The NASA Electronic Parts and Packaging (NEPP) Program: Roadmap for NASA's Radiation Effects on and Reliability of Electronics Efforts - Update

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To be presented by Ken LaBel at the Government Microcircuits Application Conference (GOMAC), San Diego, CA 3/20/06-3/24/06

Outline

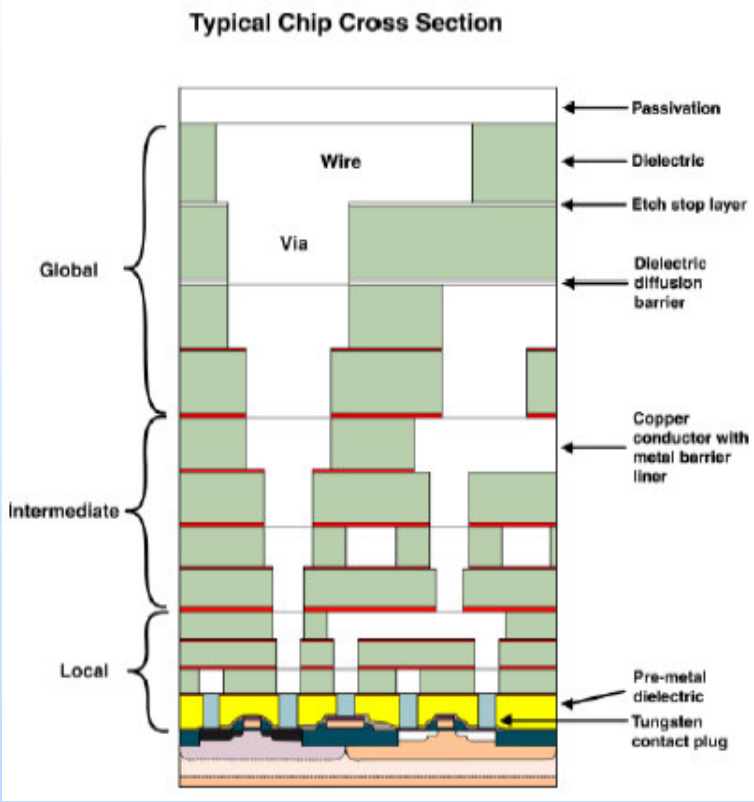
- **NEPP Mission and Overview**
  - **Goals and Objectives**
  - **NASA Electronic Parts Assurance Group (NEPAG) – a subset of NEPP**
- **Sample FY06 Tasks**
- **A Proposal for a New Space Parts Advisory Committee (NSPAC)**

Abstract:

The NEPP Program is responsible for developing the plans for and leading the research on reliability and radiation response in the space and aeronautics environments. Presented herein is the updated NASA task list as well as a consideration of future research areas.

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.**

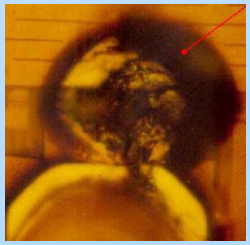


NEPP Overview

- **NEPP has been a One NASA success story for more than 15 years; 7 NASA Centers and JPL actively participate**
- **The NEPP Program focuses on the reliability aspects of electronic devices (integrated circuits such as a processor in a computer or optical components such as might be used in a communication link like in phone lines).**
- **There are three principal aspects of this reliability:**
  - **Lifetime, inherent failure and design issues related to the EEE parts technology and packaging,**
  - **Effects of space radiation and the space environment on these technologies, and**
  - **Creation and maintenance of the assurance support infrastructure required for mission success.**

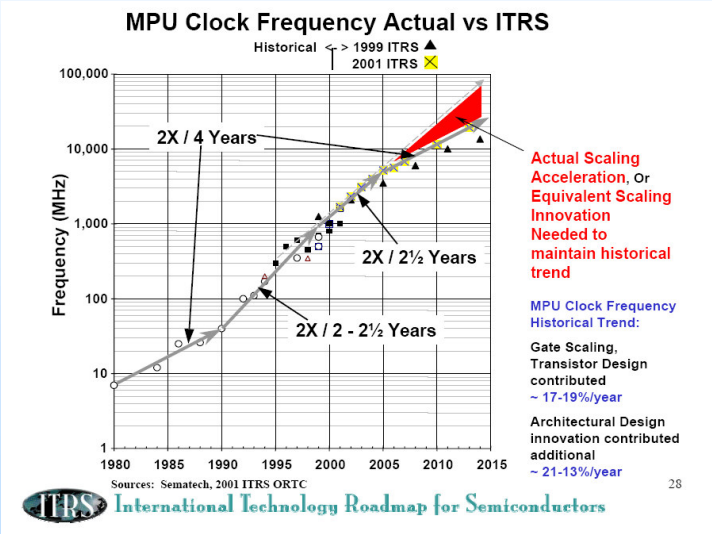
Electrical overstress failure

in a commercial electronic device



NEPP Overview – cont'd

- NEPP interests span EEE parts technologies from those just emerging from research to commonly-used "building block" parts for every mission
- NEPP is multi-disciplinary involving radiation, materials, test, experimentation, process and specification experts across NASA and its partners
- NEPP has close, cooperative and long-standing relationships with government and non-government entities worldwide
- NEPP provides a unique capability within NASA to evaluate technologies in advance of mission needs, to provide assistance with risk management of technology insertion

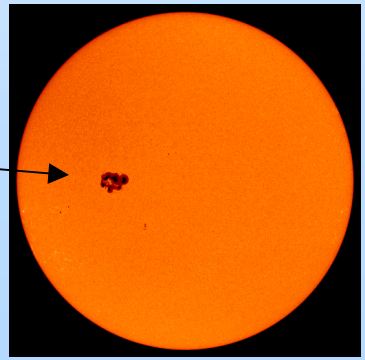


Increasing device speed is a challenge for test, validation, and qualification

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 by knowledge gathering and research***
    - **Minimize engineering resources required to maximize safety as well as ensure space and earth science data collection**
- **NEPP objectives**
  - **Evaluate 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**

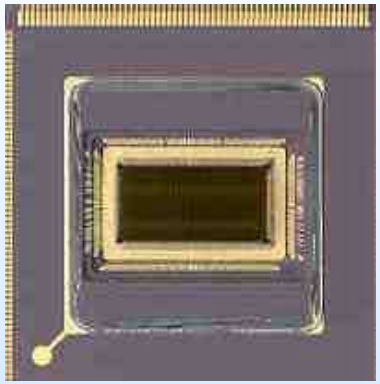
"There's a little black spot on the sun today"
- A precursor to a solar particle event



SOHO Image

NASA EEE Parts Assurance Group (NEPAG) A Subset of NEPP

- **A flexible, multi-entity, multi-national,cooperative group**
  - **Organized and led by NASA but includes government and non-government entities worldwide**
- **Objective: To limit the number of EEE parts failures both on-orbit and on the ground**
  - **Emphasis is on mature and already deployed technologies**
- **Develops tools, shares information & resources as One NASA**
  - **Supports vendor audits, specification reviews and problem part investigations in support of US MIL system**
  - **Supports efforts of non government standards bodies:**
    - **Electronic Industries Alliance (EIA) and JEDEC**
  - **Investigates problems and performs focused evaluations on "basic" technologies, notably passives**
- **Complements NEPP focus and objectives**
  - ***One Continuum***

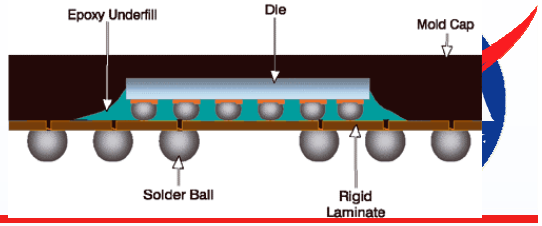


ACTEL RTSX72S FPGA

A part that passed "standard" qualification, but requires more complex testing

FY06 NEPP Sample Tasks

Microelectronics Radiation Test and Evaluation
(Includes NVMs, Mass Memories, Scaled CMOS)



Description:

This is a continuation task for evaluating the effects of scaling (<100nm) , new materials, etc. on state-of-the-art CMOS technologies. The intent is to:

- Determine inherent radiation tolerance and sensitivities,
- Identify challenges for future radiation hardening efforts,
- Investigate new failure modes and effects, and
- Provide data to DTRA/NASA technology modeling programs.

Testing includes total dose, single event (proton and heavy ion), and proton damage (where appropriate)

Test vehicles are expected to be: memories (SDRAMs, SRAMs), non-volatile memories (Flash, nanocrystal, other), as well as test transistors and structures. Related data from NASA FPGA efforts will be applied as well.

FY06 Plans:

This is essentially a test and report task. The plan is straightforward.

-Obtain appropriate test samples via: partnering or procurement.
-Develop appropriate test setup.
-Perform radiation tests.
-Analyze test data. Investigate further new failure modes and effects
-Provide test report.
-In the case of partnering, work with the vendor on result interpretation.

For FY06 in particular, main partnered efforts include:

-Test transistors from vendor partner and IMEC/ESA
-Test chips from LSI Logic (including “hardened” versions)
-SDRAMs from Samsung (90nm and below)
-Si Nanocrystal (and hopefully CMOS SRAM arrays) from Freescale, and,
-MRAM and CRAM tests as available

Other potential tests include commercial Flash (Micron, other), test chips from Fujitsu, and other SDRAMs.

IBM foundry evaluation effort pends available samples.

Schedule/Costs:

Microelectronics T&E	2005			2006								
	O	N	D	J	F	M	A	M	J	J	A	S
On-going discussions for test samples												
Radiation Test Sets Development												
Test Devices and reports			◆			◆					◆	

Deliverables:

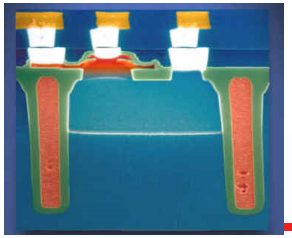
-Test reports
- Quarterly reports
- Expected submissions to SEE Symposium, IEEE NSREC, and RADECS.

NASA and Non-NASA Organizations/Procurements:

University partners: Vanderbilt University
Other agencies: DTRA, Navsea Crane, ESA
Industry:
- Test chips: Vendor X, LSI Logic, possible IBM, TSMC, IMEC
- SDRAMs: Samsung, Elpida
- NVMs: BAE, Honeywell, Micron, Samsung, Freescale, other
- FPGA: Xilinx, Actel, Aeroflex

Lead Center/PI: GSFC/LaBel/Poivey/Oldham/Ladbury
Lead Center/PI: Collateral work at JPL
Patterson/Johnston

Related Reliability Tasks at JPL



Radiation Effects in SiGe and Other High-Speed Technologies

Description:

SiGe microelectronics are commercially available high-speed, mixed signal technology applicable to a diverse range of digital, RF, and mixed signal wideband systems. In FY04-5, we proved this technology is extremely well suited for space with respect to ionizing radiation and particle damage issues, but problems arise due to the extreme sensitivity to soft errors. Our research has targeted these issues using collaborative test chips (including DoD-funded hardening methods) to acquire radiation effects data and support device physics and circuit level modeling.
In FY06, we propose to continue this effort by:
-Testing IBM 8 and/or 9HP, National SiGe, Jazz SiGe, and other commercial processes
-Modeling of technology for radiation and temperature effects.

FY06 Plans:

This task involves multiple parties providing testing (NASA), analysis and modeling (NASA, Georgia Tech, Auburn University, Vanderbilt University), and test device preparation (Mayo, Boeing)
-Radiation single event (heavy ion, proton) testing rad hard by design (RHBD) IBM 8hp shift registers designed by GT under the DARPA RHBD Program and packaged by Mayo. GT, et al to analyze data.
-Charge collection data on IBM 8HP and/or 9HP as available using SNL microbeam and/or NRL: laser. Jazz and NSC test samples will also be used as available.
-Continued TID (low dose and other) and proton damage tests on samples as available. Low dose rate data is expected by end of 1Q FY06.
-- We will also continue to seek samples of other competing technologies such as InP for comparison.
-We may also support Ron Pease in future high-speed tests as appropriate.

Schedule for FY05:

	2005						2006					
FY06	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**
Test circuit development												
Ion, proton, laser testing												
First Order Model												
SEU/SET in HBT												
On-orbit for IBM 5HP												

Lead Center/PI: **GSFC/ Paul Marshall**
Co-Is: **Ray Ladbury**

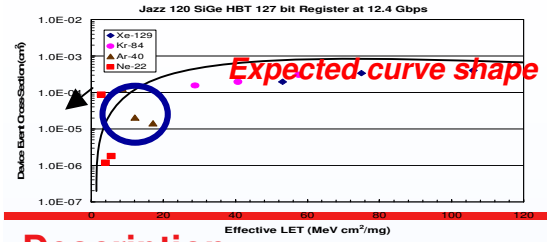
Deliverables (FY06 only):

- **Baseline (unhardened) technology performance**
- **Improved model of SEU/SET in HBTs**
- **Improved on-orbit model for IBM 5HP devices**
- **Test reports**
- **Expected submissions to NSREC, RADECS, and SEE Symposium**

NASA and Non-NASA Organizations/Procurements:

University: Georgia Tech, Auburn U., Vanderbilt
Industry: Mayo Foundation, Boeing
Other Government: SNL, NRL

Related Reliability Tasks (Extreme Temp) at NASA-GRC



Radiation Effects Simulation System Development

Description:

Several years of physics based research on radiation effect has led to well developed, conservative radiation environment models, ground-based test approaches, and performance prediction models. Recent research on emerging technology has uncovered several shortfalls in the techniques used to predict the component performance, i.e. the data cannot be collected in a way that it can be used as input to any existing model. A very promising approach to improving the prediction techniques involves the application and development of software packages to simulate radiation effects. The specific and immediate need is to develop Single Event Effect and displacement damage techniques.
FY05 and FY06 focus on first order model development.
The overall effort is dubbed RADSAFE and looks to tie in full circuit and system effects into a cognizant solution.

FY06 Plans:

This is a research tool development task focused on appropriate solutions for improving radiation effects prediction capabilities for modern devices. Ex., a replacement for CREME96 for SEE rate prediction tool. In FY06, we:

-Evaluate under another task emerging CMOS and utilize this to develop physics-based models of radiation performance
-Utilize data on optocouplers as above.
-Continue tool architecture to make realizable (I.e., not require weeks on a supercomputer) as well as define user needs more clearly
-Support use of framework for aiding Rad Hard foundry product development (re: low LET tail, etc) as required.
-Continue evaluating differing physics-based codes (GEANT4, FLUKA, etc) and developing appropriate particle models of interest for electronics technology.

Schedule for FY06:

	2004						2005					
FY05	O	N	D	J	F	M	A	M	J	J	A	S
Short Fall Document							■	■	■			
Framework Develpoment	■	■	■	■	■	■						
Technology Model												
SEE optodiode							■	■	■	■	■	■
SEE Advanced CMOS											■	■
	2005						**2006**					
FY06	O	N	D	J	F	M	A	M	J	J	A	S
Technology Model												
SEE optodiode	■	■	■	■	■							
SEE Advanced CMOS	■	■	■	■	■	■	■	■	■	■	■	■
First Order Tool												
SEE optodiode					■	■	■	■	■	■	■	■
SEE Advanc ed CMOS							■	■	■	■	■	■

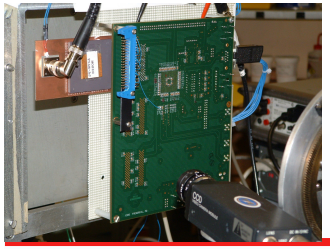
Lead Center/PI: Vanderbilt/Robert Reed
Co-Is: Vanderbilt/Robert Weller, et al, GSFC/ Mike Xapsos

Deliverables (FY06 only):

- Document short falls of current radiation performance models and tools
- Develop framework for user interface and models
- Develop preliminary technology model for advanced CMOS
-

NASA and Non-NASA Organizations/Procurements :

University: Vanderbilt University, U of Florida
Industry: EMPC (Tom Jordan)
Other Gov: SLAC
Other: GEANT4 Space User's Group, CERN, ESA, CNES, Qinetix



Digital SEE Test Board Development

Description:

Develop a board-level SEE tester based on the advanced Xilinx FPGAs to allow an "at speed", reconfigurable test platform. FY04 work delivered a survey of reprogrammable FPGAs for suitability and capabilities. Based on the recommendations from that work, the hardware and software was developed and tested, demonstrating the capability in FY05 using the Xilinx Spartan-III version of the tester.
The concept in FY06 is to complete V2Pro based tester modules for higher-speed and communication and re-spin design with Virtex-4 devices if deemed required.

FY06 Plans:

This is a straightforward plan to validate the new testers.
-Complete hardware development on v2 PRO tester
-Integrate VDHL modules for board support packages as needed including ethernet I/f
-Demonstrate high-speed test capabilities
-Determine if MGTs (>3GHz) can be used for BERT testing
-Test devices of interest and validate tester
-Determine if V4 version is needed and if so (and if ISI obtains other funds) develop.
-Document all aspects of the tester for tech transfer to other organizations.

Schedule for FY06:

FPGA Tester	O	N	D	J	F	M	A	M	J
Develop Modular Architecture									
Hardware/Software Development									
Hardware/Software Demonstration									
Periodic Tests and Reports									

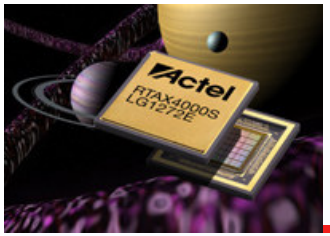
Lead Center/PI: GSFC/ Dr. James Howard
Co-Is: GSFC/ Ken LaBel, MEI/Melanie Berg, MEI/Hak Kim, ISI/Scott Stansbury

Deliverables (FY06 only):

- Full documentation (schematics, user guides, VHDL developer's guides
etc) for Spartan-III and V2Pro tester versions.
- Design is being "black-boxed" for outside groups
- Test reports using test vehicles for other NEPP/DTRA/flight program devices of interest.

NASA and Non-NASA Organizations/Procurements:

DARPA, DTRA, NAVSEA, ATK, Boeing, ISI



Radiation Effects on Volatile and Non-Volatile Field Programmable Gate Arrays (FPGAs)

Related Reliability Task at JPL/GSFC

Description:

FPGA (field-programmable gate array) technologies continue to advance, commercially and are highly desired by NASA flight projects as either low-cost or schedule-effective alternatives to custom ICs such as ASICs. Reprogrammable devices such as FPGAs are considered enabling for future reconfigurable processing efforts for space systems.

In this task, we will evaluate state-of-the-art commercial as well as new radiation hardened FPGA devices. We will also support radiation evaluation in support of developing new radiation hardened FPGA devices. Testing will be primarily focused on single events, variable frequency (including high-speed), and worst-case destructive issues. Heavy ions and/or protons will be utilized for these tests. Total ionizing dose tests may also be included.

FY06 Plans:

Test - Non-Volatile
- ACTEL RTSX-SU and ACTEL RTAX-S
- Aeroflex Eclipse
- ACTEL RHAX250-S (radhard - pending availability)

Test - Volatile
- Xilinx Spartan-III (commercial 90nm)
- Xilinx Virtex-IV

We may also support testing of test structures for:
-Defense Threat Reduction Agency (DTRA) Non-Volatile Rad Hard Reprogrammable FPGA development (ACTEL), and
-Air Force/MDA/NASA funded SEU Immune Reconfigurable FPGA (SIRF – Xilinx).
-A white paper on trade spaces of FPGA will be developed.
--JPL support Xilinx SEE Consortia testing and guideline development for reprogrammable FPGAs

Schedule/Costs:

FPGA Radiation Testing	2005			2006								
	O	N	D	J	F	M	A	M	J	J	A	S
SEU Test of RTAX-S and RTSX-SU		◆			◆							
Proton Test of Spartan-III	◆											
SEU Test of Eclipse					◆							
Proton Test of Virtex-IV						◆						
White paper on trade space							◆					
SEU Test of Virtex-IV								◆				
TBD other tests (TID/SEU)				◆						◆		
Potential LASER tests				◆					◆			

Lead Center/PI: Ken LaBel/GSFC, Melanie Berg/MEI Ray Ladbury/GSFC, Gary Swift/JPL

Deliverables:

-Test Reports (~2-4 weeks post-test)
-Test lessons/guidance (SEE Symposium presentation)
- Quarterly Reports
-TBD Technical papers documenting results (IEEE NSREC)
-White paper on FPGA trade space (rad hard versus performance vs…) (HEART Conference)

NASA and Non-NASA Organizations/Procurements:

Industry
- Xilinx, Actel, Aeroflex – all are partners
- ATK/MRC, SEAKR

University
- Vanderbilt University, BYU, U of NM (via AFRL)

Other Government
- DTRA, AFRL, MDA, NAVSEA Crane

TBD Beam procurements (TAMU, IUCF, other)

A Proposal for Developing a New Space Parts Advisory Committee (NSPAC)

To be presented by Ken LaBel at the Government Microcircuits Application Conference (GOMAC), San Diego, CA 3/20/06-3/24/06

Why is NSPAC Needed:

Lessons Learned from Recent Experiences

- **MIL-qualification methods may not adequately identify reliability or radiation issues with new technology (or architecture) devices**
- **Programs (designers) want to use these new devices for enabling electrical performance characteristics and believe the vendors statements on "qualification"**
  - **Head in the sand approach when vendors say all is good**
    - **No blame: devices passed standard MIL-qual**
  - **Fear of cost/time to perform additional reliability/radiation tests**
- **Design/application-related issues affect device reliability and radiation performance**
- **Programming algorithms/software may affect device reliability**

All complex new technologies should be considered.

Normal Accident Theory states that unexpected failures will occur in all complex systems

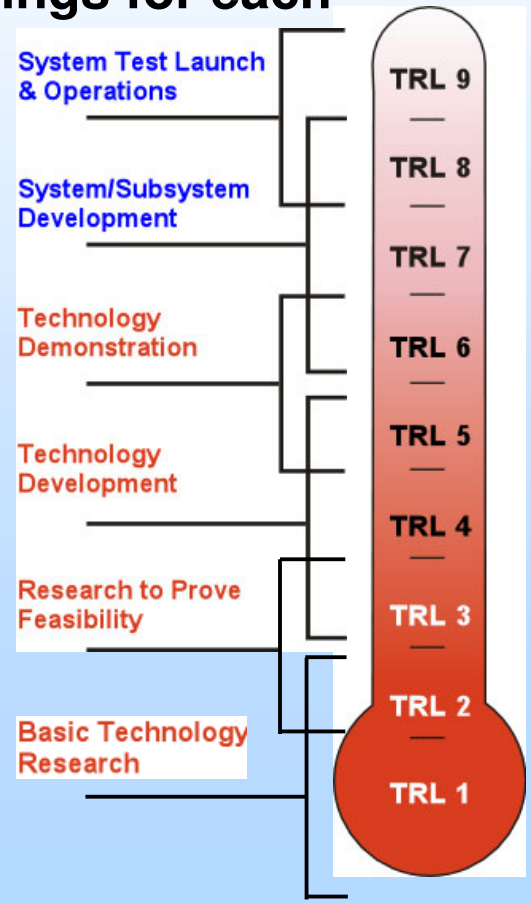
SO, How Do We Improve the Process?

- New devices need to be reviewed "out-of-the-box"
  - Not just "this is how we tested", but how relevant the standard qualification data/approach is and what is required to determine reliability
    - Consider this as a "360 degree" Failure Modes and Effects Analysis (FMEA)
  - Applies to: FPGAs and other devices such as new memories, processors, etc… as well as to changing process technologies (I.e., scaling, dielectrics, oxides, …) and packaging methods.
- A "National Space" approach is recommended
  - Form an an advisory committee responsible for review of qualification data/approach on key new electronics technologies/devices
    - A representative from each organization
      - Technical experts as required for each identified new device or technology
    - Meet quarterly with regular telecons
  - Understanding that "upscreening" does not increase reliability, but does attempt to measure it and eliminate defectives

New Space Parts Advisory Committee (NSPAC)

NSPAC Deliverables

- An overall NSPAC Readiness Rating modeled after the NASA Technology Readiness Level. Research to Mature = 1 to 9
- Overall rating to be compiled from ratings for each discipline (weighted?)
- Identification of primary factors affecting rating
  - The gaps to be filled
  - The tests needed
  - The evaluations needed
  - = The COST to meet risk
- Provides Project Manager with quick decision tools
  - Can I afford to mitigate the risk?
  - What resources do I need?
  - How long will it take?



Example: FPGAs

- **Goals:**
  - **Determine adequacy of existing qualification methods for the specific FPGA technology**
  - **Identify gaps in existing test data**
  - **Determine requirements for testing beyond standard MIL-qual**
    - **Use these requirements as guide for further device reliability/radiation testing**
- **Provide a "360 approach" similar to FMEA using multiple areas of expertise:**
  - **Design**
  - **Reliability**
  - **Radiation**
  - **Packaging**
  - **Semiconductor physics**
  - **Semiconductor process, etc**
- **The objective is NOT to add undue overhead to "qual" processes, but to identify risks that would remain unknown without further investigation**

Organizational Notes

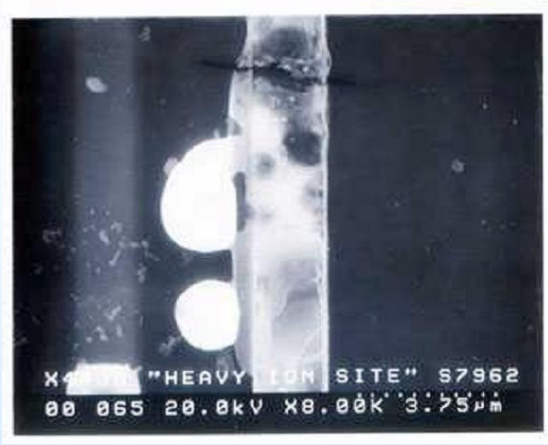
- We would partner with other government organizations such as
  - DoD
  - DOE
  - NASA
- We would also like to have industry involvement
  - Boeing
  - Lockheed Martin, etc…
- Each organization would provide "in-kind" support of NSPAC (I.e., fund their own participation)
- Further testing
  - Organizations can share existing plans and testing
  - Funding is TBD
    - Can be discussed on a case-by-case basis

Recommended Next Steps

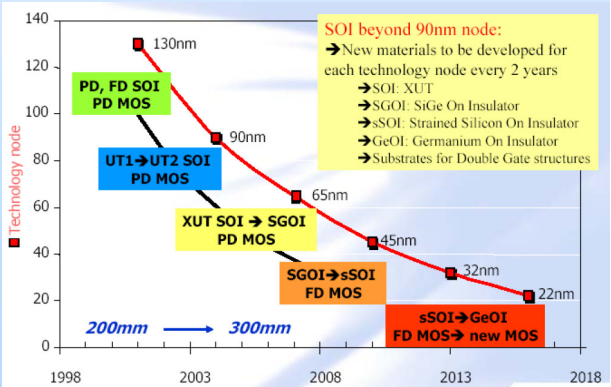
- **Near-term**
  - **Obtain agreement from principles to participate in NSPAC and get going!**
  - **NASA is working towards performing additional reliability/radiation tests on the RTAX-S device**
    - **So are most other government space oriented entities**
    - **A collaborative approach would reduce individual costs while expanding collective knowledge**
    - **Interagency collaboration on tests and results is essential**
- **Longer term**
  - **Identify device/technology list for review**
  - **Determine state of MIL-qual and test procedures for this list**

Summary Comments

- **Technology needs to be strategically planned**
  - **Long-term needs and not point solutions**
- **Mission risk revolves around radiation and reliability "unknowns"**
  - **Need a significant effort in advance of mission timelines for new technology development/testing/modeling**
    - **Infrastructure required to support technologies**
      - **Schedules don't allow time for creating new capabilities once mission design has started**
    - **Lower TRL technologies need evaluation as well**
- **Updated tools and models are required to reduce risk of new technology insertion**
  - **Coordinated risk assessment group suggested (NSPAC)**
- **A diatribe: Easy access to flight technology testbeds desired to validate technology modes**
  - ***Ground-testing can mitigate some risk without flight data, but new technologies may have more complex space environment issues (synergistic environment)***



Latent damage from a single particle strike can cause failures post-event



Next Generation SOI:
Weak or no body ties will not solve SEU problems

http://nepp.nasa.gov