NASA Electronic Parts & Packaging (NEPP) Program: Contributions to MER Success

C. Barnes, R. Ramesham, A. Johnston, P. Zulueta,
R. Ghaffarian and L. Scheick
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
charles.e.barnes@jpl.nasa.gov

K. LaBel and M. Sampson
NASA Goddard Space Flight Center
Greenbelt, MD 20771

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Packaging Issues and Applications

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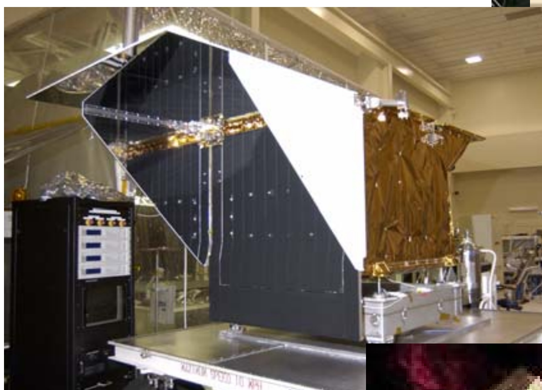
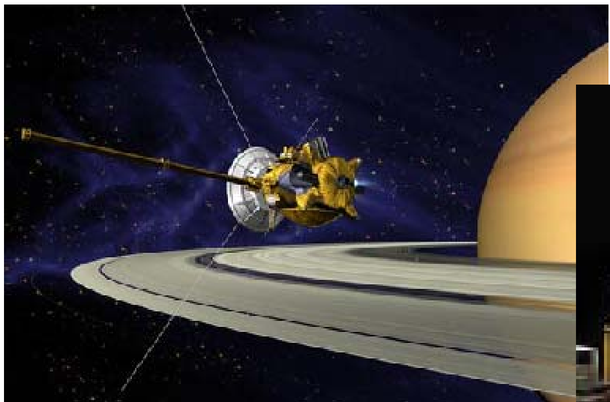
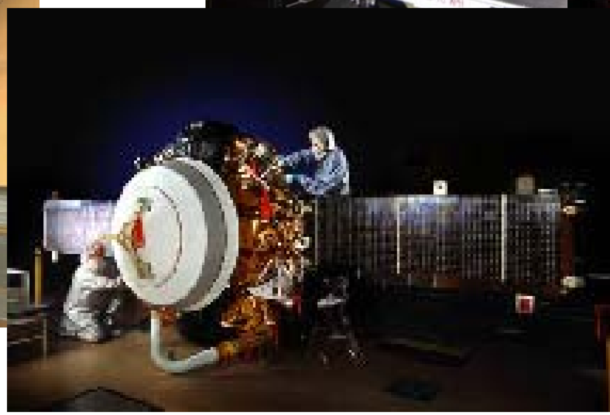
Outline

- **Risks of the Space Environment**
- **Goals, Objectives and Features of the NEPP Program**
- **Contributions of NEPP to Mars Exploration Rover (MER) Mission**
    - Packaging
    - Radiation
- **Conclusions**

We would like to acknowledge the contributions to this presentation by the MER Project



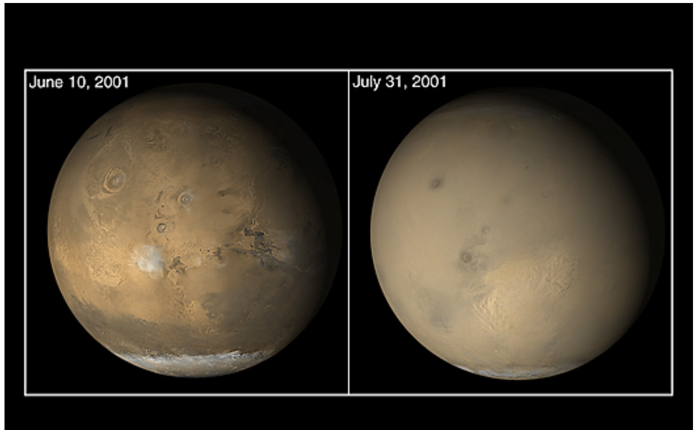


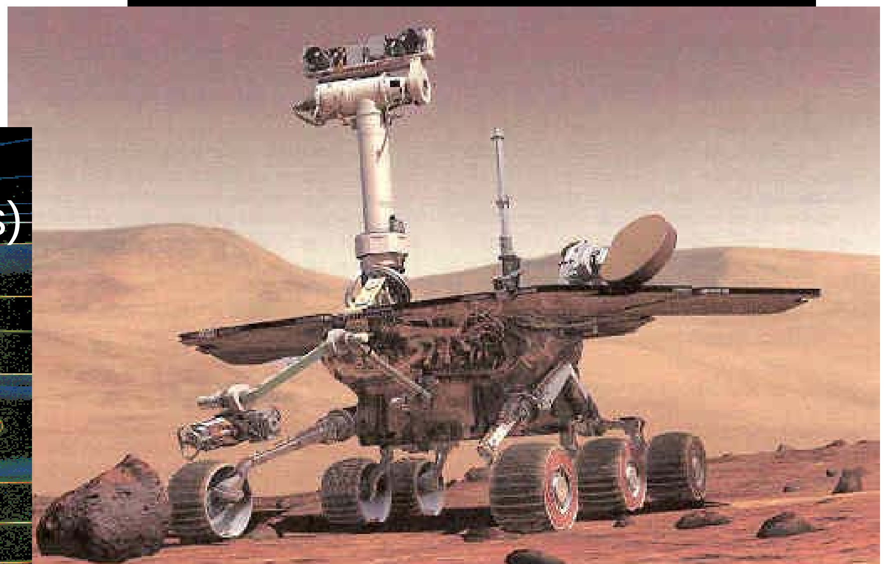


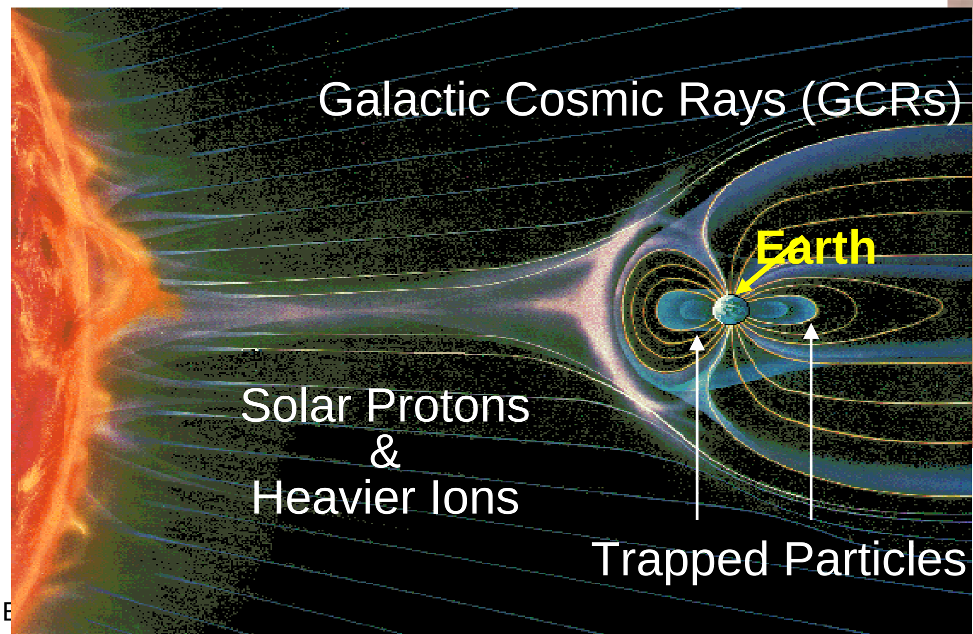
NASA Missions – A Wide Range of Needs

- **NASA typically has over 200 missions in some stage of development**
  - Range from balloon and short-duration low-earth investigations to long-life, deep space
  - Robotic to Human Presence
- **Radiation and reliability requirements vary widely**
- **Environment also varies but always poses risks**
  - Radiation exposure
  - Shock
  - Thermal
  - Vacuum
  - Microgravity
  - Dust, etc…

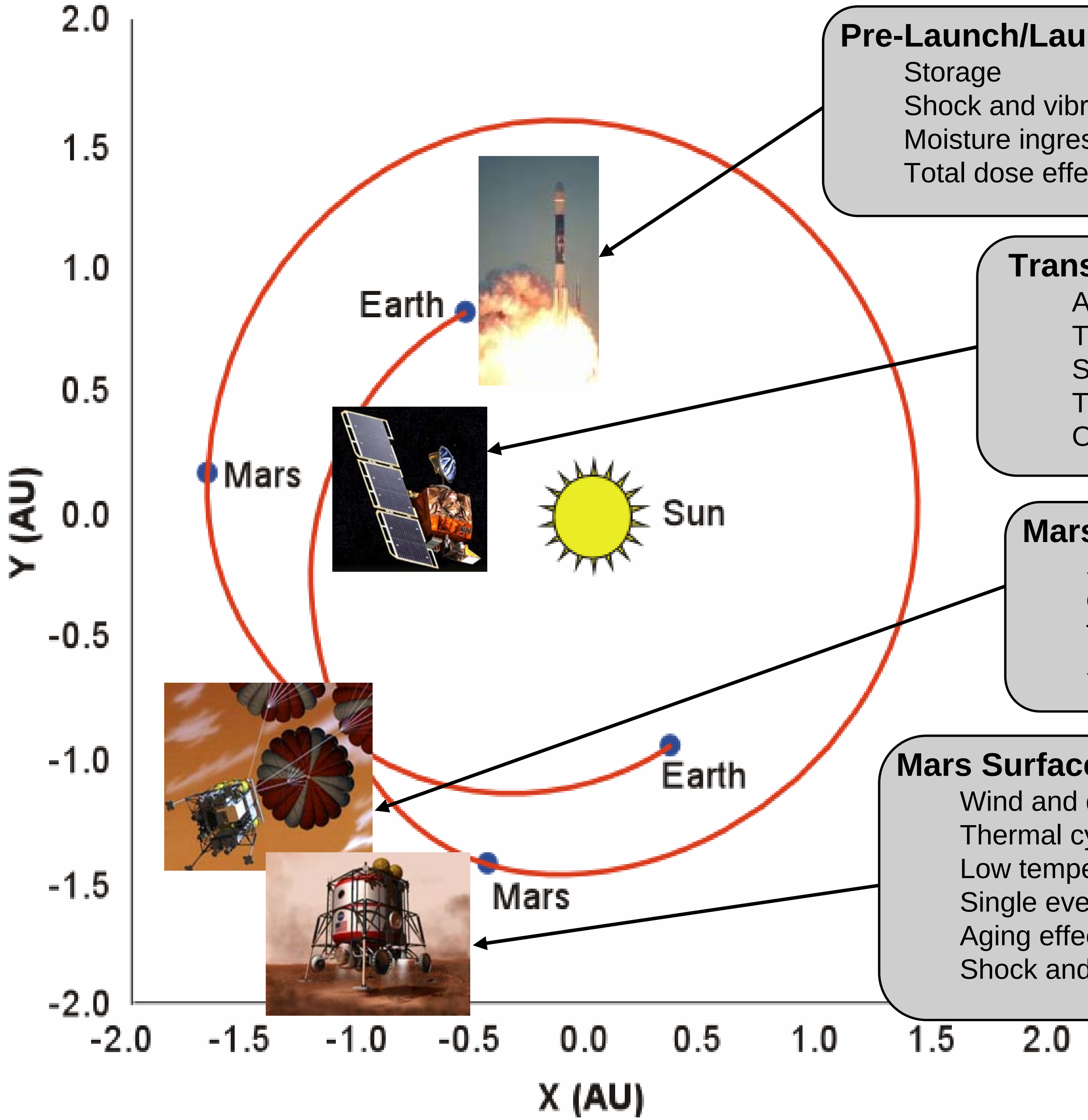
Mars Global Surveyor Dust Storms in 2001







Reliability/Radiation Concerns for Electronics on Mars Missions



Pre-Launch/Launch
- Storage
- Shock and vibration
- Moisture ingress
- Total dose effects due to passage through belts

Transit
- Aging effects
- Total dose effects due to flares
- Single event effects from GCR and flares
- Thermal cycling
- Outgassing

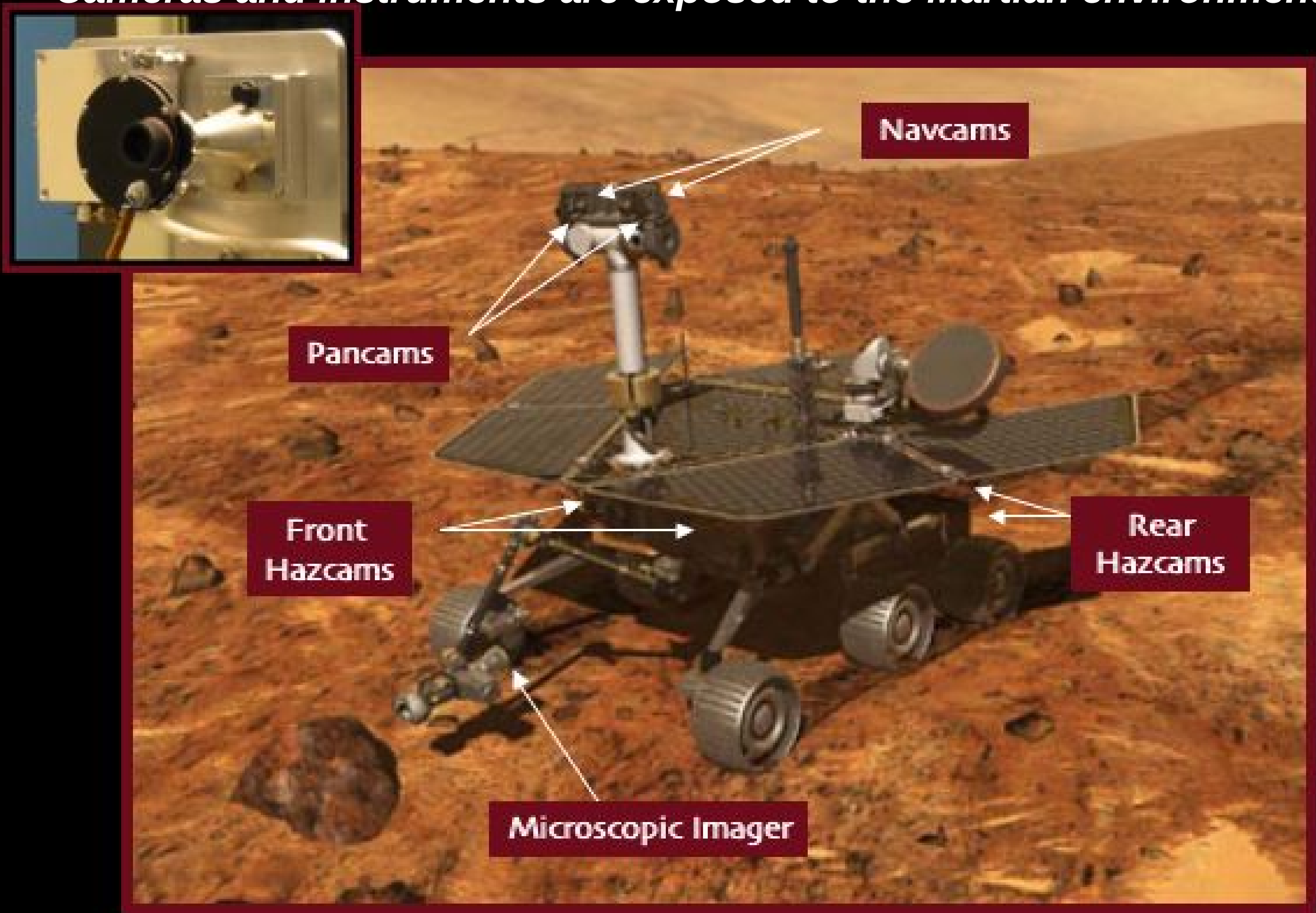
Mars Orbit/Descent
- Shock and vibration
- Charging effects in ionosphere
- Total dose effects from electrons/solar flares
- Single event effects

Mars Surface
- Wind and dust, contamination
- Thermal cycling
- Low temperatures
- Single event effects
- Aging effects
- Shock and vibration

MER Rover

The rover's "eyes" are its cameras.
Each rover has 9 "eyes."

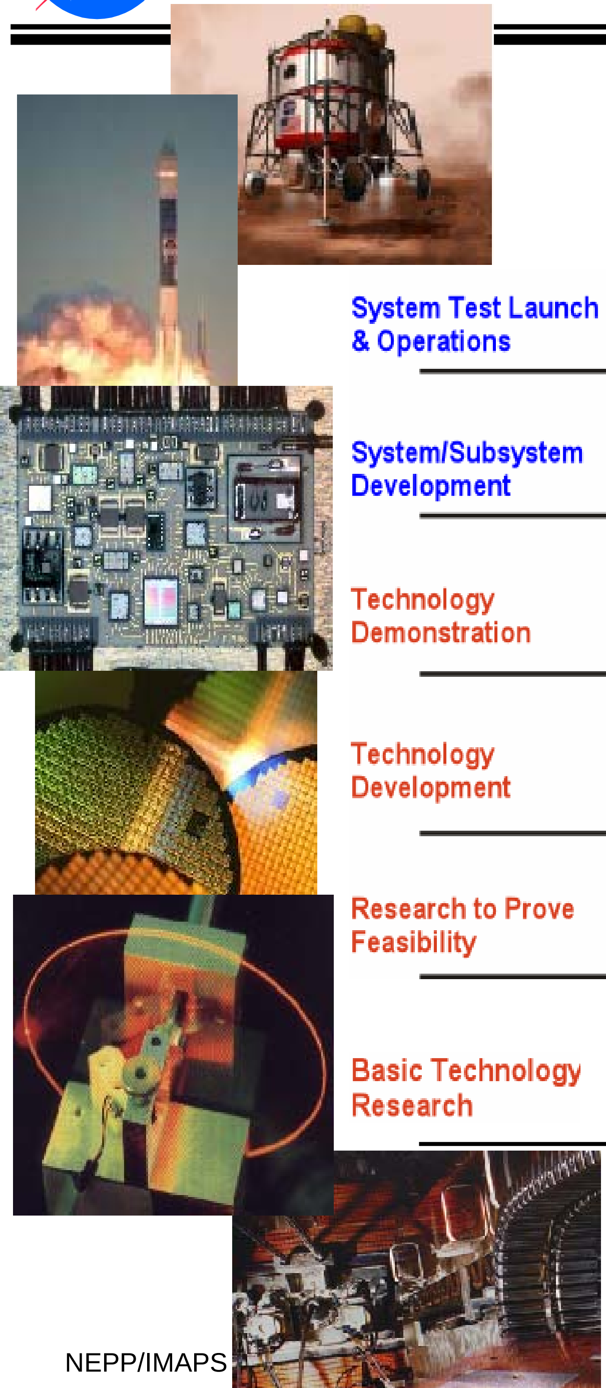
Cameras and instruments are exposed to the Martian environment

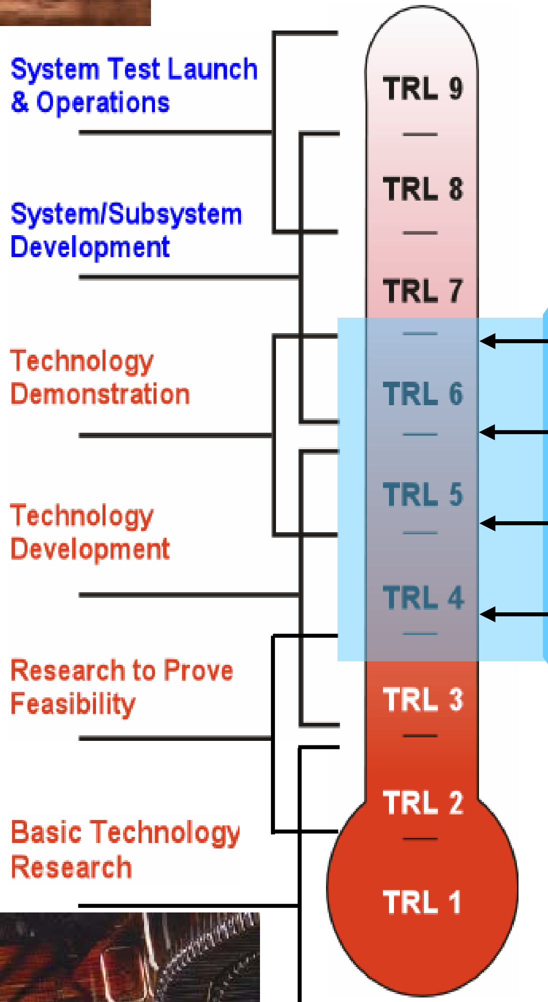


NEPP Program – Goals and Objectives

- **Main goal – Mission reliability to meet NASA exploration and science objectives**
    - Ensure reliability of missions by “smart” investments in EEE parts technology, knowledge-gathering, research and new qualification methods
        - Minimize engineering resources required to maximize space and earth science data collection
- **NEPP objectives**
    - Evaluate reliability and radiation issues of new and emerging EEE technologies with a focus on near to mid term needs
        - Explore failure mechanisms and technology models
    - Develop methods and guidelines for technology usage, selection, and qualification
    - Facilitate risk-free insertion of advanced COTS in NASA systems through parts evaluation and development of upscreening and qualification methods
    - Disseminate information to the NASA community and its contractors

NEPP and TRLs: A Path to Rapid Technology Infusion





Ground testing and character-ization provide a basis for qual-ification for flight

Newly available COTS assess-ments establish reliability and radiation tolerance for low risk insertion into NASA systems

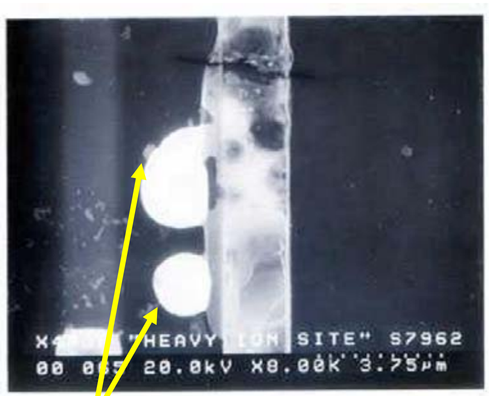
Through alignment of its tasks with applied research, technology develop-ment and technology demonstration, the NEPP Program expedites the infusion of reliable, radiation tolerant technologies into NASA systems

Emerging technology evaluations provide guidance for building reliability into technology fabrication processes

Partnering and collaboration early in development phase helps to establish feasibility for reliability

Sample Tasks for NEPP Program - FY04

- **Operational Tasks**
  - **University**
    - CALCE
    - CAVE
    - Vanderbilt (ISDE)
  - **One NASA**
    - Practices/standards Coordination
    - Radiation Coordination
    - JPL Task Management
    - COTS Information Exchange
    - Coordination with Micro-Nano Working Group (MNWG)



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

- **Strategic Tasks**
  - **Architectural Assessments**
    - Transformational Communications Architecture
    - Nuclear Propulsion
    - Future Avionics
  - **Risk Assessment Surveys**
    - Board-level Qualification
    - Package Level Testing
    - Extreme Environments
    - EEE Obsolescence
    - Reliability Tools
    - MEMS/MOEMS Insertion Opportunities
    - Parts Data Management
    - Printed Wiring Board (PWB) Rework
    - Modern Digital Electronic Radiation-Induced Transients

- **Tactical Tasks**
  - **Test Guidelines**
    - Analog to digital converters (ADCs)
    - Radiation
      - Fiber Optic Link
      - Field Programmable Gate Array (FPGA)
      - Microprocessor
  - **Lessons Learned**
    - Charge Coupled Devices (CCD) and Radiation
  - **Applied Research**
    - COTS Plastic Encapsulated Microelectronics (PEMs)
    - Radiation Effects
      - SiGe
      - Sensor Technology
      - Non-Volatile Memories (NVM)
  - **Survey Documents**
    - Microprocessors and Microcontrollers
    - ASICs
    - Laser diode reliability
    - Embedded devices
    - FPGA
    - COTS Memories
    - Mixed Signal

How NEPP has Assisted MER

- **NEPP developed part/package qualification procedures for Mars mission applications**
  - Procedures for thermal cycling and evaluation at extreme temperatures critical for MER
- **NEPP has focused on space environment qualification issues for COTS parts**
  - MER camera electronics
  - Emphasize what's value-added for upscreening and qualifying COTS for Mars missions
- **Single event transients (SET) in linear devices were a threat on MER**
  - NEPP results provided an upper bound for SET in operational amplifiers and comparators,
  - Eliminated need to do expensive radiation testing on the numerous linear devices used on MER
- **MER linear circuits were sensitive to enhanced damage at low dose rate**
  - Extensive testing under NEPP allowed quick, efficient focus on sensitive devices in MER systems
- **Radiation-induced latchup was a major concern on MER**
  - NEPP testing established the requirements for data evaluation and necessary latchup testing
- **Cobalt-60 gamma ray tests were done on the MER camera CCD array to confirm earlier X-ray tests**
  - Results showed that CCDs were three times more sensitive to radiation with Co-60 gamma rays
  - Corrected risky underestimate of radiation damage from earlier tests
- **Evaluation of the effects of the October 2003 solar flare on MER electronics**
  - NEPP research and testing allowed necessary quick development of operational recovery

Common theme is co-funded work between projects like MER and the NEPP Program to establish assurance technologies that help to insure minimization of risk in NASA missions

Packaging Qualification &Verification (PQV) Plan

NEPP Electronics Packaging tasks were leveraged to support MER Hardware Thermal Design and Environmental Verification Processes

New Packaging Qualification & Verification Plan (D-18799) developed to specifically address electronics packaging


JET PROPULSION LABORATORY JPL D-18799

Packaging Qualification Verification (PQV) Plan

Prepared by M. Gibbel, Reliability Technology Group, Reliability Engineering Office

Approved by: Phillip Zulueta, Applications Engineering Group Supervisor, Quality Assurance

Approved by: Timothy Larson, Reliability Technology Group Supervisor, Reliability Engineering Office

Approved by: Arvin Mottwala, Deputy Section Manager Electronic Packaging and Fabrication Section

Applicable Requirements and Standards:

"Flight Project Practices", 6.13 Design & Verification for Environmental Compatibility (Doc ID 58032)

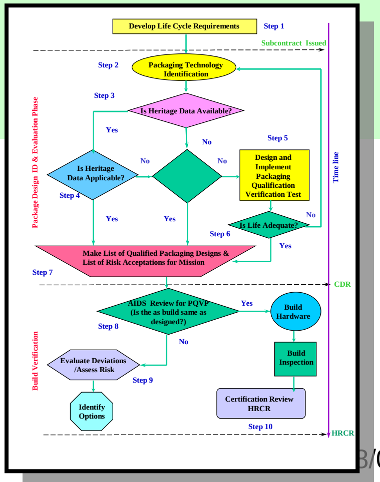
"Assembly & Subsystem Level Environmental Verification", 6.0 Thermal Verification (Doc ID 60133)

"Spacecraft Design & Fabrication Requirements" (D8208, Doc ID 35120) "Electronic packaging systems shall be qualified by test to a fatigue life margin of three"

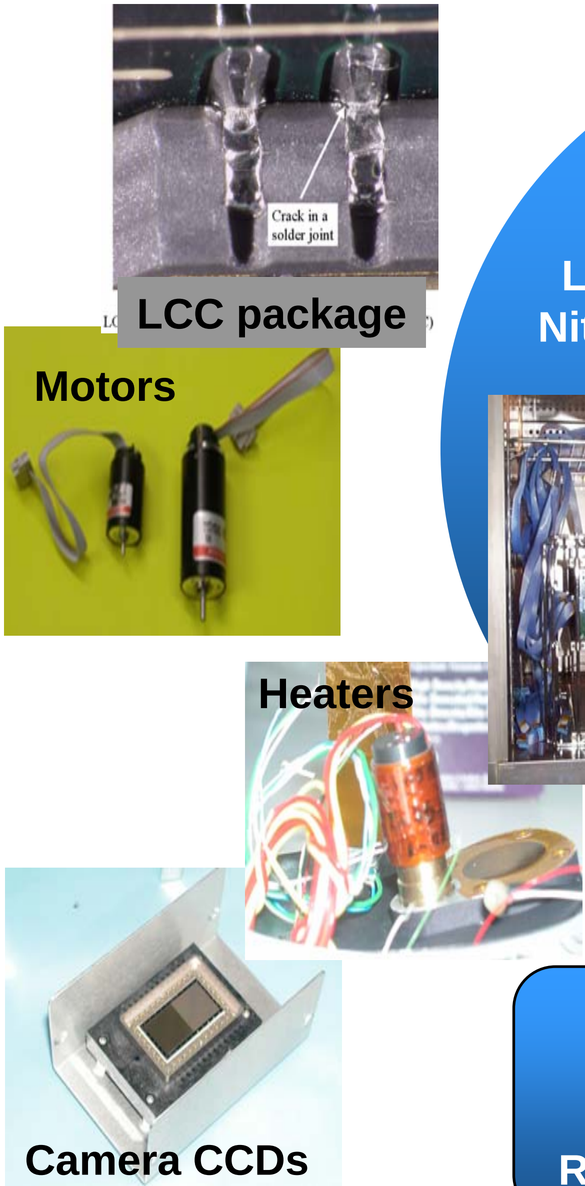
"**NASA Workmanship Standards**" (NASA STD8739.2-5)

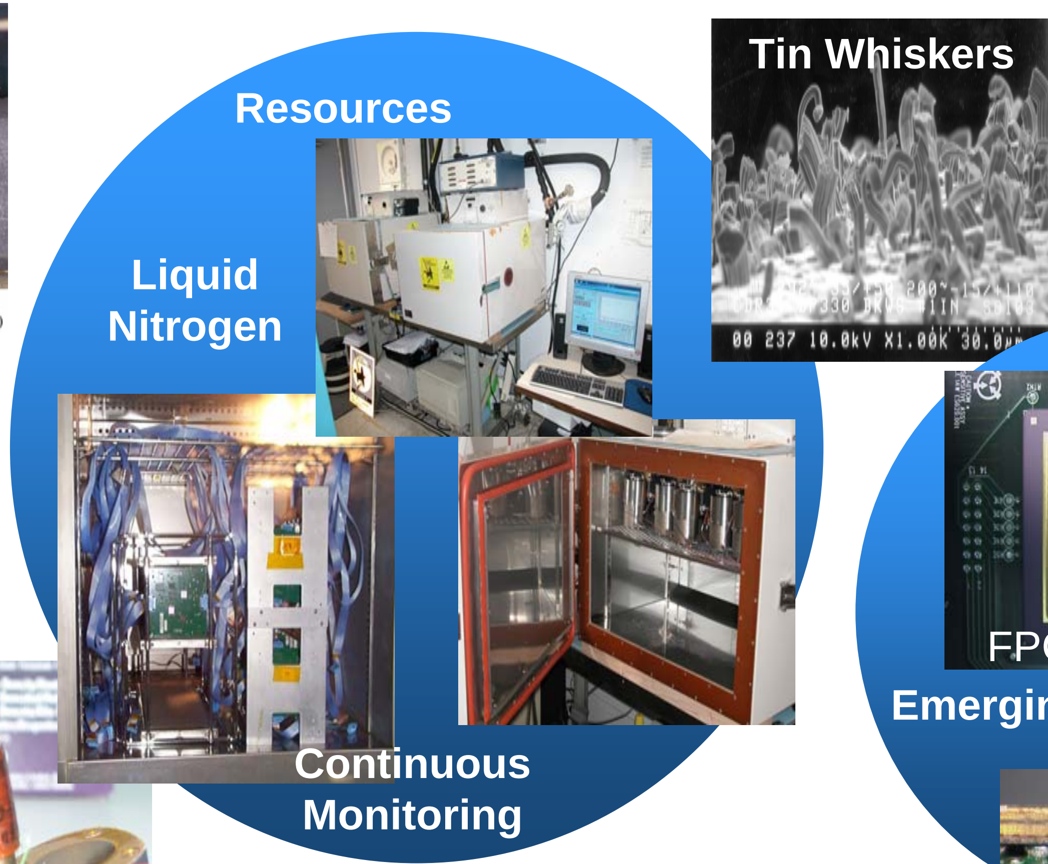
These documents required to minimze the likelihood of packaging failures occurring in flight

PQV Process Flow first considers heritage data in the decision to conduct testing



NEPP Resource Leveraging With the MER Project





Other MER Hardware tested:
RAT, Potentiometers, Airbag Retraction Actuators (ARA), APXS, RLAE, LPAE, IMU, Monopole Antenna

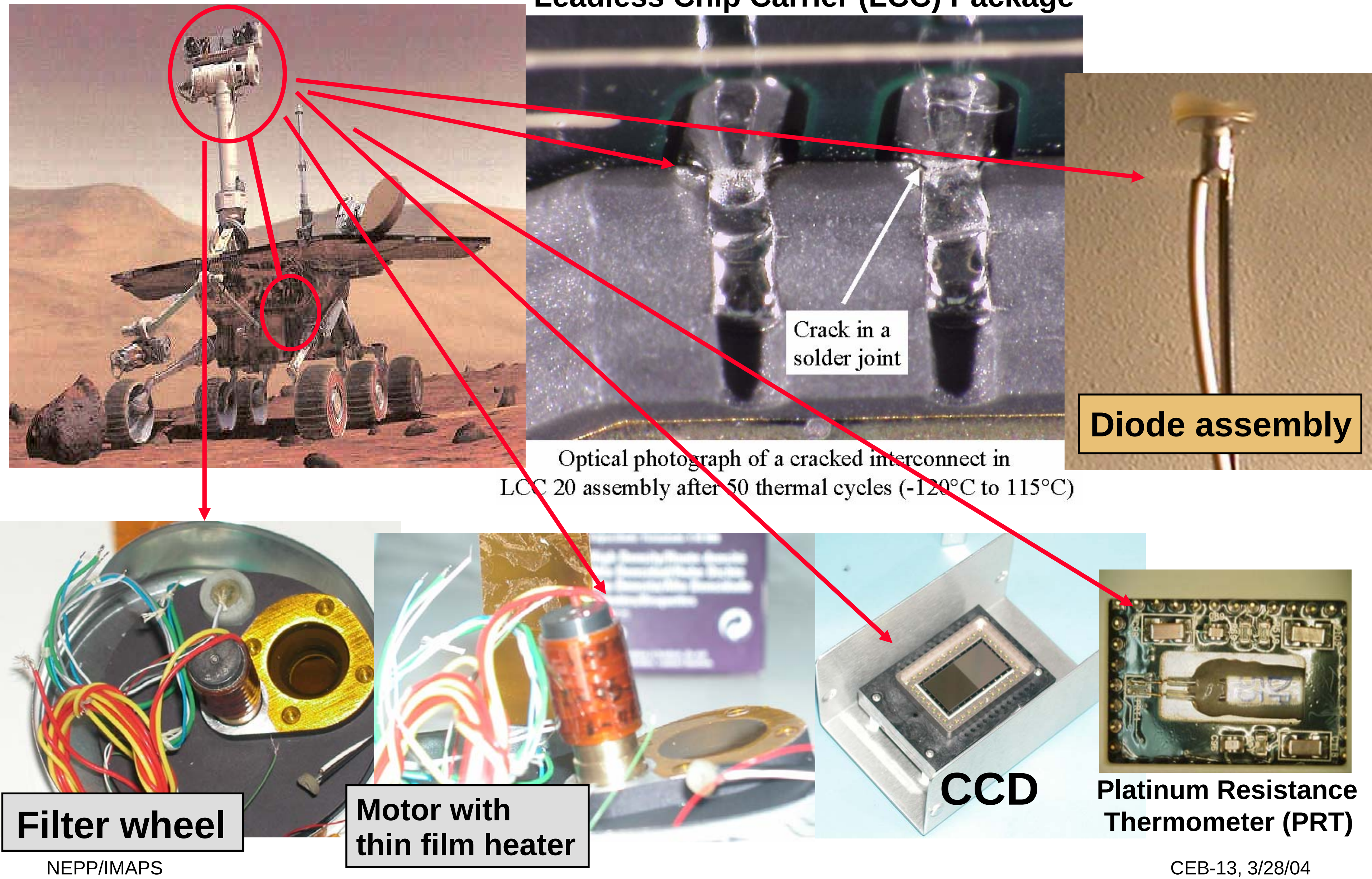
Package Qualification and Verification:
Thermal Cycling and Extreme Temperature Evaluation

- **Packaging Qualification, MER-A/B**
  - NEPP co-funded evaluation of high risk electronics used in foreign science instruments
  - Qualification of leadless packages used in APXS (Alpha-Particle X-ray Spectrometer) and camera co-funded by NEPP
  - Qualification of IMU, Camera's Charge Coupled Devices (CCDs), Brush motor encoders, UHF monopole antenna was leveraged with the NEPP tasks (Getters,MEMS, cold, etc.)
  - Qualification of RAT (Rock Abrasion Tool) science element payload was leveraged with NEPP for reliability of brazing joint and electronic switches
  - Testing of several aluminum adhesive tapes for their EMC compatibility and survivability by leveraging with NEPP funds
- **Materials and Failure Analysis, MER-A/B**
  - Motor brushes, polymeric bonding materials, adhesion issues, bonding in diode assembly of cameras

Work only co-funded by NEPP when results were broadly applicable to other NASA systems and projects

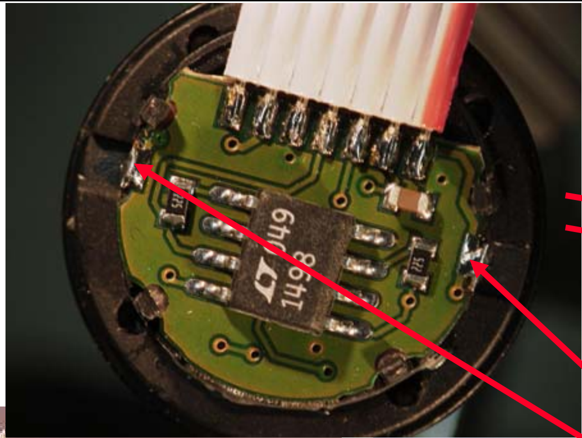
Camera Assembly Package Components of the Rovers

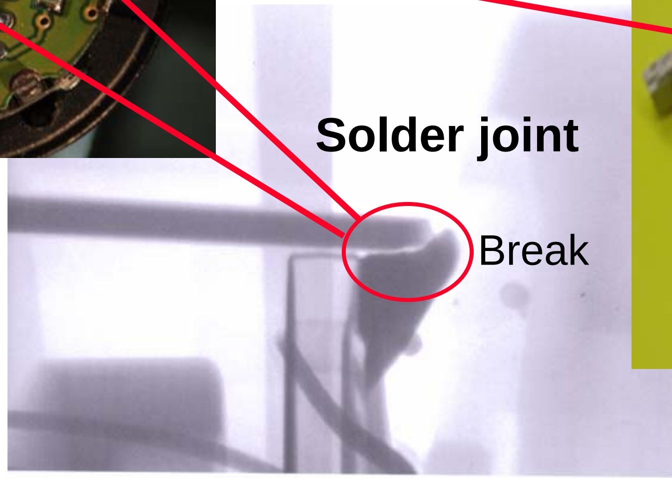
Leadless Chip Carrier (LCC) Package



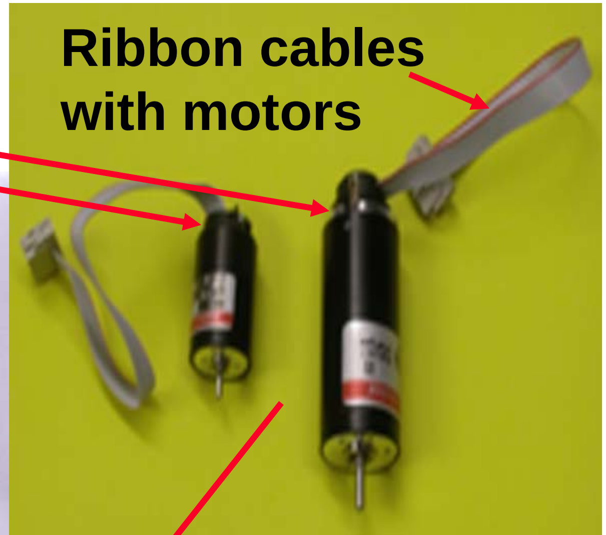
Optical photograph of a cracked interconnect in LCC 20 assembly after 50 thermal cycles (-120°C to 115°C)

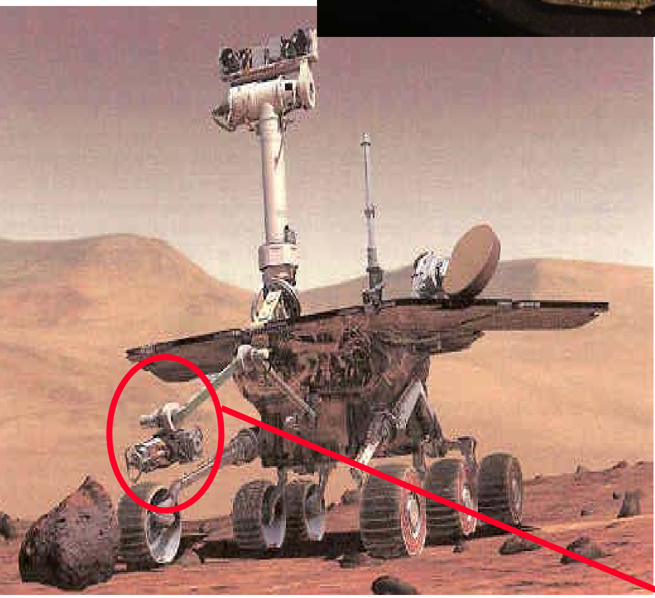
Rover Brush Motors In Extreme Environments



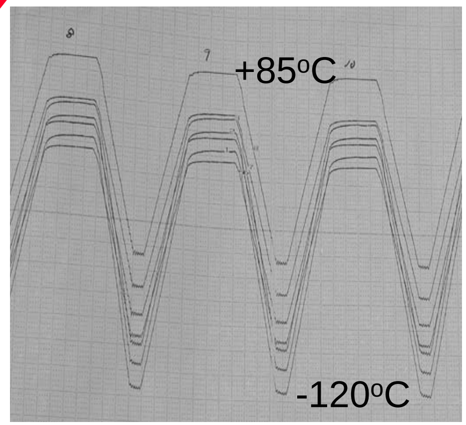


X-ray imaging of solder joints in [redacted] Motor#004





39 brush motors in Instrument Deployment Device (IDD) and elsewhere in rover



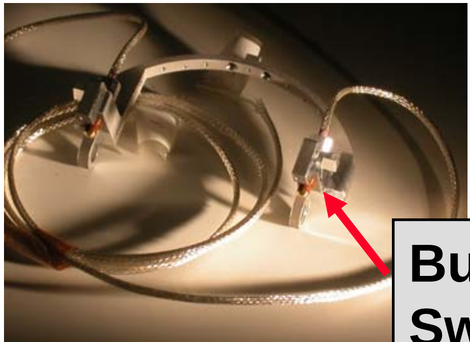
Typical thermal cycling test data

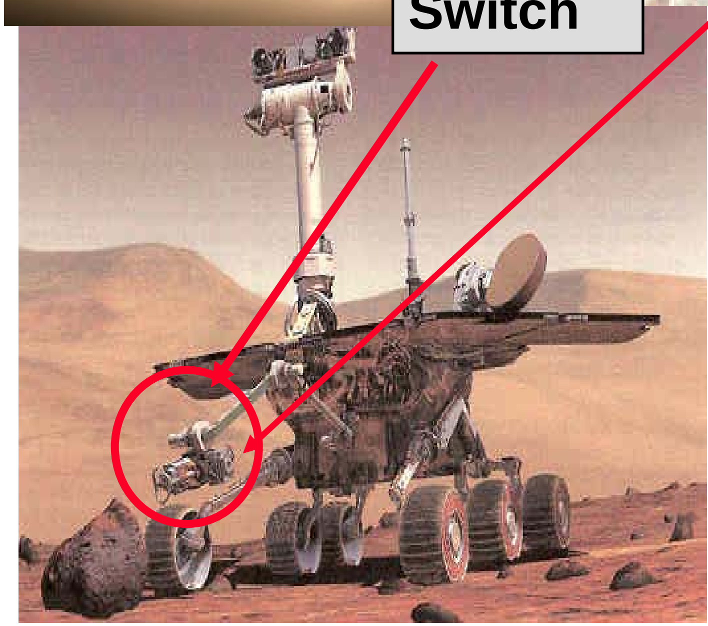
Rock Abrasion Tool (RAT)

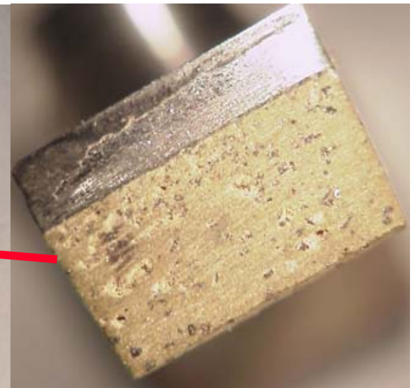
Survivability of brazing components in RAT grinding wheels in extreme environments and also polymerics etc.

RAT located in IDD of Rover

Butterfly Switch

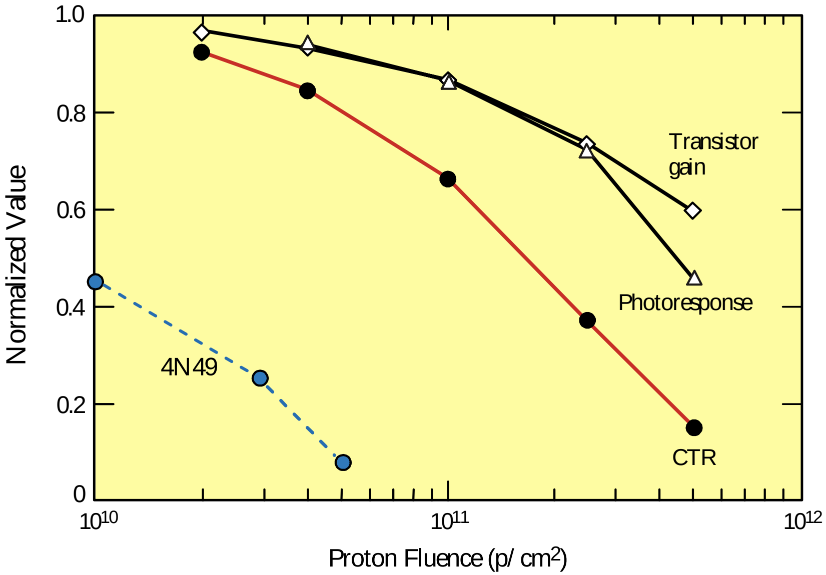






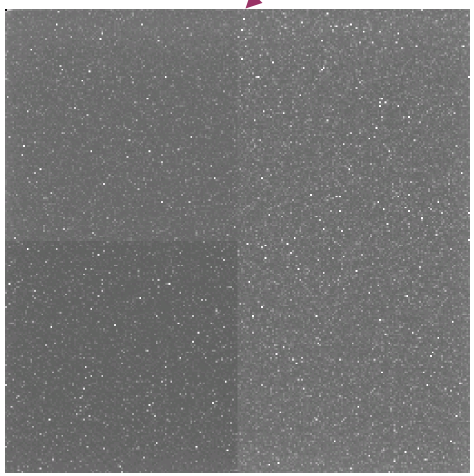
Two critical areas for design in the natural space radiation environment

- Long-term effects: failure/degradation increases with mission lifetime
  - Total ionizing dose (TID)
  - Displacement damage



Displacement damage in optocouplers

- Transient or single particle effects (Single event effects or SEE): random strikes by a particle
  - Soft or hard errors



Active Pixel Sensor (APS) array strikes

- **Four quadrants, each representing a different design**
- **Particle hits spread among multiple pixels**
- **Ion strikes are min-imized by utilization of a non N-well, n+ recessed implant photodetector design**

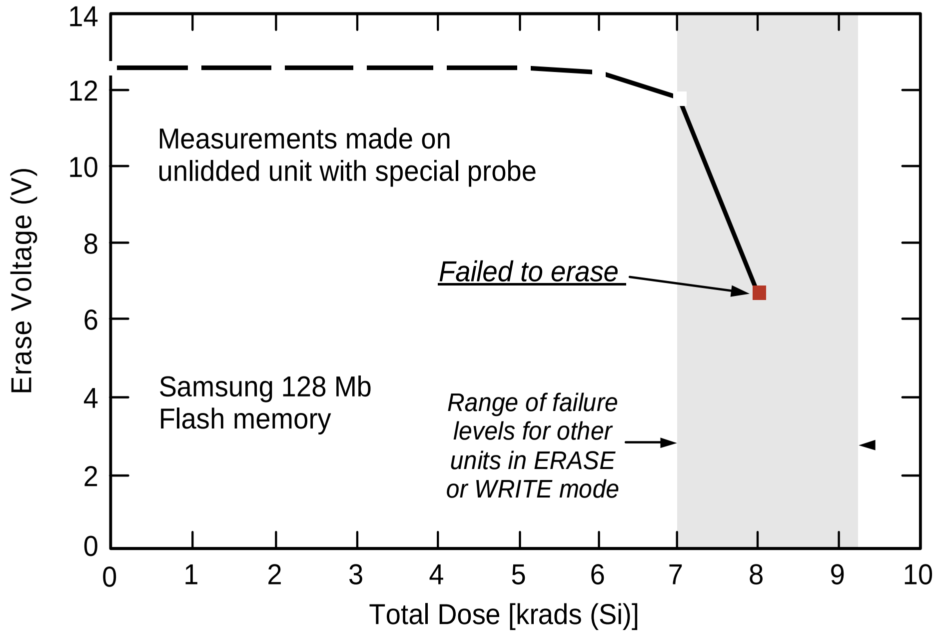
Radiation Damage from the October Solar Flare

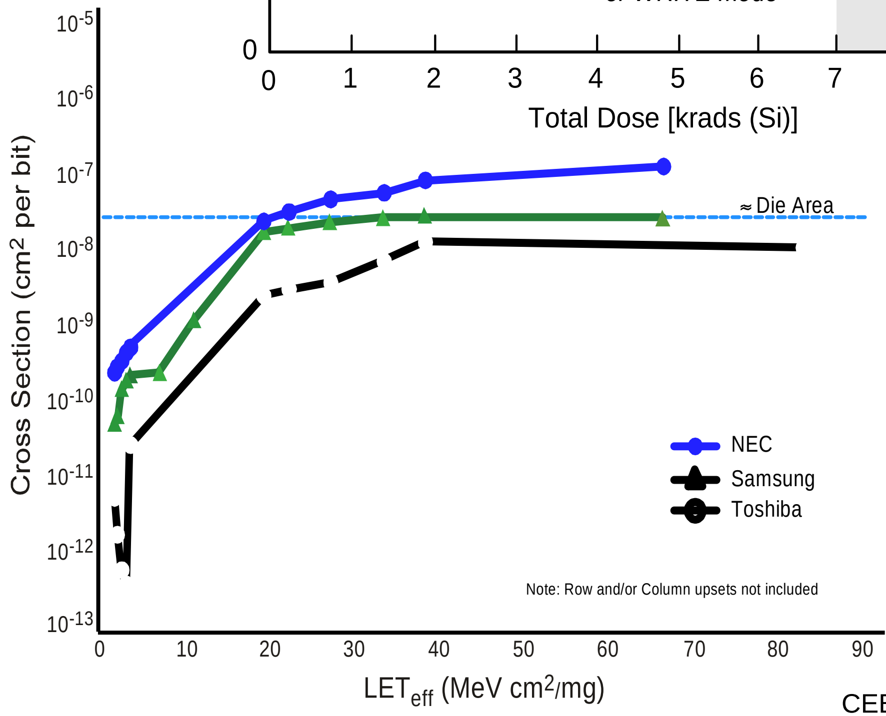
- Solar Flare Effects
  - Star trackers lost “lock” – quick assessment of electronics was needed before operation could be resumed safely
    - No radiation data was available for op-amps, transistors in star tracker
    - NEPP Radiation modeling and experience with similar devices allowed this analysis to be done within 48 hours
    - Radiation testing would have delayed the decision to resume operation by several weeks
  - Displacement damage from protons in the flare was also a concern
    - Extensive work on displacement damage under NEPP showed that displacement damage would not affect MER operation
    - Earlier work done on the camera CCD showed that there was sufficient margin in the CCD radiation response to allow it to function properly after the flare

Typical Star Tracker

Anomalies after Landing

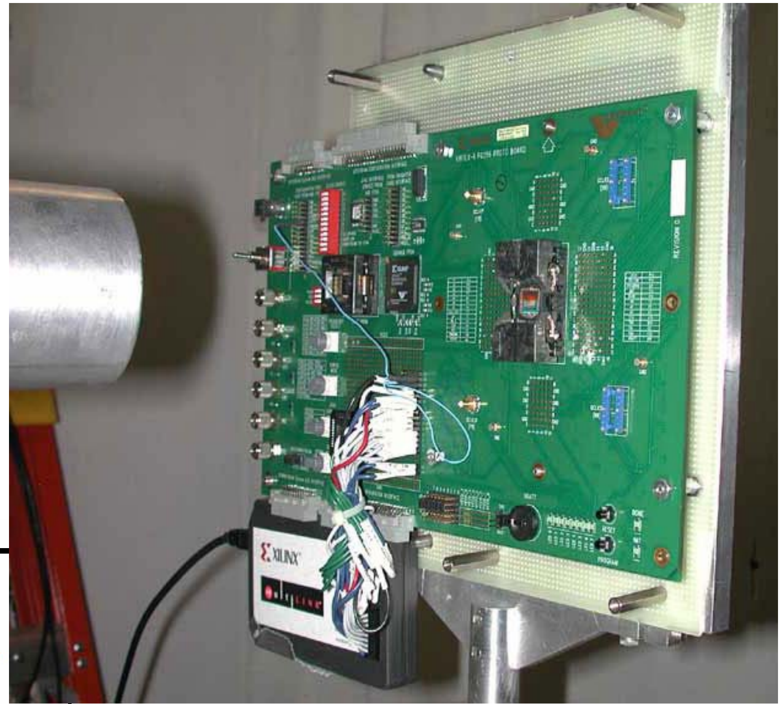
- **MER-A**
  - Radiation studies done on flash memories under NEPP clearly showed that radiation damage was not significant in the flash memory problem
- **MER-B**
  - NEPP radiation studies of operational amplifiers, power MOSFETs and transistors provided the technical rationale to rule out radiation damage in the malfunction of the heater circuit

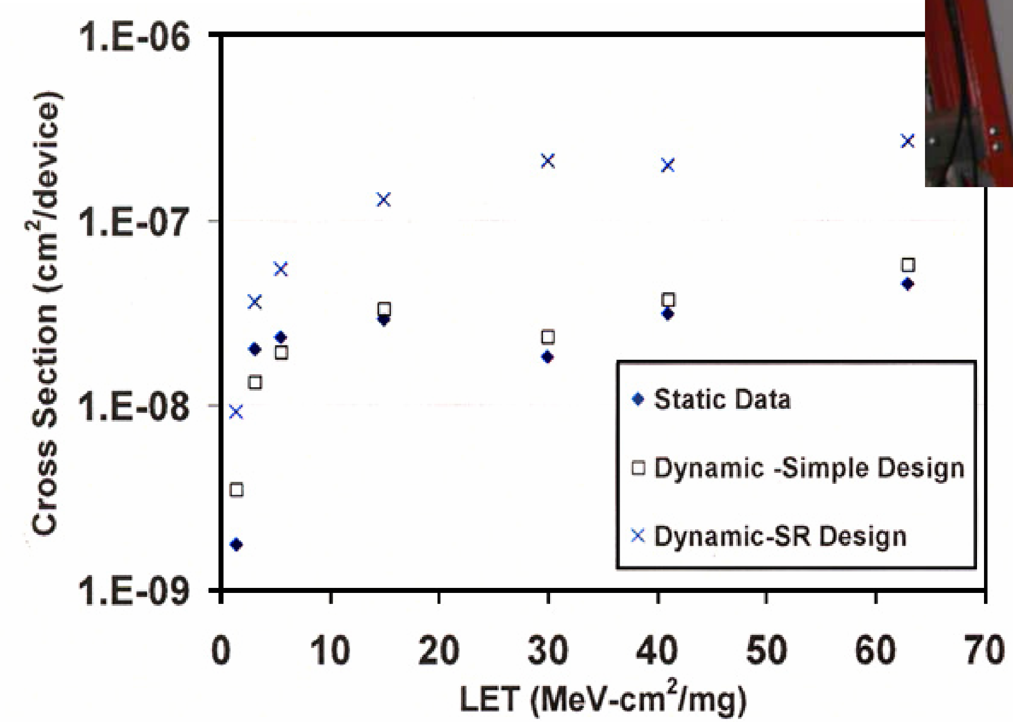




Concern about Upsets in Pyro Board

- **Issue**
  - The board that controls firing of the pyros used a field-programmable gate array (FPGA), which is susceptible to upsets from protons and heavy ions
  - NEPP has funded work on single-event effects in FPGAs that allowed us to show that the upset rate in the FPGAs was low enough so the risk was acceptable. Without the NEPP work, a costly time consuming radiation test would have been required





Conclusions

- **The NEPP Program has assisted a variety of flight projects through its evaluations of advanced COTS and emerging technologies, and its identification of the risks associated with their use in the space environment**
  - In particular, the NEPP Program has contributed significantly to the stunning successes of the MER Project
- **To continue these successes, technology needs must be strategically planned well-ahead of project insertion**
  - Allows NEPP to assist in reducing technology risk prior to and in early project phases
  - Meeting broad, long-term needs and not point solutions is the appropriate approach
- **The challenges posed by the use of COTS in space must be met in order to realize the advantages of the state-of-the-art performance of COTS**
- **Parts, packaging and radiation engineers must work together through Programs like NEPP in order to achieve the risk-free insertion of high performance microelectronics and photonics into NASA systems**