The NASA Electronic Parts and Packaging (NEPP) Program – *Results and Direction*

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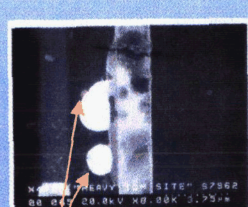
Outline of Presentation

- Introduction – a NEPP overview
- Partnering and Impact on the Community
- Cost of Doing Business
- Highlights of FY06 (Current Tasks)
- FY07 Task Planning Based on FY06 Tasks and New Efforts

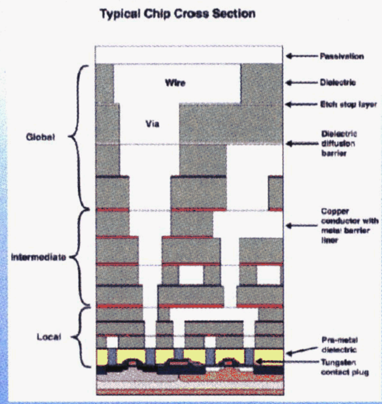


Latent damage sites: device did not fail during ground irradiation, but at some time afterward

To be presented by Kenneth LaBel at Radiation Hardened Electronics Technology (RHET) Meeting, Denver, CO 10/24-25/06.

NEPP Mission

- The NEPP mission is to provide guidance to NASA for the selection and application of microelectronics technologies, to improve understanding of the risks related to the use of these technologies in the space environment and to ensure that appropriate research is performed to meet NASA mission assurance needs.
- NEPP subset: NASA Electronic Parts Assurance Group (NEPAG)
  - *Focuses on daily needs of parts assurance knowledge-base*



A typical IC takes over 1500 processing steps

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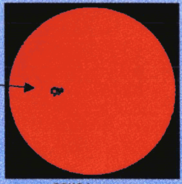
NEPP Program – Goals and Objectives

- Main goal – *Mission reliability* to meet NASA exploration and science objectives
  - *Ensure reliability of missions by "smart" investments in EEE parts technology, knowledge gathering and research*
    - Minimize engineering resources required to maximize space and earth science data collection
- NEPP objectives
  - Evaluate NASA needs for and reliability/radiation issues of new and emerging EEE technologies *with a focus on near to mid term needs*
    - Explore failure mechanisms and technology models
  - Develop guidelines for technology usage, selection, and qualification
  - Investigate radiation hardness assurance (RHA)/reliability issues
    - Increase system reliability and reduce cost and schedule

"There's a little black spot on the sun today"



SOHO Image

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NEPP and NEPAG: Overview

Feature	NEPP	NEPAG
Target customer	Projects in preliminary design and planning phases	Projects in or near hardware build phases
Target technologies	Current state-of-the-art and next generations	Commercially available
Sample partners	Technology developers, radiation hardened microelectronics programs	Defense Supply Center Columbus (DSCC)
Sample products	Technology guidelines, test methods, evaluation reports, models	GIDEP alerts, FAs, DPA,s audit report
Website (w/ cross-links)	nepp.nasa.gov	nepag.nasa,gov
Other information dissemination paths	Conferences, NEPP flash and newsletter	Weekly telecon, GIDEP system, space parts working groups

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5

Samples of NEPP Impact to the Community (1 of 2)

NASA Flight Projects and some of the related areas that NEPP has provided a knowledge-base that has directly aided flight projects

- MAP
  - Single Event Transients (SETs) – anomaly resolution led to NASA alert
- TERRA
  - Optocouplers, Solid State Recorders (SSR), High Gain Antenna anomaly
- AURA
  - Oscillators
- AQUA
  - Interpoint DC-DC converters
- TRMM, XTE
  - SSRs, Fiber Optics
- TOPEX/Poseidon
  - Optocouplers
- SeaStar
  - SSRs
- Launch Vehicles
  - Optocouplers
- Suborbital
  - Parts screening
- LWS
  - FPGAs, memories
- Hubble Space Telescope
  - Optocouplers, Capacitors, SSRs, Fiber Optic Data Bus (FODB), Xilinx FPGAs, detector technologies
- Hubble Robotic Servicing
  - Processors, memories, FPGAs, packaging
- JWST
  - Detector technologies, memories
- Cassini
  - Interpoint DC-DC converters, optocouplers, processors
- AXAF/Chandra
  - Optics
- SWIFT
  - ACTEL FPGAs
- MER, MRO
  - ELDRS, Processors, Memories, Packaging, FPGAs
- ISS
  - Fiber optics, wire/cable
- Shuttle
  - ACTEL FPGAs, capacitors
- GLAST
  - Lasers

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6

Samples of NEPP Impact to the Community (2 of 2)

NEPP has supported DoD and other government anomaly/problem issues, technology developments, as well as joint knowledge-base development that have import to the NASA community

In addition, NEPP has worked with industry to develop improved products for spaceflight including many small businesses

- Government partners
  - DoD
    - USD(AT&L)
    - Defense Threat Reduction Agency (DTRA)
    - Air Force Research Laboratory (AFRL)
    - Air Force Space and Missile Command (AFSMC)
    - Missile Defense Agency (MDA)
    - Defense Advanced Research Projects Agency (DARPA)
    - NAVSEA
    - NAVAIR
    - Naval Research Laboratory
    - US Army Strategic and Missile Defense Command (USASMDC)
    - OGA
  - DOE
    - Sandia National Laboratories
    - Lawrence Livermore National Laboratories
    - Brookhaven National Laboratories
    - Los Alamos National Laboratories
  - NSF
    - National Superconducting Cyclotron Laboratory
  - ESA
  - JAXA
  - CNES
- Industry partners
  - Actel
  - Lambda/International Rectifier
  - Interpoint
  - Vishay
  - Presidio
  - BAE Systems
  - Honeywell
  - Aeroflex
  - Intersil
  - Xilinx
  - IBM
  - Freescale (formerly Motorola)
  - Cardinal
  - LSI Logic
  - Ball Aerospace
  - ATK
  - Micro RDC
  - Seakr
  - Maxwell
  - Texas Instruments
  - SAIC
  - Boeing

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Sample Partnership Matrix

Task Area	Other Government	Industry	University	NASA
Scaled CMOS	DARPA, AFRL, LANL, NAVSEA, MDA, OGA, AFOSR – in-kind; DTRA – direct funding, in-kind	TI, Samsung, Elpida, IBM, Boeing, Xilinx, Actel, Aeroflex, Nantero, Freescale– test samples, Mayo Foundation – mitigation design, packaging	Vanderbilt, Arizona State MIT – modeling and data analysis - test support	Multiple flight programs
SiGe Radiation	DARPA, OGA, AFOSR – in-kind; DTRA – direct funding, in-kind	Jazz Semiconductor, IBM, TI – test samples, Mayo Foundation – mitigation design, packaging	Auburn, Georgia Tech, Arizona State, Vanderbilt – modeling and data analysis	RHESE - (Georgia Tech)
Sensor Technology	AFRL – test samples, joint test; DTRA – direct funding, in-kind	Ball Aerospace, Raytheon, Full Circle Research – joint test and data analysis	U of Arizona, U of Hawaii	JWST, HST WFC3

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Hypothetical New Technology Part Qualification Cost

Item	Cost	Note
Parts Procurement (500-1000 devices for testing only)	$25-1000K	Individual device costs can run from cents to tens of thousands
Standard Qualification Tests	$300K	
Radiation Tests and Modeling	$400K	Assumes total dose and single event (heavy ion) only
Failure Modes Analysis	$300K	Out-of-the-box look at the "hows and whats" for non-standard research required for qualification
Additional Tests, Modeling, and Analysis based on Failure Modes	$500K	
Total cost for one device type	$1.5-3M	Not all new technologies will meet standard qualification levels: technology limitations document

Assumption: it takes 12-24 months to develop sufficient data for technology confidence

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The Increasing Cost of Doing Business -

Example: Radiation Single Event Effect Test Costs
Qualification Testing of a Commercial Memory – 1996 to 2006 (1 of 2)

- Device under test (DUTs): Commercial Memory
  - For use in solid state recorder (SSR) applications
- 1996
  - SRAM memory
    - 4 Mbits per device
    - <50 MHz bus speed
    - Ceramic packaged DIP or LCC or QFP
- 2006
  - DUT: DDR2 SDRAM
    - 1 Gbit per device
    - >500 MHz bus speed
    - Plastic FBGA or TSOP
    - Hidden registers and modes
    - Built-in microcontroller

- Issues
  - Size of memory
    - Drives complexity on tester side for amount of storage, real time processing, and length of test runs
  - Speed
    - Difficult to test at high-speeds reliably
      - Need low-noise and high-speed test fixture
    - Classic bit flips (memory cell) extended to include transient propagation (used to be too slow a device to respond)
    - Thermal and mechanical issues (testing in air/vacuum)
  - Packaging
    - Modern devices present problems for reliable test board fixture, die access (heavy ion tests) requiring expensive facility usage or device repackaging/thinning
    - Difficulty in high-temp testing (worst-case)
  - Hidden registers and modes
    - Functional interrupts driving "anomalous data"
      - Not just errors to memory cells!
  - Microcontroller
    - Not just a memory

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Example: Radiation Single Event Effect Test Costs

Qualification Testing of Commercial Memories - 1996 to 2006 (2 of 2)

1996 SEE Test of a 4M SRAM				
Description	Man-weeks or units	Cost in $	Total	Note
Heavy Ion at BNL SEUTF				
Test plan	0.20	$4,000.00	$800.00	Includes eng, rad, other to define what needs to go into test set with project.
Device procurements	10.00	$50.00	$500.00	
Misc parts	1.00	$250.00	$250.00	Sockets, connectors, etc...
Device delidding	0.05	$3,500.00	$175.00	
Test board design - electrical and layout	0.40	$4,000.00	$1,600.00	
Board fab and population	1.00	$3,500.00	$3,500.00	In-house board build
Board/tester debug	0.50	$4,000.00	$2,000.00	
Rad expert (test oversight and plan)	0.40	$5,000.00	$2,000.00	
Heavy ion test performance - contractor	2.00	$1,500.00	$3,000.00	
BNL Beam	6.00	$700.00	$4,200.00	Simple data: bit flips, latchup
Data analysis	1.00	$3,500.00	$3,500.00	
Test report (eng, rad expert, rad lead)	0.50	$4,000.00	$2,000.00	
			Total:	$23,525.00

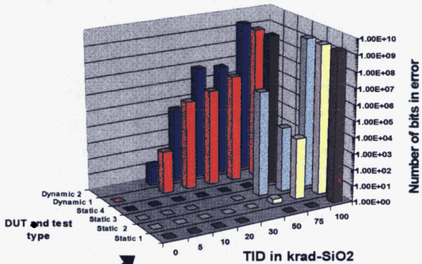
2006 SEE Test of SDRAM				
Description	Man-weeks or units	Cost in $	Total	Note
Heavy Ion at TAMU				
Test plan	1.00	$4,000.00	$4,000.00	Includes eng, rad, other to define what needs to go into test set with project.
Device procurements	10.00	$75.00	$750.00	
Misc parts	1.00	$1,000.00	$1,000.00	Higher speed drives cost
Device thinning and package processing	10.00	$350.00	$3,500.00	Assumes FBGA package; If this does not work, more expensive test facility like NSCL needed: >$100K delta
Daughterboard Board design - electrical	0.40	$4,000.00	$1,600.00	
Daughterboard Board design - PCB	0.50	$3,500.00	$1,750.00	
Test Boards	10.00	$500.00	$5,000.00	
Board population	0.40	$3,500.00	$1,400.00	
Board/tester debug	0.50	$4,000.00	$2,000.00	
Tester VHDL development	3.00	$4,000.00	$12,000.00	
Technician	1.00	$3,500.00	$3,500.00	
Rad expert (test oversight and plan)	0.60	$5,000.00	$3,000.00	
Heavy ion test performance - contractor	2.00	$2,000.00	$4,000.00	
TAMU	16.00	$750.00	$12,000.00	2X time required: more data, more error types, more complex results
Data analysis	3.00	$3,500.00	$10,500.00	
Test report (eng, rad expert, rad lead)	1.00	$4,000.00	$4,000.00	
			Total in	$70,000.00

1996 vs 2006 a 3X Cost Delta

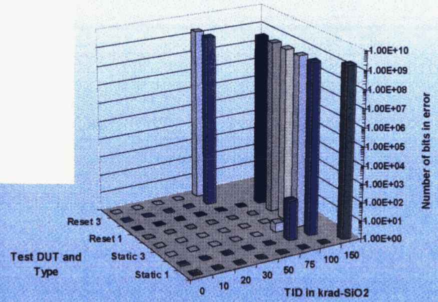
Other test costs (radiation and reliability) have increased commensurately!

State-of-the-art Flash Memory Evaluation

Micron 2Gb NAND Flash - Number of Bad Bits
90 nm CMOS



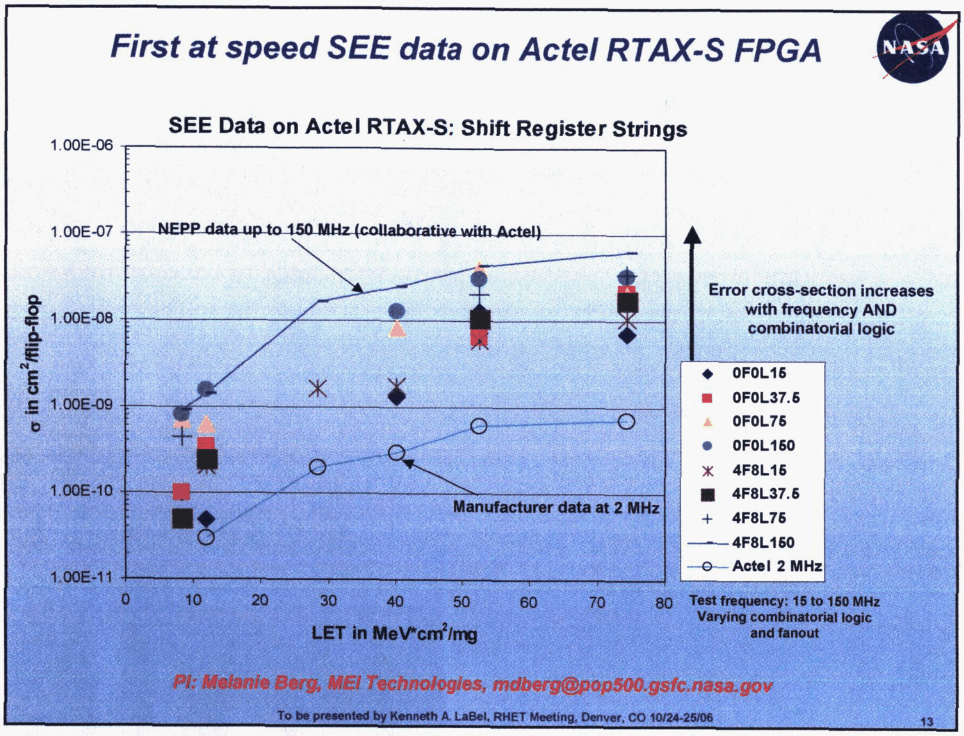
ST 1Gb NAND Flash - Number of Bad Bits
110 nm CMOS



Note mode dependence of results.
Novel error mode observed

NEPP evaluates state-of-the-art and emerging non-volatile memories (NVMs) focusing on:
- Technology, architecture, and application issues

PI: Tim Oldham, QSS Corp, toldham@pop500.gsfc.nasa.gov


First at speed SEE data on Actel RTAX-S FPGA
SEE Data on Actel RTAX-S: Shift Register Strings
NEPP data up to 150 MHz (collaborative with Actel)
Manufacturer data at 2 MHz
Error cross-section increases with frequency AND combinatorial logic
0F0L15
0F0L37.5
0F0L75
0F0L150
4F8L15
4F8L37.5
4F8L75
4F8L150
Actel 2 MHz
σ in cm²/flip-flop
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E-11
0
10
20
30
40
50
60
70
80
LET in MeV*cm²/mg
Test frequency: 15 to 150 MHz
Varying combinatorial logic and fanout
PI: Melanie Berg, MEI Technologies, mdberg@pop500.gsfc.nasa.gov
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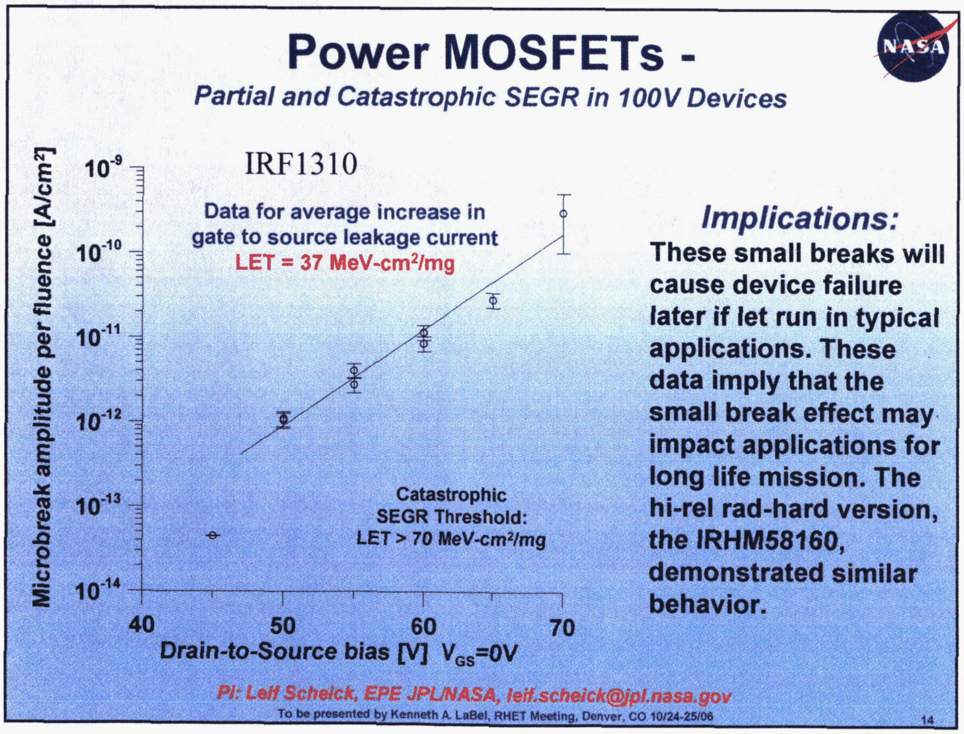
13


Power MOSFETs -
Partial and Catastrophic SEGR in 100V Devices
IRF1310
Data for average increase in gate to source leakage current
LET = 37 MeV-cm²/mg
Catastrophic SEGR Threshold: LET > 70 MeV-cm²/mg
Microbreak amplitude per fluence [A/cm²]
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁻¹⁴
40
50
60
70
Drain-to-Source bias [V] V_GS=0V
Implications:
These small breaks will cause device failure later if let run in typical applications. These data imply that the small break effect may impact applications for long life mission. The hi-rel rad-hard version, the IRHM58160, demonstrated similar behavior.
PI: Leif Scheick, EPE JPL/NASA, leif.scheick@jpl.nasa.gov
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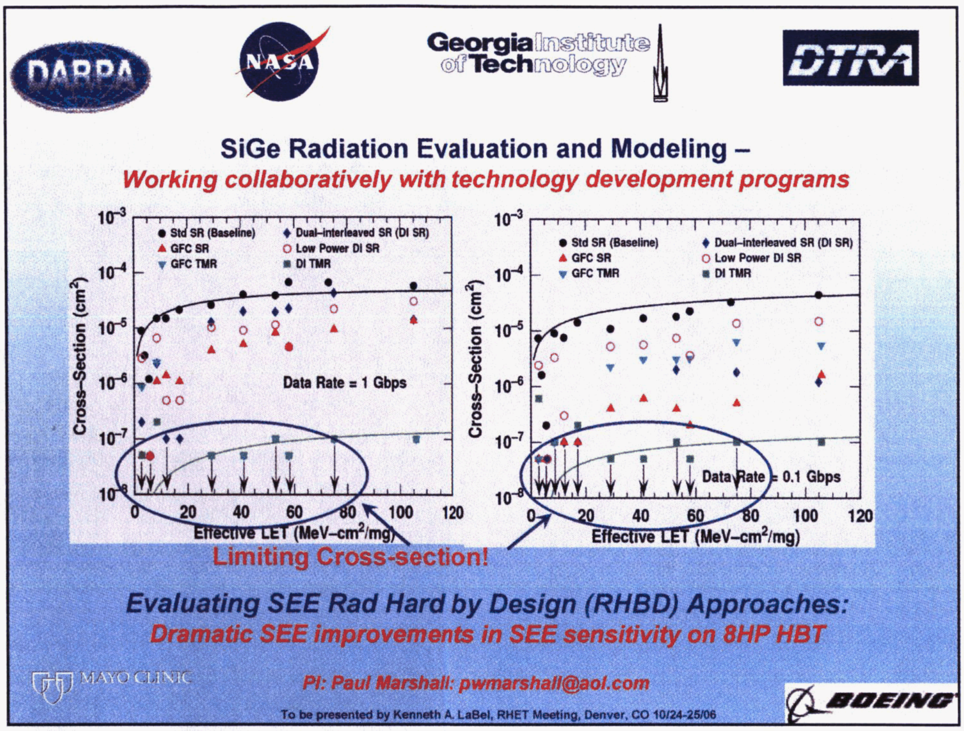
14


DARPA
NASA
Georgia Institute of Technology
DTRA
SiGe Radiation Evaluation and Modeling –
Working collaboratively with technology development programs
Std SR (Baseline)
GFC SR
GFC TMR
Dual-interleaved SR (DI SR)
Low Power DI SR
DI TMR
Data Rate = 1 Gbps
Data Rate = 0.1 Gbps
Cross-Section (cm^2)
Effective LET (MeV–cm^2/mg)
Limiting Cross-section!
Evaluating SEE Rad Hard by Design (RHBD) Approaches:
Dramatic SEE improvements in SEE sensitivity on 8HP HBT
MAYO CLINIC
PI: Paul Marshall: pwmarshall@aol.com
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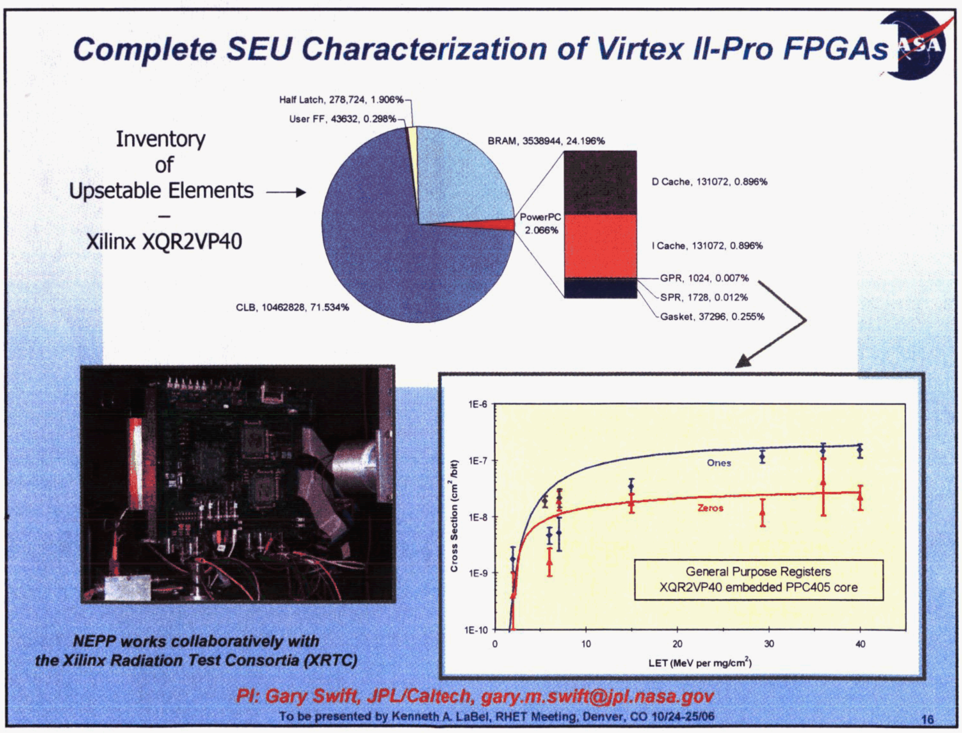
BOEING


Complete SEU Characterization of Virtex II-Pro FPGAs
NASA
Inventory of Upsetable Elements – Xilinx XQR2VP40
Half Latch, 278,724, 1.906%
User FF, 43632, 0.298%
BRAM, 3538944, 24.196%
PowerPC 2.066%
CLB, 10462828, 71.534%
D Cache, 131072, 0.896%
I Cache, 131072, 0.896%
GPR, 1024, 0.007%
SPR, 1728, 0.012%
Gasket, 37296, 0.255%
Ones
Zeros
General Purpose Registers
XQR2VP40 embedded PPC405 core
Cross Section (cm^2/bit)
LET (MeV per mg/cm^2)
NEPP works collaboratively with the Xilinx Radiation Test Consortia (XRTC)
PI: Gary Swift, JPL/Caltech, gary.m.swift@jpl.nasa.gov
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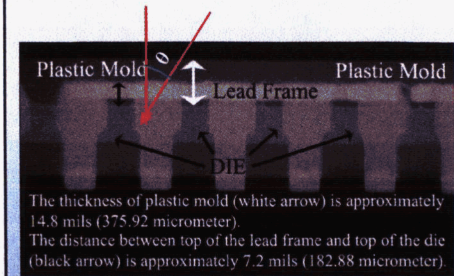
16

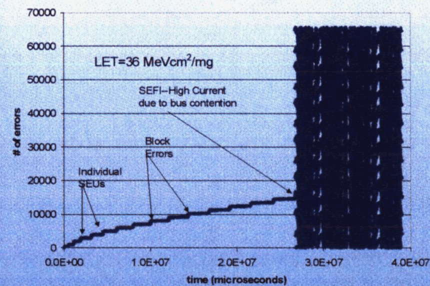
State-of-the-art SDRAM Memory Evaluation –

Challenges for test preparation and data collection/analysis



X-Ray Photo of a DUT

Determining effective LET as a function of angle requires correcting for the energy lost by the ion as it traverses overburden to the sensitive volume, as well the usual 1/cosθ dependence.



NEPP evaluates state-of-the-art and emerging SDRAMs focusing on:
- Technology, architecture, and test methodology issues

PI: Ray Ladbury, NASA-GSFC, rladbury@pop500.gsfc.nasa.gov

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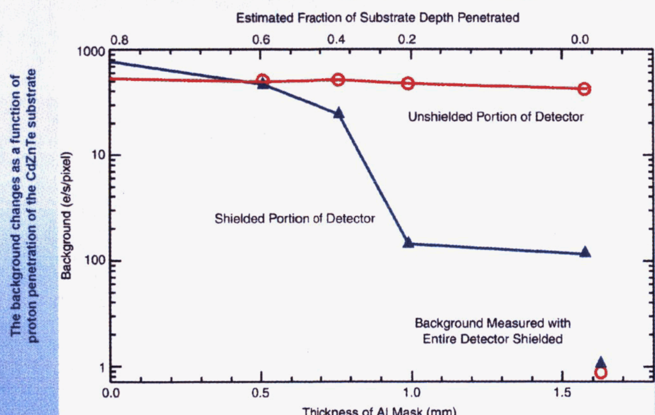
Sensor Technologies – Key Results



The background changes as a function of proton penetration of the CdZnTe substrate

Investigation of anomalously high background noise in infrared imagers during proton irradiation

-DUT:	1.7 micron Wide Field Camera 3 (WFC3) HgCdTe imagers for Hubble Space Telscope
-Issue:	High background signal which was about 10 times higher than expected at 150K temperature
-Suspected cause:	Proton-induced luminescence in the CdZnTe substrate.
-Verification of cause:	Probe the detector layers with proton beams of varying energy and therefore varying penetration depths as shown in the graph above
-Results:	Validated hypothesis

WFC3: new devices with substrate removed were acquired and tested with protons in December 2005. No evidence of the luminescence-induced background was observed. HAPPY SCIENTISTS!

PI: Cheryl Marshall, NASA-GSFC, cmarshall2@aol.com

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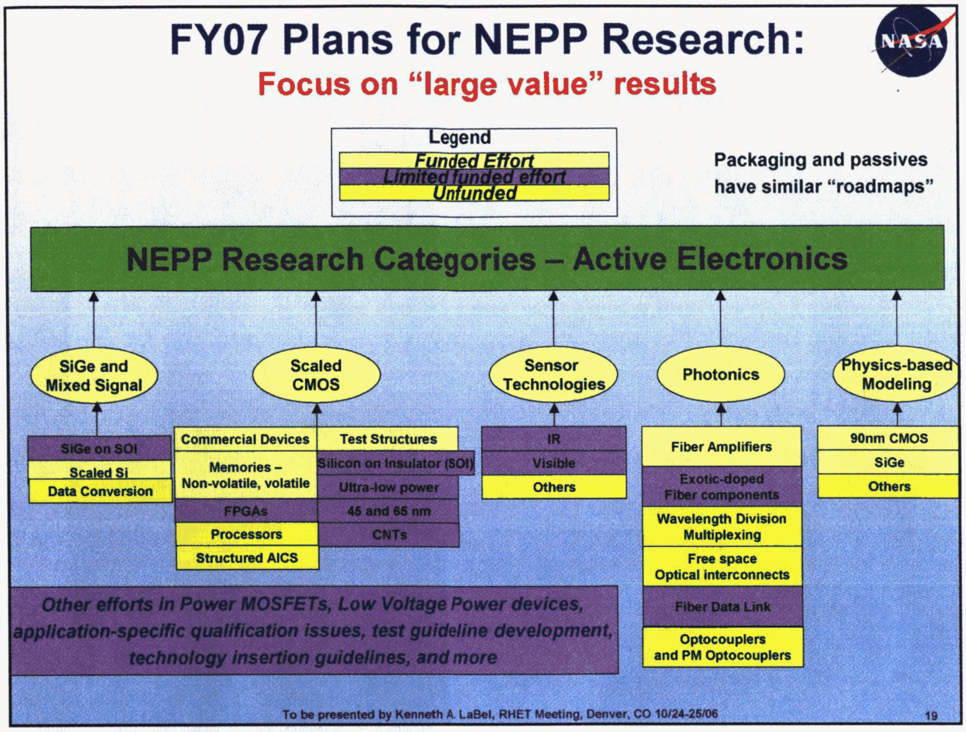

Summary and Comments

- NEPP Provides Critical Guidance for Flight Projects
  - Challenge: Keeping ahead of the flight projects
    - New technology devices are often inserted by flight projects at 1st silicon; the same time NEPP gets access to the technology!
    - Given a 12-24 month time period for test, evaluation, and qualification definition as a minimum, flight projects take a large risk by not waiting.
      - *We provide guidance, but are not policeman!*
- NEPP Partners Throughout the Aerospace Industry
  - NEPP/NEPAG lead in fostering information exchange throughout NASA and the community
    - Example: NEPP has initiated partnering with the Radiation Hardened Electronics for Space Exploration (RHESE) Program
- NEPP Strives to Develop Cost-Effective Qualification Methods
  - Challenge is the ever-increasing cost of doing business
- Suggested NEPP Augmentation Areas
  - Sample technical effort shortfalls were highlighted in FY07 plans
    - Example: Entire NEPP planned FY07 budget could be used for FPGA efforts!
  - New training modules are required for new technology insertion
    - More than just a parts, packaging, and radiation issue
    - Currently collaborating with CNES, ESA and others on radiation training class (SERESSA)
  - Increased university presence
    - Shortfall of qualified parts, packaging, and radiation specialists
      - Example: Difficulty in finding US citizens for radiation positions
    - Scholarships, post-doc opportunities, etc are being considered

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