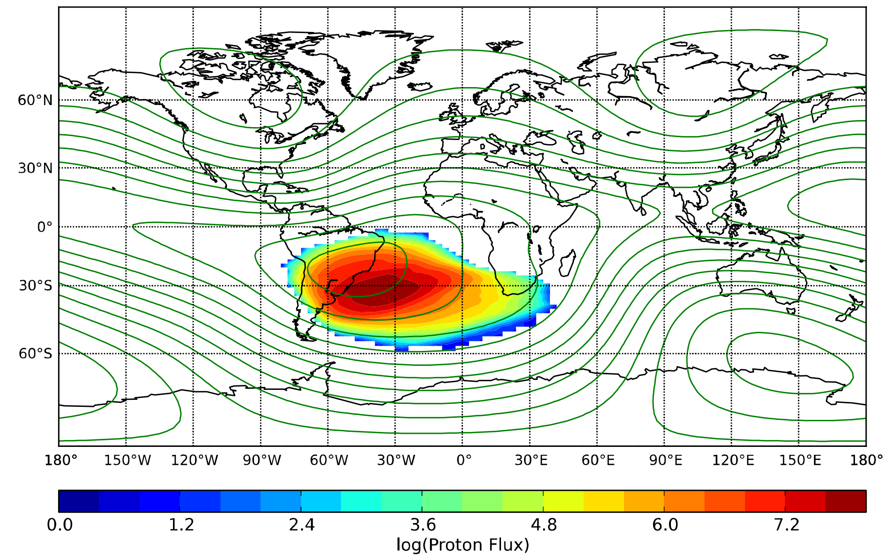



Earth's Magnetic Field

Environment – Spectra and Shielding

- Model environment with SPENVIS
- Flux AND energy important – Spectra
  - Average spectra useful, but flux not uniform temporally or geographically!
- Shielding attenuates some particles
  - Effectiveness: Electrons > Low energy protons > high energy protons
- Heavy ions – low flux, big damage!

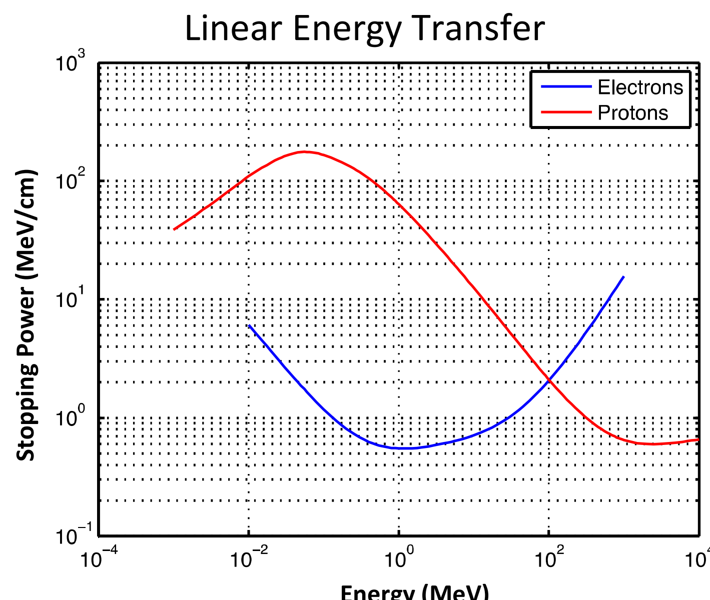


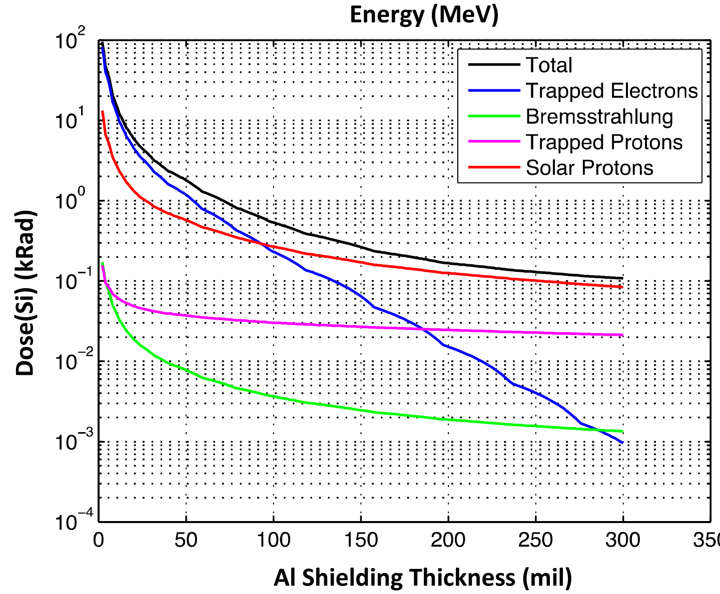


Global Flux at 600km and the South Atlantic Anomaly

Environment LET and TID

- Linear Energy Transfer (LET)
  - Rate at which a particle loses energy moving through matter (material dependent)
  - Higher LET -> higher probability of single event effect
  - LET $\propto$ stopping power – effectiveness of shielding
- Total Ionizing Dose (TID)
  - Measure of accumulated material damage due to ionizing radiation over time
  - For particles ~ LET x Fluence

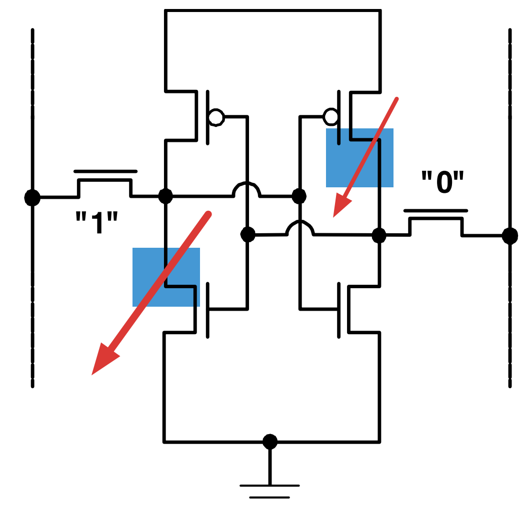




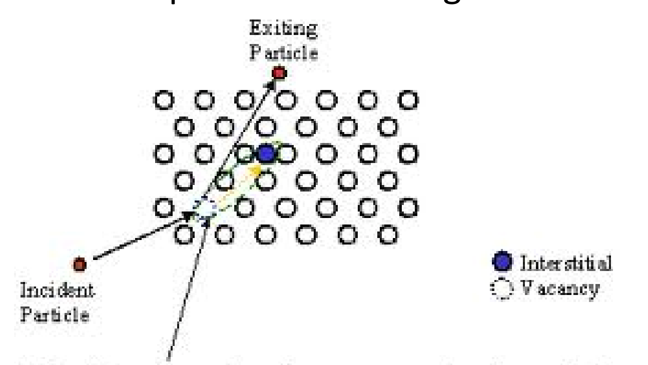
Radiation effects and damage mechanisms

- Single Event Effects
  - "Event in time" – associated with single particle strike
  - Effects range from annoying to catastrophic
  - Single Event…
    - Upset (SEU) – bit flip in memory
    - Latch-up (SEL) – Parasitic SCR "short"
    - Burn-out (SEB) – Destructive transistor short
    - Functional Interrupt (SEFI) – Digital reconfiguration (FPGA, registers, etc)
- Cumulative Effects
  - MOS transistor threshold voltage changes (TID)
  - Bipolar transistor gain drops (TID + Displacement Damage)
  - Optical lenses/fibers turn brown

SRAM SEU-sensitive regions



Displacement Damage



A Frenkel pair consists of a vacancy and an interstitial atom.

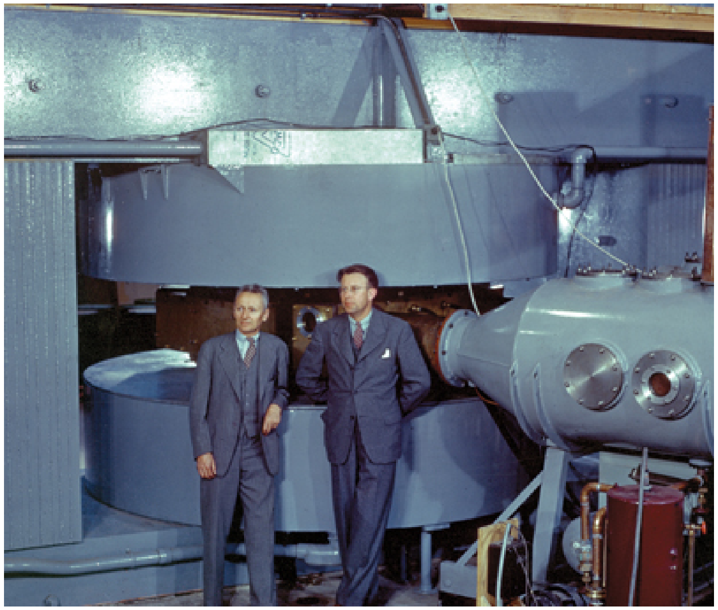
Design Best Practices

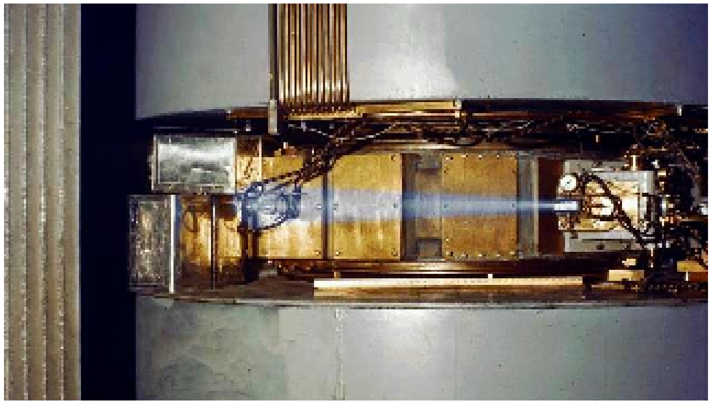
There are circuit design techniques that will increase survivability

- Choose lowest supply voltages and duty cycles
  - Low bias reduces SEL. Massive derating reduces SEB.
  - Zero bias eliminates single event effects, and reduces TID effect.
- Reduce number of different ICs
  - Few massively integrated parts more likely to succeed than many less complex parts
- Plan for SEUs
  - Make sure no I/O pin reconfiguration can cause damage
  - Find COTS memories with built-in ECC
  - Implement software ECC where hardware ECC unavailable

Radiation test options

- Gamma source (Co-60, etc)
  - TID only, no SEE
  - Cheap ($)
- Proton
  - TID and displacement damage
  - SEE up to LET ~ 25 MeV-cm^2/mg from heavy ion generation
  - Need cyclotron / synchrotron to get high enough energies
  - More Expensive ($$)
- Heavy Ion
  - Primarily high energy SEE
  - Low energy source – must decap parts
  - High energy source – massive facility
  - Very expensive ($$$)





Lawrence and his 60in Cyclotron ionizing air

Evaluating Test Success

- Test 2 boards, built from controlled flight-candidate lots
- Board #1 test to expected dose
- Board #2 test to 2x expected dose
- Anneal boards following dose

- If both boards survive, unconditional success
- If board #1 survives but board #2 fails in cumulative dose, marginal success
  - Either reduce design life by 50%, or add shielding (bulk or spot)
- If both boards fail, or any destructive SEE seen, test unsuccessful
  - Must revise design and re-test

Typical Failure Mechanisms

- TID and Displacement Damage
  - Drift in analog components – voltage refs. usually first to go
  - Increased leakage, timing / propagation change, eventual failure in digital electronics
- Single Event Effects
  - Unacceptably high SEU (need ECC)
  - Destructive SEL (CMOS) or SEB (N-MOSFET)
  - Hardware reconfig SEFI – FPGA’s, complex CPU / MCU

Why we like our approach

- Modern high-performance tightly-integrated parts
  - Low mass, volume and power of final product
  - Overnight availability allows rapid design revision
  - Technology familiar to many non-space engineers
- Quantified radiation lifetime
  - Test at the board level with protons, most closely simulating the space environment
  - Satellite owners can make sensible business decisions
  - We all sleep better when hope is replaced by certainty