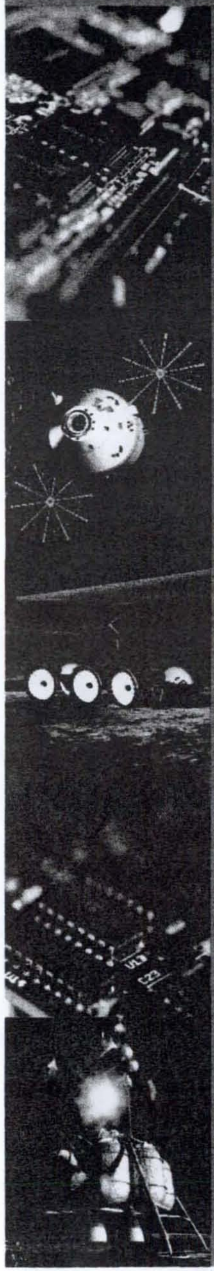
AIAA SPACE 2007
Avionics, Surface and Mission Operations Logistics Session

NASA



Exploration Technology Development Program's

Radiation Hardened Electronics for Space Environments (RHESE)

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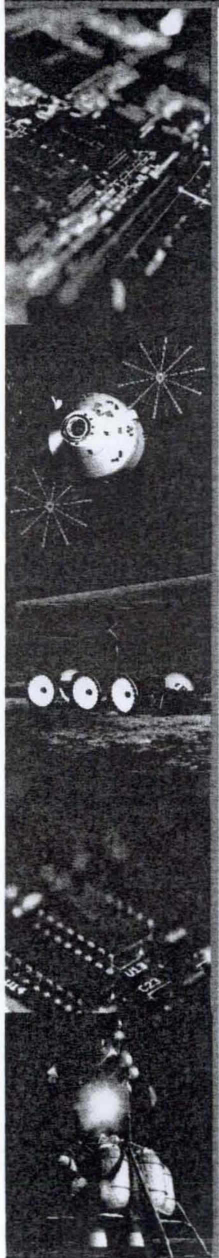
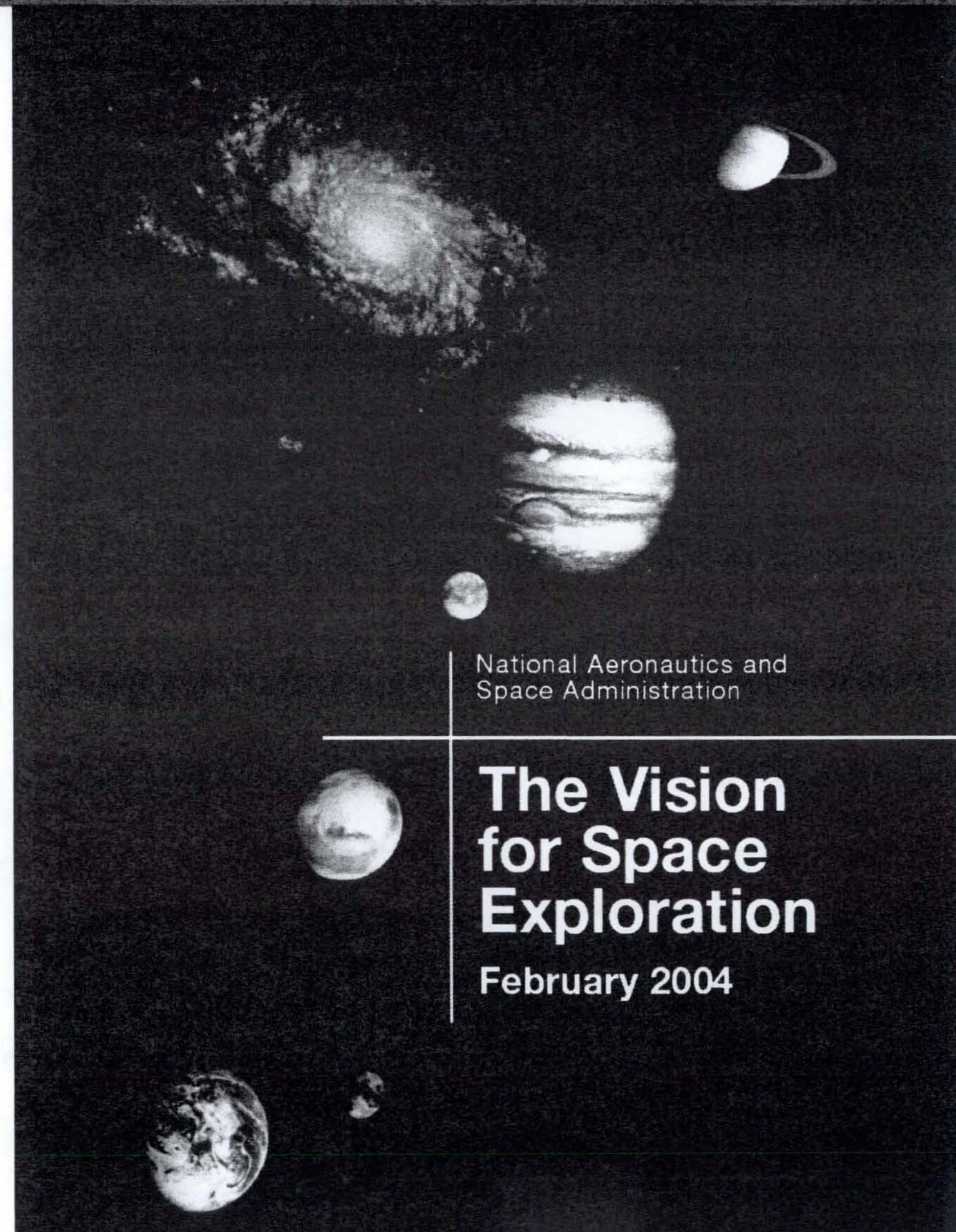
SPACE 2007 – 20 September 2007

Vision for Space Exploration



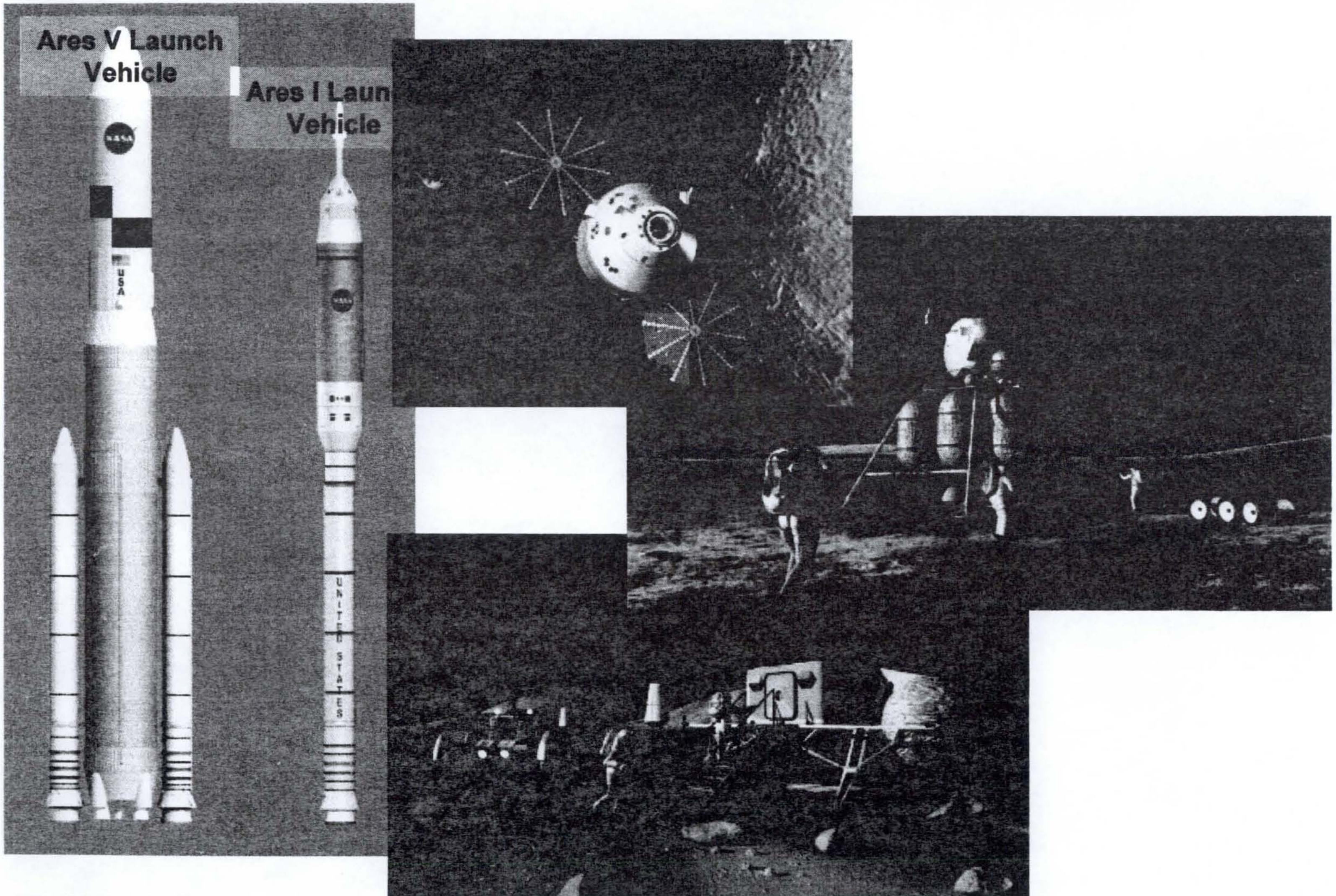
- **The Vision for Space Exploration (VSE) directs NASA to pursue a long-term human and robotic program to explore the solar system.**

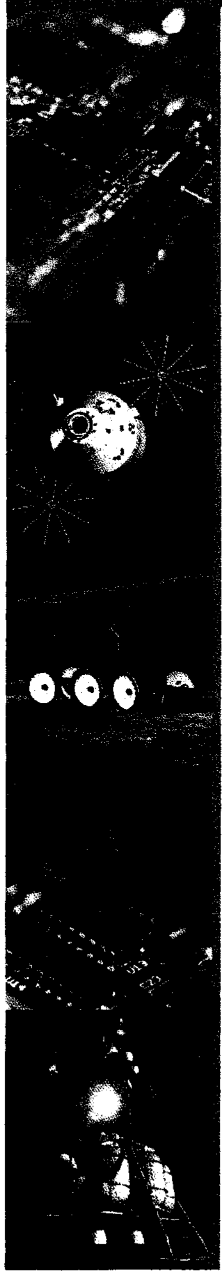
- **The VSE is based on the following goals:**
  - Return the shuttle to flight (following the Columbia accident) and complete the International Space Station by 2010.
  - Develop a Crew Exploration Vehicle, test by 2008, first manned mission no later than 2014.
  - Return to the Moon as early as 2015 and no later than 2020.
    - Gain experience and knowledge for human missions to Mars.
    - Increase the use of robotic exploration to maximize our understanding of the solar system.



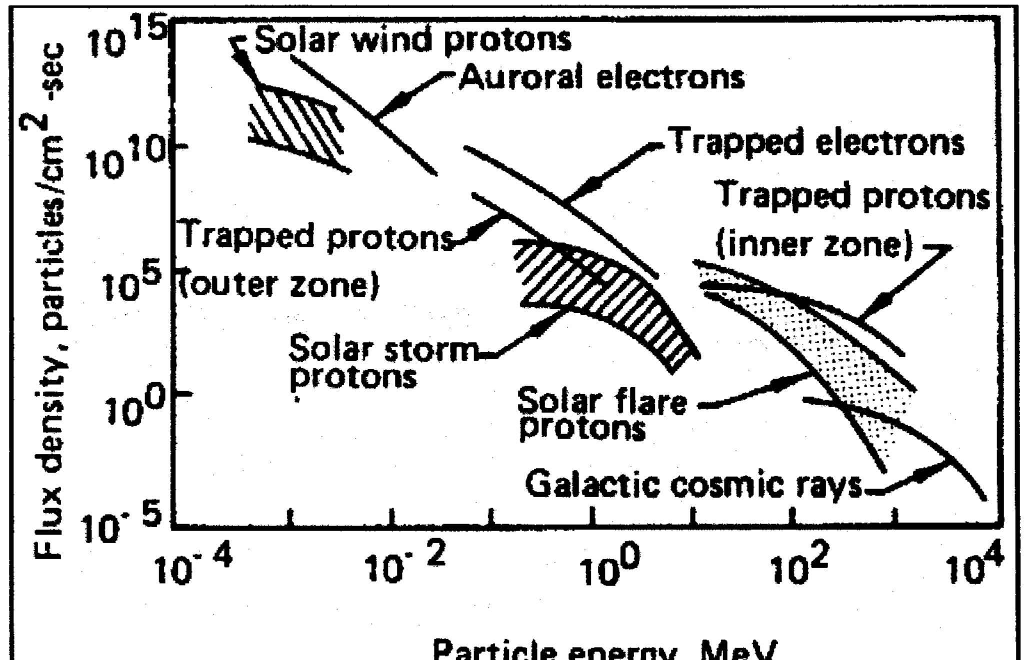
Constellation Program

- **The Constellation Program consists of multiple projects, jointly being developed to fulfill the goals of the VSE.**



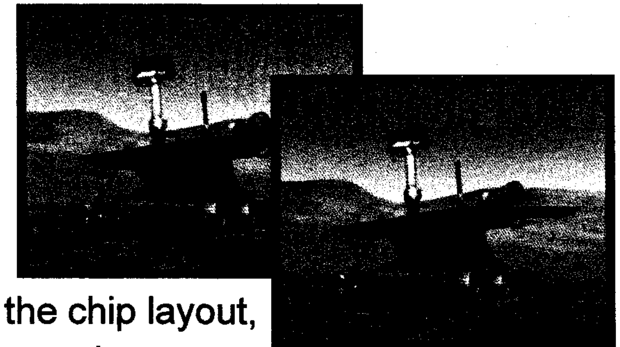


- **Space Radiation affects all spacecraft.**
  - Spacecraft electronics have a long history of power resets, safing, and system failures due to:
    - Long duration exposures,
    - Unpredictable solar proton activity,
    - Ambient galactic cosmic ray environment.



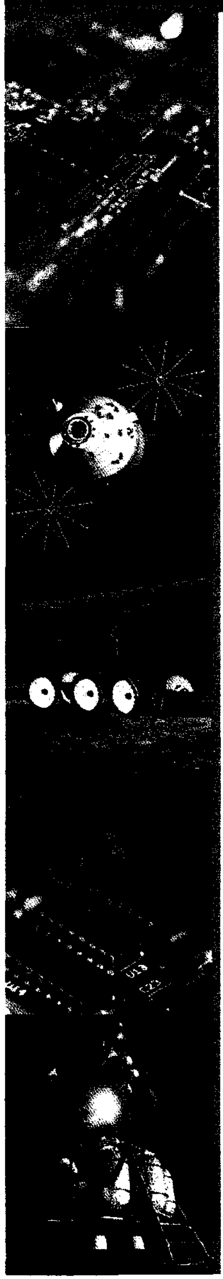
The Radiation Environment

- **Multiple approaches may be employed (independently or in combination) to protect electronic systems in the radiation environment:**
  - Shielding,
  - Mission Design (radiation avoidance),
  - Radiation Hardening by Architecture,
    - Commercial parts in redundant and duplicative configurations (Triple Module Redundancy),
    - Increases overhead in voting logic, power consumption, flight mass
    - Multiple levels of redundancy implemented for rad-damage risk mitigation:
      - Component level
      - Board level
      - Subsystem level
      - Spacecraft level
  - Radiation Hardening by Design,
    - TMR strategies within the chip layout,
    - designing dopant wells and isolation trenches into the chip layout,
    - implementing error detecting and correction circuits, and
    - device spacing and decoupling.
  - Radiation Hardening by Process,
    - Employ specific materials, processing techniques,
    - Usually performed on dedicated rad-hard foundry fabrication lines.



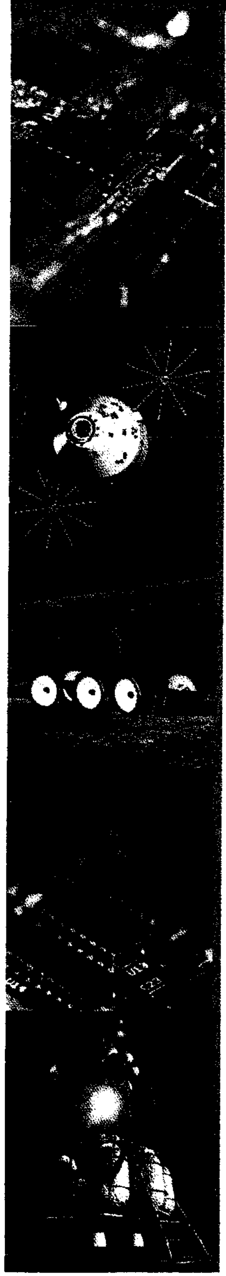
Radiation Hardened Assurance

NASA



- **NASA spacecraft developers have defined a Radiation Hardness Assurance (RHA) methodology process*.**
- **In general, the process may be described by the following steps:**
  - 1) define the radiation hazard,
  - 2) evaluate the hazard,
  - 3) define the requirements to be met by the spacecraft's electronics,
  - 4) evaluate the electronics to be used,
  - 5) engineer processes to mitigate hazard damage, and
  - 6) iterate on the methodology, if and when necessary.
- **To promote the successful implementation of RHA for Constellation (and other NASA) missions, the RHESE project aims to deliver products that assist in *mitigating the hazard damage*.**

***LaBel, K. A., Johnson, A. H., Barth, J. L., Reed, R. A., and Barnes, C. E., "Emerging Radiation Hardness Assurance(RHA) Issues: A NASA Approach for Space Flight Programs," *IEEE Transactions on Nuclear Science*, Vol. 45, No. 6, Dec. 1998, pp. 2727-2736.**

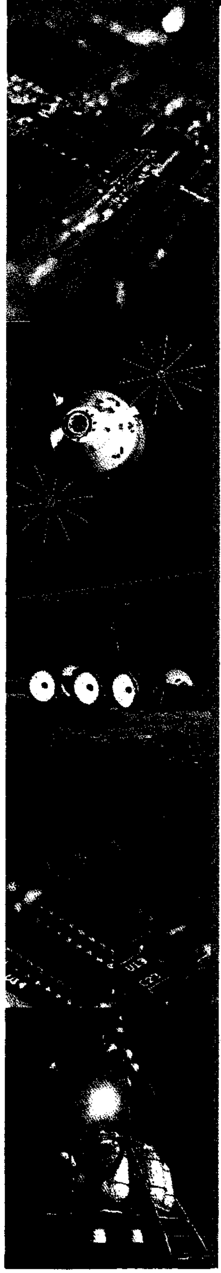


The **Radiation Hardened Electronics for Space Environments (RHESE)** project expands the current state-of-the-art in radiation-hardened electronics to develop high performance devices robust enough to withstand the demanding radiation and thermal conditions encountered within the space and lunar environments.

The specific goals of the RHESE project are to foster technology development efforts in radiation-hardened electronics possessing these associated capabilities:

- improved total ionization dose (TID) tolerance,
- reduced single event upset rates,
- increased threshold for single event latch-up,
- increased sustained processor performance,
- increased processor efficiency,
- increased speed of dynamic reconfigurability,
- reduced operating temperature range's lower bound,
- increased the available levels of redundancy and reconfigurability, and
- increased the reliability and accuracy of radiation effects modeling.

Customer Requirements and Needs



- **RHESE is a "requirements-pull" technology development effort.**
- **RHESE is a "cross-cutting" technology, serving a broad base of multiple project customers within Constellation.**
  - Every project requiring…
    - operation in an extreme space environment,
    - avionics, processors, automation, communications, etc.

    …should include RHESE in its implementation trade space.
- **RHESE's products are developed in response to the needs and requirements of multiple Constellation program elements, including:**
  - Ares V Crew Launch Vehicle,
  - Orion Crew Exploration Vehicle's lunar capability,
  - Lunar Lander,
  - Lunar Outpost,
  - Surface Systems,
  - Extra Vehicular Activity (EVA) elements,
  - Future applications to Mars exploration architecture elements.
- **Constellation Program requirements for avionics and electronics continue to evolve and become more defined.**
- **RHESE will develop products per derived requirements based on the Constellation Architecture's Level I and Level II requirements defined to date.**

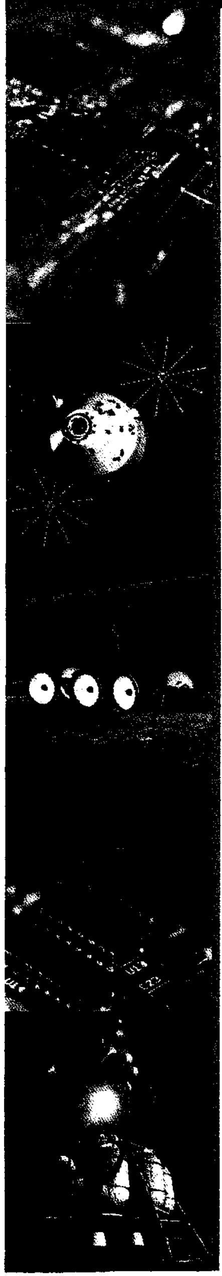
RHESE Tasks

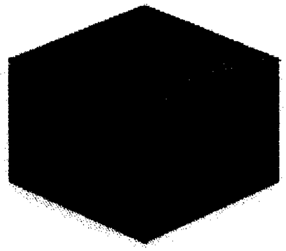
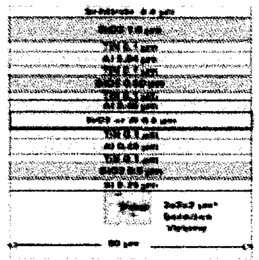
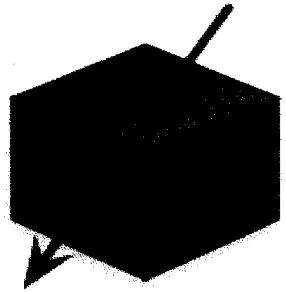
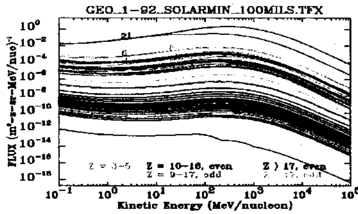
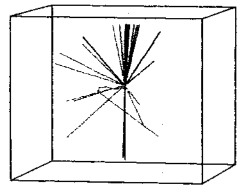
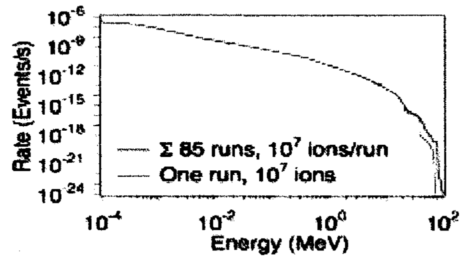
- **Specifically, the RHESE tasks are:**
  - Model of Radiation Effects on Electronics (MREE),
  - Single Event Effects (SEE) Immune Reconfigurable Field Programmable Gate Array (FPGA) (SIRF),
  - Radiation Hardened High Performance Processors (HPP),
  - Reconfigurable Computing (RC),
  - Silicon-Germanium (SiGe) Integrated Electronics for Extreme Environments.

MREE Technology Objectives

- **The Main Objective**
  - A computational tool to estimate radiation effects in space in support of spacecraft design
    - Total dose
    - Single Event Effects
- **Secondary Objectives**
  - To provide a detailed description of the radiation environment in support of radiation health and instrument design
    - In deep space
    - Inside the magnetosphere
    - Behind shielding

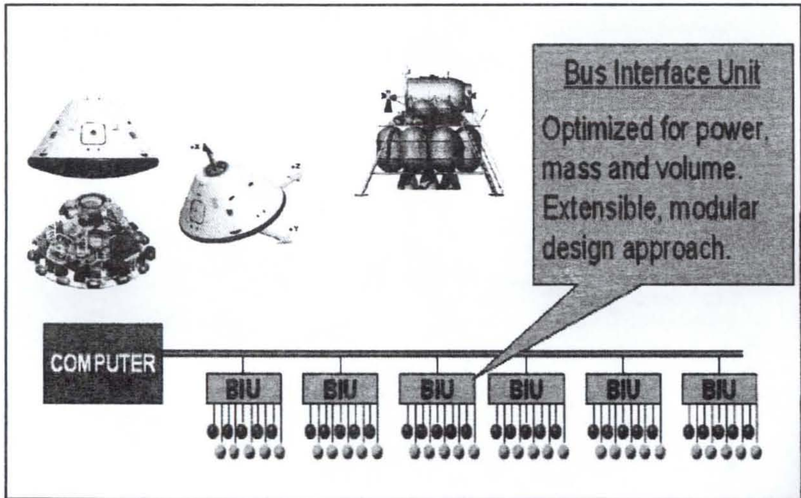
Update the Method for SEE Calculation

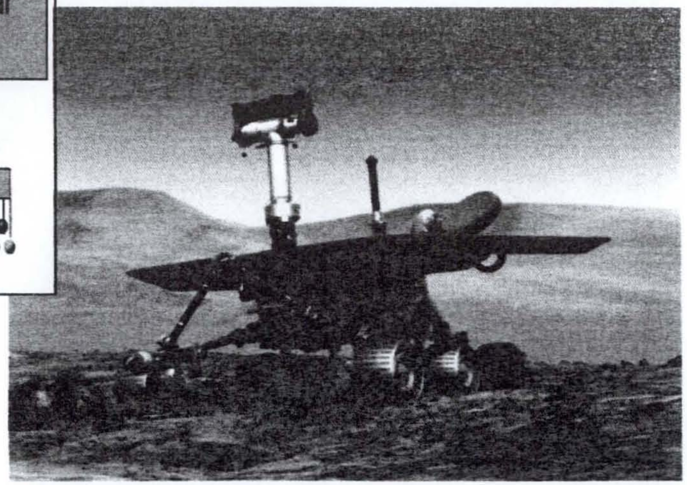


	CREME96	MREE
Device/Circuit/System Virtualization		
Radiation Event Generation		 
Response Prediction	Integral over path length Distribution + critical charge	 Multi-volume Calorimetry + Charge-collection models + Critical charge

SIRF Drivers

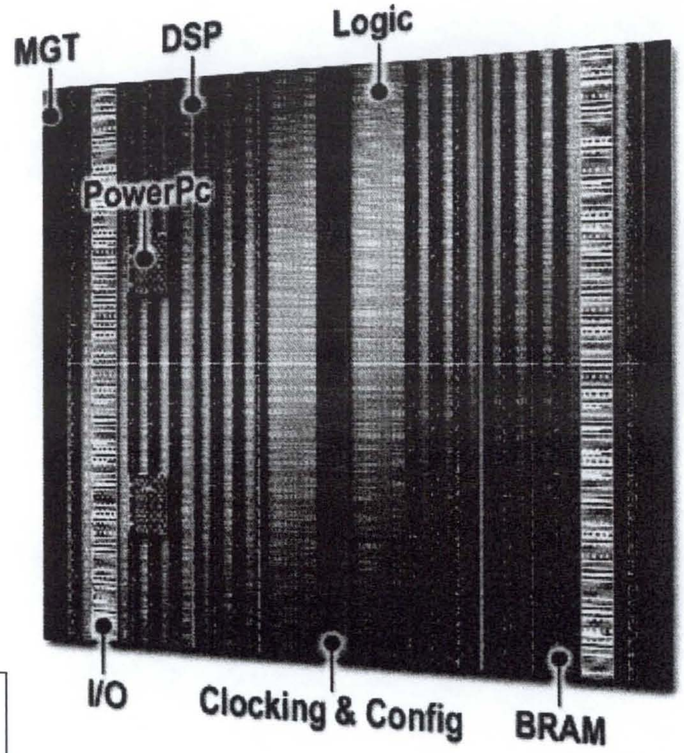
- **Reconfigurable gate arrays form the basis of many adaptable, scaleable, computing engines**
  - Add flexibility, capability and robustness to surface and flight systems



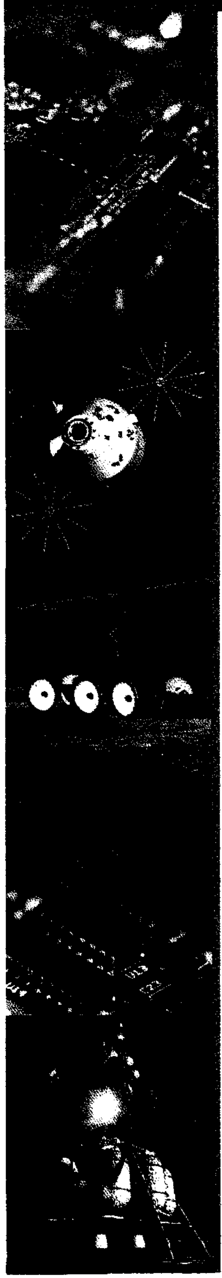


SIRF Architecture
Based on Commercial Devices

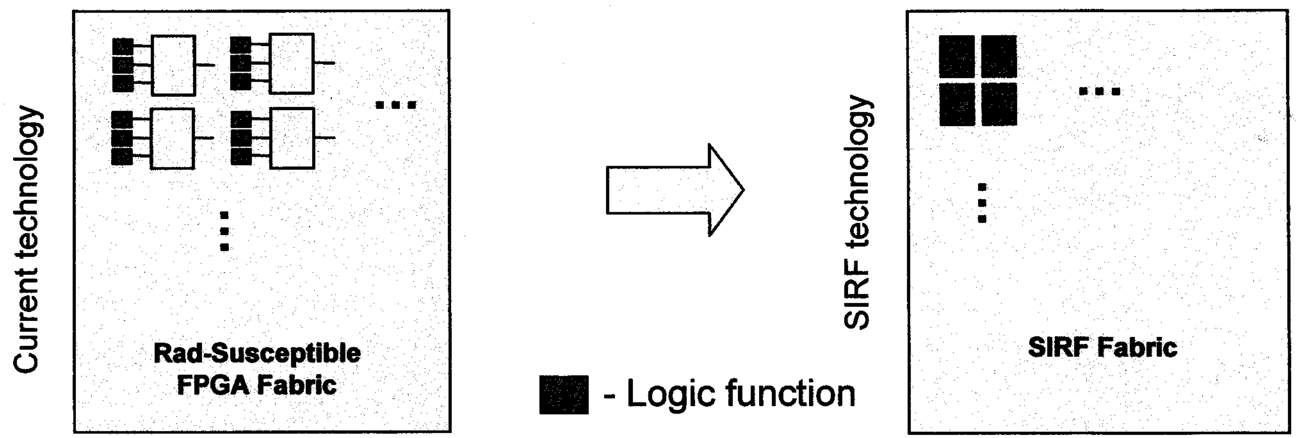
- **5th generation Virtex™ device**
  - 90 nm process
  - 11 metal layers
  - Up to 8M gates
- **Columnar Architecture enables resource "dial-in" of**
  - Logic
  - Block RAM
  - I/O
  - DSP Slices
  - PowerPC Cores



Fabrication process and device architecture yield a high speed, flexible component



- **Existing reconfigurable FPGAs are very susceptible to radiation-induced single event effects**
  - Significant FPGA resources are currently required to mitigate radiation-induced single event effects



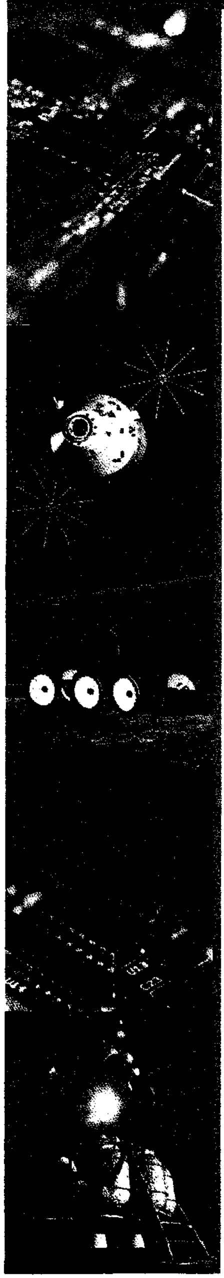
User invoked TRM required (requires FPGA resources)

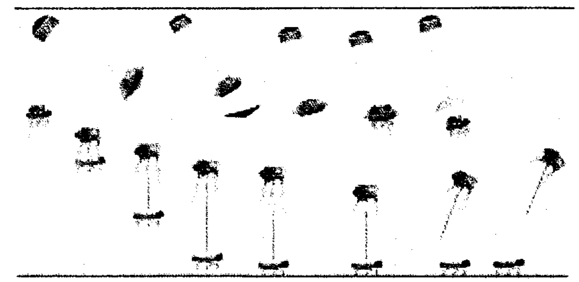
Mitigation implemented at device level

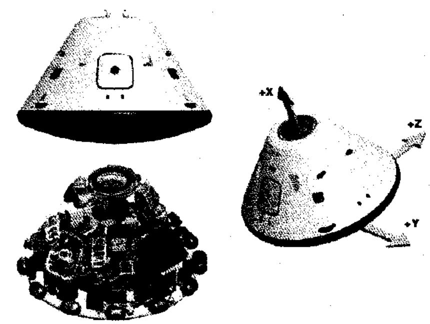
Objectives: Eliminate need for user-invoked TMR. Bring a state-of-the-art radiation hardened reconfigurable FPGA to the space electronics market by ~2010.

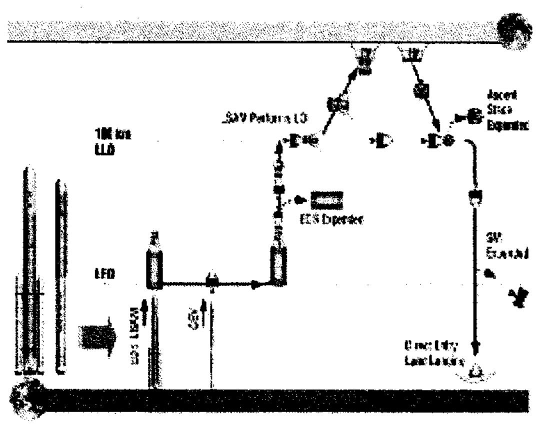
HPP Drivers

- **Problem:** Exploration Systems Missions Directorate objectives and strategies can be constrained by computing capabilities and power efficiencies
  - Autonomous landing and hazard avoidance systems
  - Autonomous vehicle operations
  - Autonomous rendezvous and docking
  - Vision systems

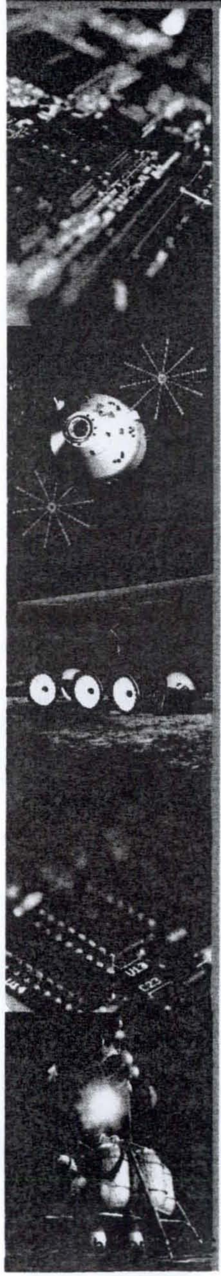






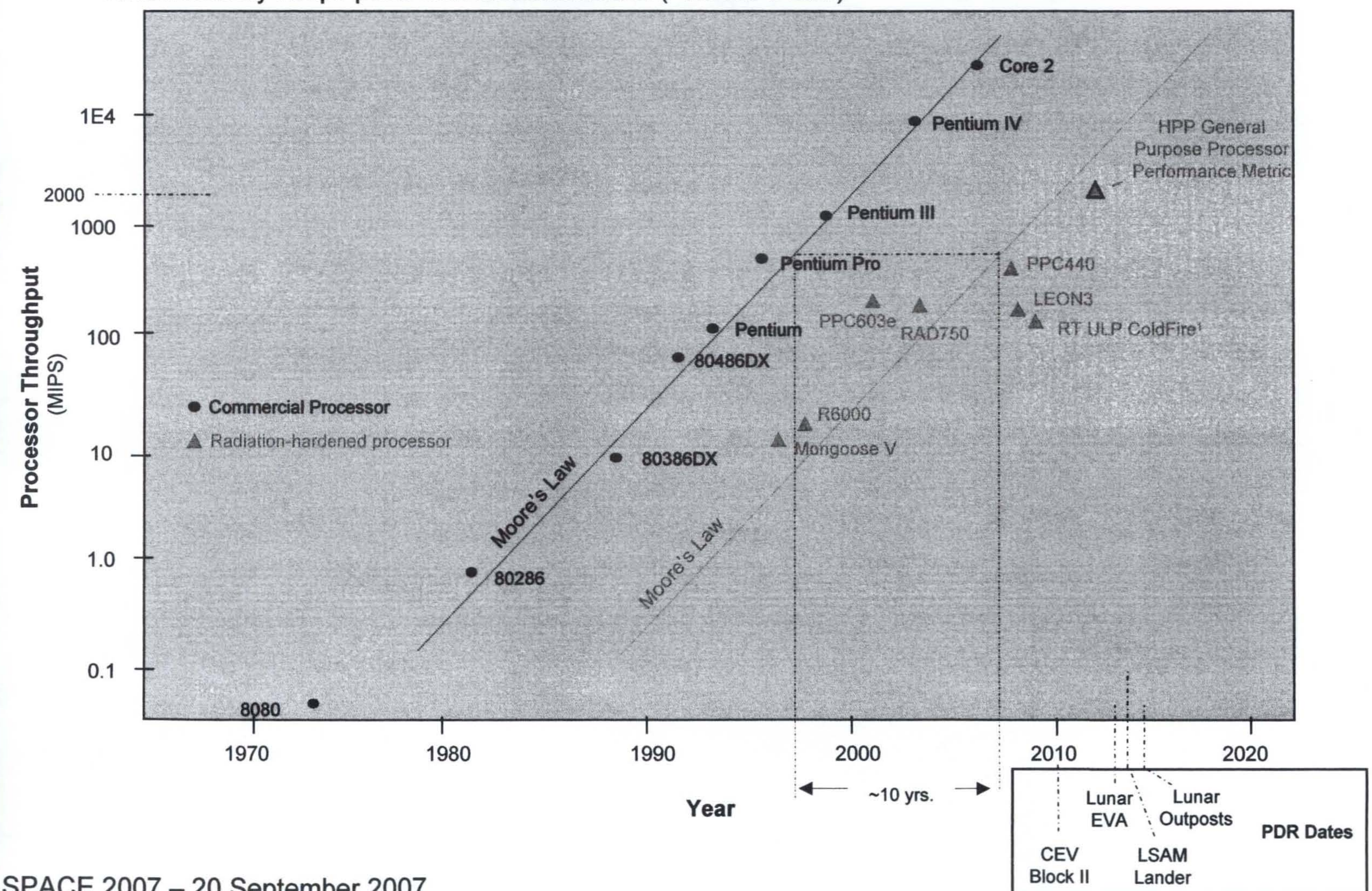


HPP Technical Approach
Multi-generation Performance Lag



Radiation-hardened processors lag commercial devices by several technology generations (approx. 10 years)

- RHESE High performance Processor project full-success metric for general purpose processors conservatively keeps pace with historical trend (~Moore's Law)

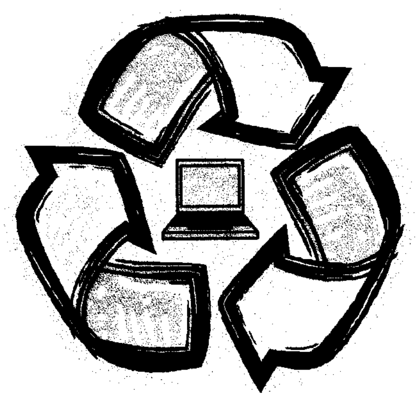


Reconfigurable Computing Subproject

- Subproject Objectives

- **Provide reconfigurable computing capabilities as a preferred alternative to conventional forms**
  - – Processor Modularity
  - – Interface Modularity
    - Reduction of Flight Spares
    - Accommodation for Circuit Life Limitations
    - Resources where needed, as needed

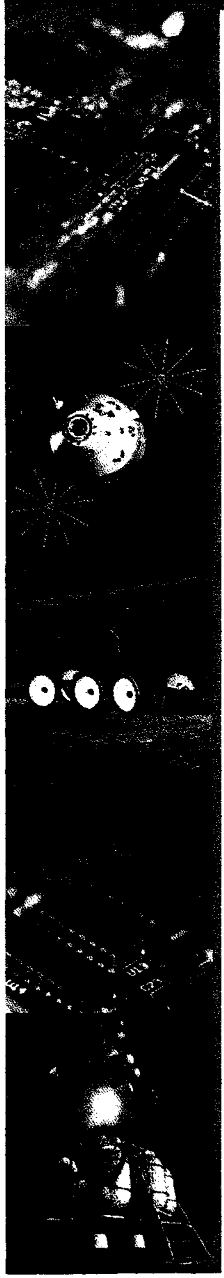
- **Supplement other efforts to mitigate environmental impacts by providing the capability to detect and work around malfunctioning circuitry**
  - – Fault Tolerance
  - – Fault Detection, Isolation, and Mitigation
-
- **Generally: capitalize on the unique capabilities of RC to adapt in target systems for changing requirements, performance and environmental parameters**



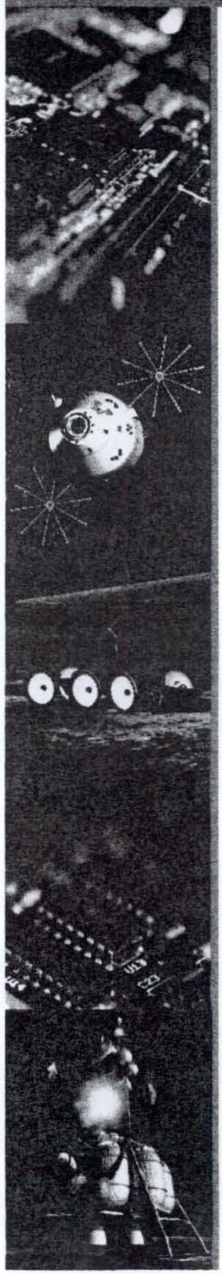
RC Technical Justification

Reconfigurable Computing Subproject

NASA



- **Flight-Qualified, Multi-String Redundant Hardware is Expensive**
  - Development, Integration, IV&V, and Flight Qualification
  - Space and Weight
  - Power Consumption and Cooling
- **Custom Design of Computing Resources for Every New Flight System or Subsystem is Unnecessary and Wasteful**
- **Requirements for Flexibility are Increasing and Make Sense**
  - Reconfigurable (Flexible) and Modular Capabilities
  - For Dissimilar Spares, and Incremental Changeover to New Technology: Capacity to use one system to back up any number of others
  - General Reusability
- **Current Options for Harsh/Flight Environment Systems are Limited**
  - Custom Hardware, Firmware, and Software
  - Dedicated and Inflexible
  - Often Proprietary: Collaboration Inhibited
- **Modular Spares == Fewer Flight Spares**



The Moon: A Classic Extreme Environment!

Extreme Temperature Ranges:

- +120C to -180C (300C T swings!)
- 28 day cycles
- -230C in shadowed polar craters

Radiation:

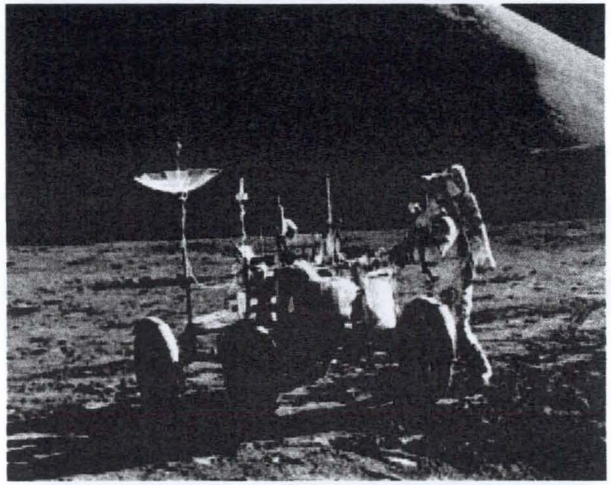
- 100 krad over 10 years
- single event effects (SEE)
- solar events

<u>Many</u> Different Circuit Needs:

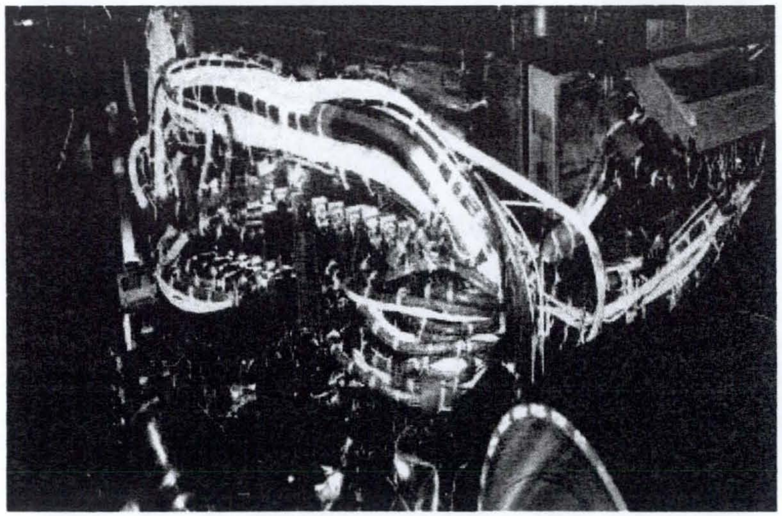
- digital building blocks
- analog building blocks
- data conversion (ADC/DAC)
- RF communications
- actuation and control
- sensors / sensor interfaces

➡ <u>Highly Mixed-Signal Flavor</u>

Current Rovers / Robotics

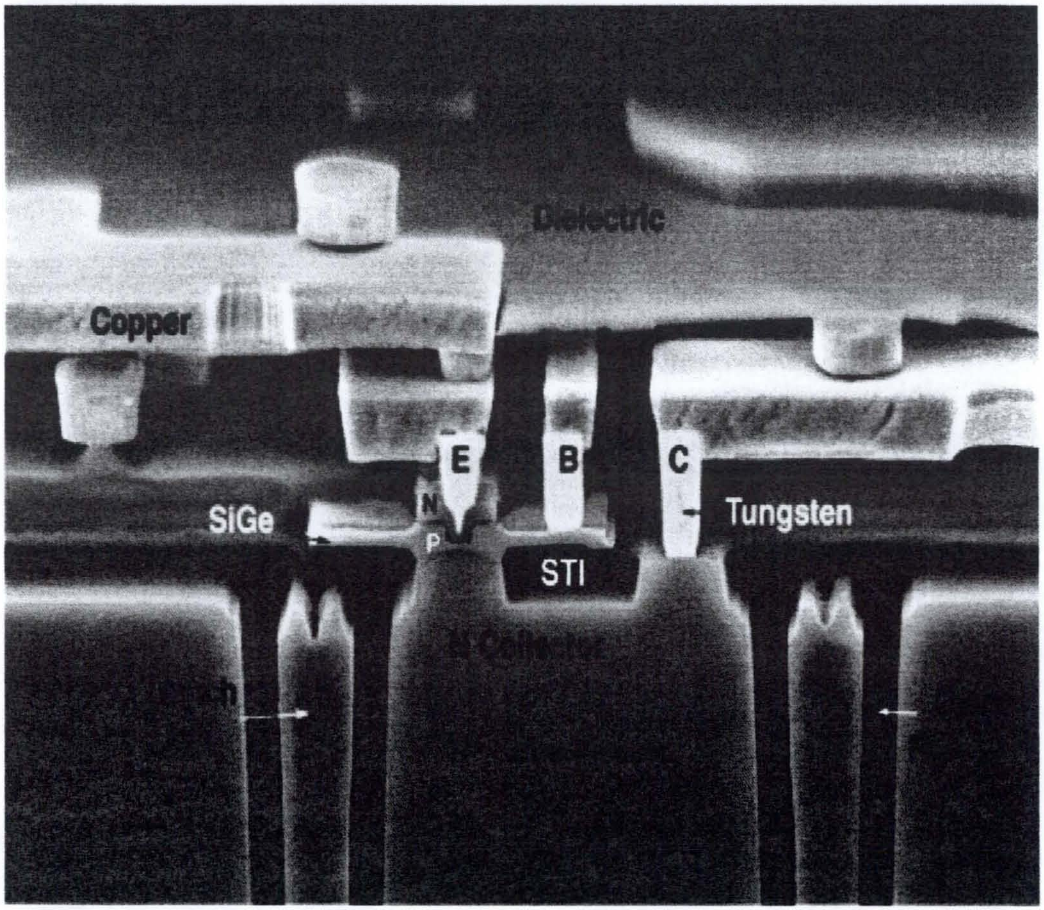


<u>Requires</u> "Warm Box"

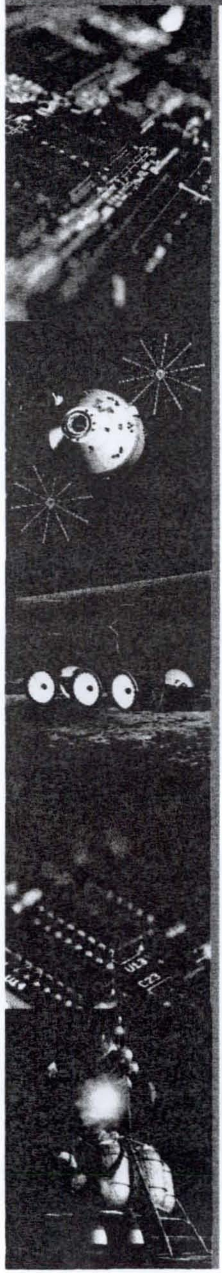


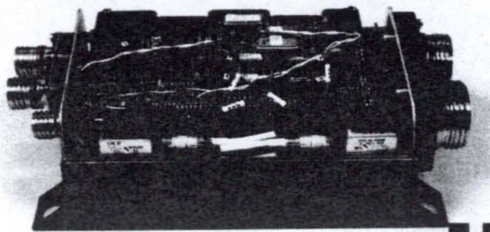
SiGe Technology

- **SiGe HBT + CMOS + full suite of passives (<u>Integration</u>)**
- **100% Si Manufacturing Compatibility (MOSIS Foundry)**
- Wide-Temperature Capable + Radiation Tolerant



SiGe-Based Remote Electronics Unit (REU)





The X-33 Remote Health Monitoring Node, circa 1998 **(BAE)**

Our Project End Game:
The SiGe ETDP Remote Electronics Unit, circa 2009

REU in connector housing!

Analog front end die

Digital control die

Conceptual integrated REU system-on-chip SiGe BiCMOS die

Specifications

- **5" wide by 3" high by 6.75" long = 101 cubic inches**
- **11 kg weight**
- **17.2 Watts power dissipation**
- **-55°C to +125°C**

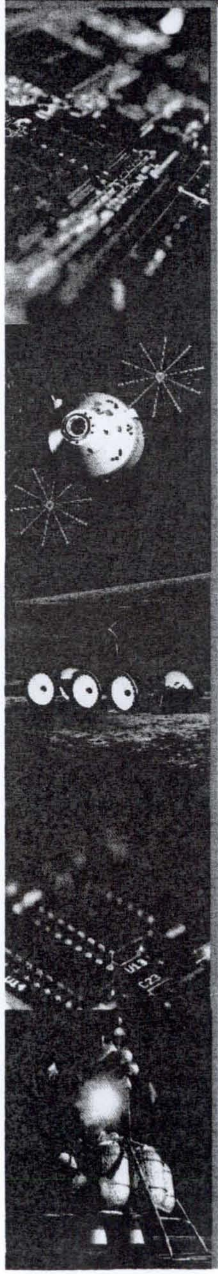
Our Goals

- **1.5" high by 1.5" wide by 0.5" long = 1.1 cubic inches**
- **< 1 kg**
- **< 1-2 Watts**
- **-180°C to +125°C, rad tolerant!**

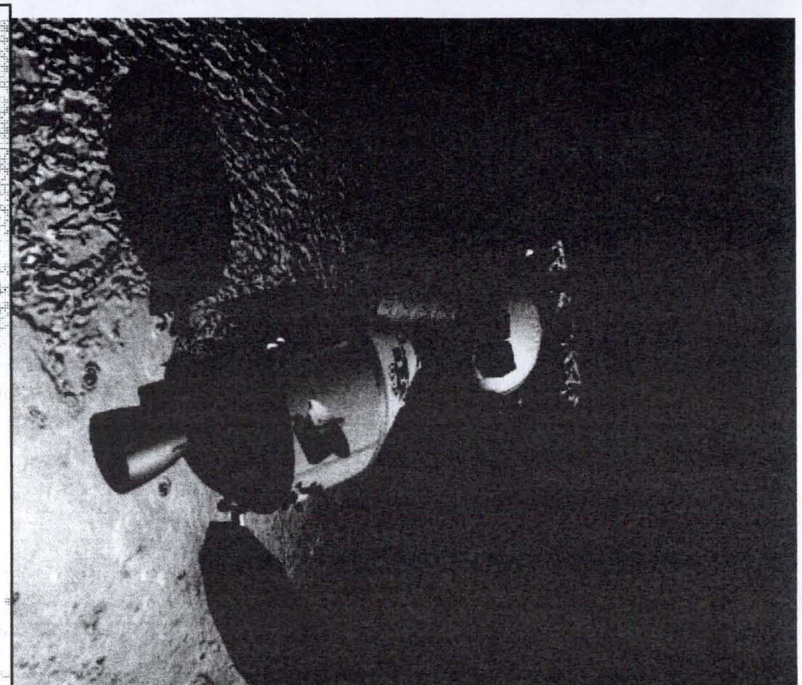
Supports MANY Sensor Types:
Temperature, Strain, Pressure, Acceleration, Vibration, Heat Flux, Position, etc.

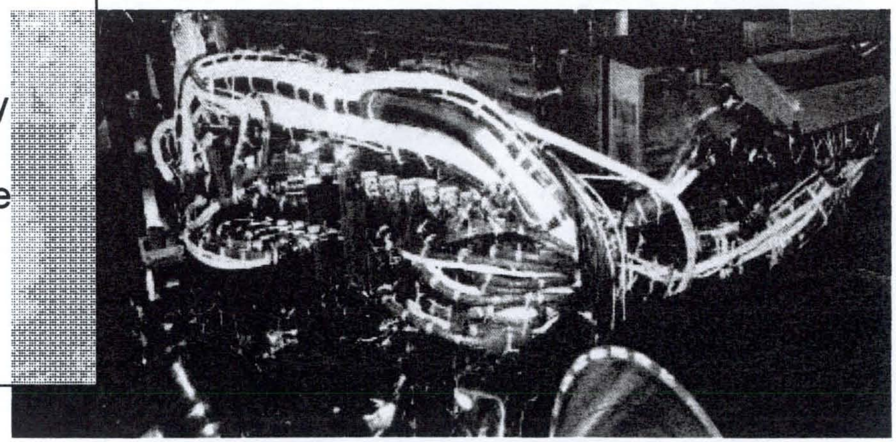
Use This REU as a Remote Vehicle Health Monitoring Node

RHESE Summary

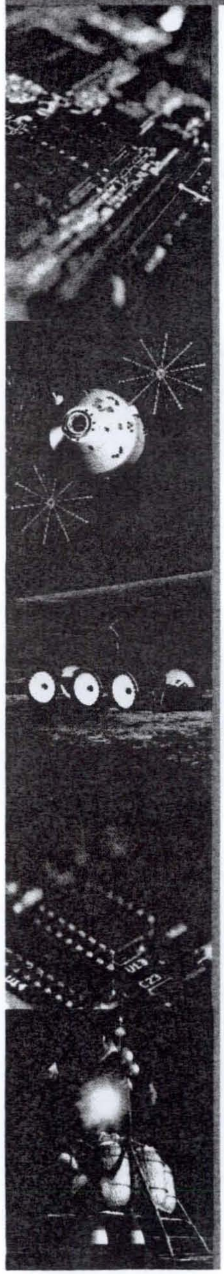


- All RHESE tasks are "requirements-pulled" **by specific CARD requirements, LAT technology needs, and surface systems' defined environments.**
- An application-dependent trade space is defined by:
  - Radiation Hardening by Architecture using COTS processors, and
  - Radiation Hardening By Design using Rad-Hard processors.
  - Considerations include performance requirements, power efficiency, design complexity, radiation
- Radiation and low temperature environments currently drive spacecraft system architectures.
  - **Centralized systems** to keep electronics warm are costly, weighty and use excessive cable lengths.
  - Mitigation can be achieved by active **SiGe electronics**.





RHESE Summary



- Radiation Environmental Modeling is crucial **to proper predictive modeling and electronic response to the radiation environment.**
  - When compared to on-orbit data, CREME96 has been shown to be inaccurate in predicting the radiation environment.
  - The NEDD bases much of its radiation environment data on CREME96 output.
- Close coordination and partnership with DoD radiation-hardened efforts **will result in leveraged - not duplicated or independently developed - technology capabilities of:**
  - Radiation-hardened, reconfigurable FPGA-based electronics,
  - High Performance Processors (NOT duplication or independent development).