# Extreme Temperature Thermal Cycling Tests and Results to Assess Reliability for Mars Rover Flight Qualification

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# PQV Team Members for Mars Exploration Rover

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Etc.

# ACKNOWLEDGEMENTS

PQV team members

MER Project Management (Barry Goldstein, Richard Brace, Richard Cook, Peter C. Theisinger, Don Sevilla, Steve Squyres, Thomas Ramsey, etc)

Several PEMs, Cog Es, and Engineers (Mike Johnson, Don Noon, Edward C. Litty, Ed Konefat, Steve Kondos, Eric Young, Mark Balzer, Mark A. Schwochert, Eric Sunada, Andy Collins, Wayne Bosze, Saverio D'Agastino, Mike Sandor, Shri G. Agarwal, Mark Johnson, Ed Erginsoy, Kevin Robinson, Glen Tsuyuki, Joseph D Vacchione , Richard Ewell, Mau Tran, Donald Nieraeth, Pablo Narvaez, Paul Stella, Kobie Boykins, Richard Paynter, etc.

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Sammy Kayali for the opportunity to give this presentation at MRQW.

# Pathfinder Sojourner Rover and Mars Exploration Rovers

1997 Mars Pathfinder Sojourner rover

2004 Mars Exploration rovers (Spirit and Opportunity) or Twin rovers

MER rovers are larger, more mobile, better equipped with payload elements.

Spirit: Launched on June 10, 2003 and landed on Jan 3, 2004 (PST)

Opportunity: Launched on July 7, 2003 and landing on January 24, 2004 (PST)

Parachute has deployed to slow down the spacecraft and airbags have inflated to cushion the landing, bounce, deflate, retract and the spacecraft petals open, lander upright position, and reveal the rover.

Pathfinder has scientific instruments on both the lander and the small Sojourner rover.

Spirit and Opportunity Rovers carried all scientific instruments.

Sojourner rover: 12 weeks, traveled a length of a football field.

MER rovers: Actual life: 90 days (12.85 weeks), travels six to 10 times the pathfinder in 90 days.

# Pathfinder Sojourner Rover and Exploration Rovers

- Sojourner rover, Spirit, and Opportunity have the heater units to some electronics battery, warm, and operational during the extremely cold Martian night time.
- The electronics inside the rovers are qualified for survival and operational for –55°C.
- The two rovers experience –105°C (-157F)
- The optical resolution of the pictures is three times greater than the pathfinder
- MER rover weighs about 180 Kg (~400 pounds), expected to travel 40 meters per sol (Martian day)
- Surface operations will last late April (2004) and could continue longer depending on the health of the rovers.
- Goal: Climate and the water???
- Landing sites: Spirit: Gusev Crater; Opportunity: Meridiani Planum

# Science Instruments

Each rover carries a set of five scientific instruments

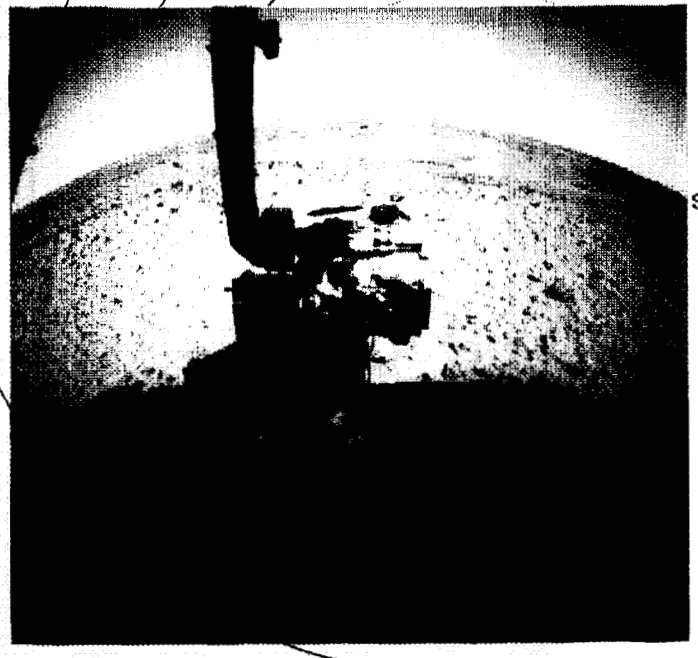
- Panoramic camera (JPL)
- Microscopic imager (JPL)
- Miniature Thermal Emission Spectrometer (ASU), Tempe
- Mossbauer Spectrometer (Johannes Gutenberg University, Germany)
- Alpha Particle X-ray Spectrometer (Max Planck, Germany)
- Rock Abrasion Tool (Honeybee Robotics)
- Magnetic targets (Niels Bohr Institute, Denmark)

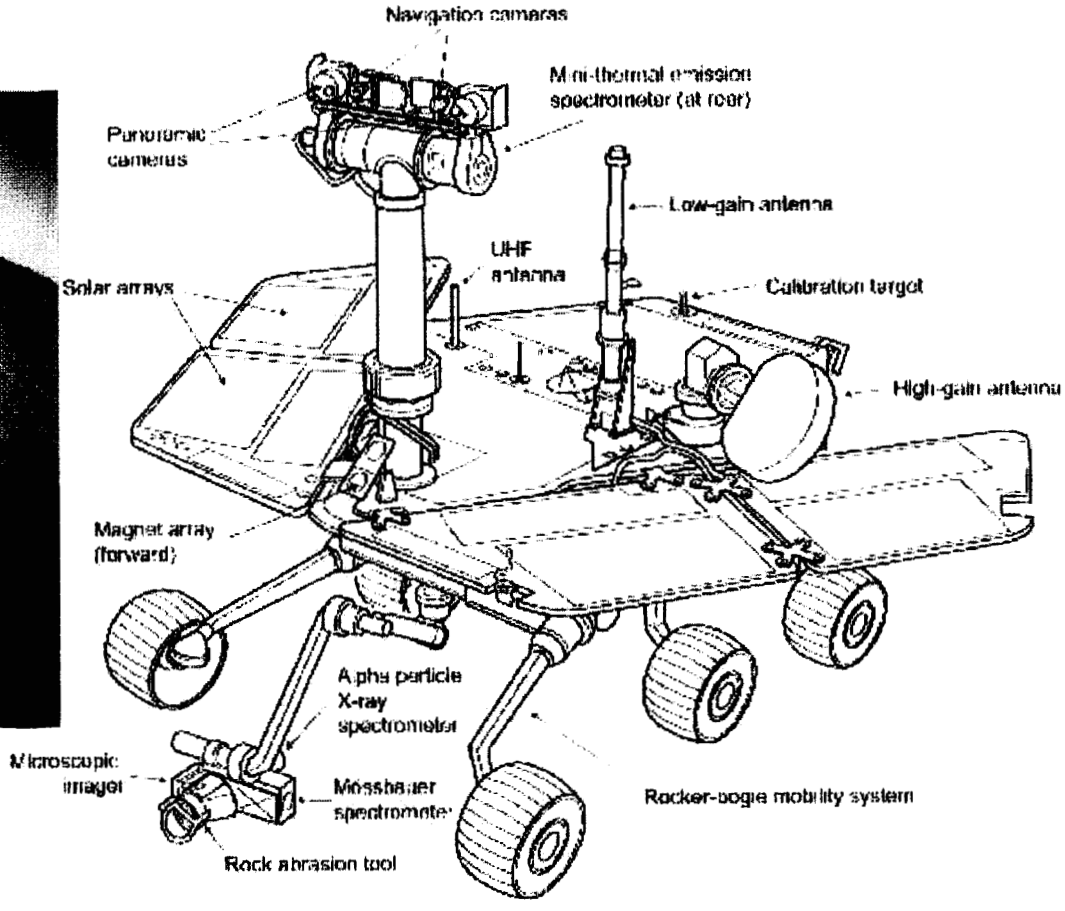
Spectrometers, microscopic imager, and RAT are deployed on a robotic arm.

# Package Qualification and Verification for JPL/NASA Projects

## JPL/NASA - Mars Exploration Rover

# Package Qualification and Verification for JPL/NASA Projects






*Mars Exploration Rover*

# Quality and Reliability

- Conformance of hardware to the specifications, guidelines, workmanship standards.
- Product performance to intended function over intended life under environmental/life-cycle loads.
- Qualification testing is to ensure reliability of the hardware.
- Qualification prior to fabrication of the flight hardware ensures cost-effective approach and enhances the mission assurance for JPL/NASA applications.

# Mars Environment, etc.

- $CO_2$ (95.3%), $N_2$ (2.7%), and Ar (1.6%)
- Pressure: ~7.6 Torr (~1/100$^{th}$ of earth)
- Surface temperature varies from –128°C during the polar night to 27°C at equator during midday at closest point tin orbit to Sun.
- Length of Martian day: 24 hrs, 39 min, 35 sec (1.027 earth days).
- Revolves around sun once every 687 earth days

# Failures

Material wear-out/life cycle/usage (repeated stress and accumulation over of damage over time)

Materials

Electrical

Mechanical

Thermal

# Critical parameters employed in solder joint selection

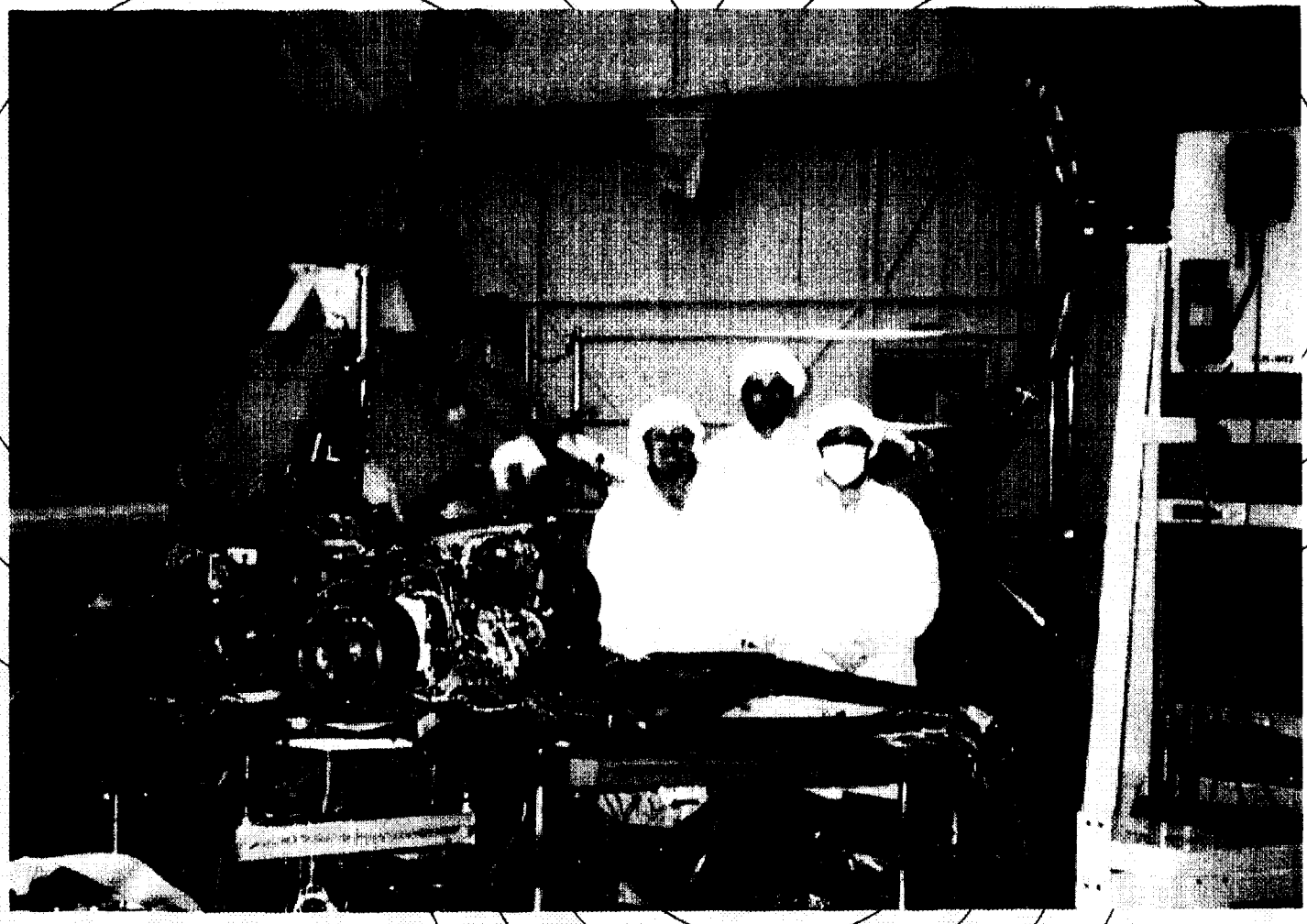
- CTE of the lead material, substrate, package, etc.
- Size of the package
- Compliance of the lead
- Height of the solder joint
- Area of the footprint
- Creep properties of the solder
- Fatigue properties of solder
- Wetting, intermetallics, etc.

## Package Qualification and Verification for JPL/NASA Projects

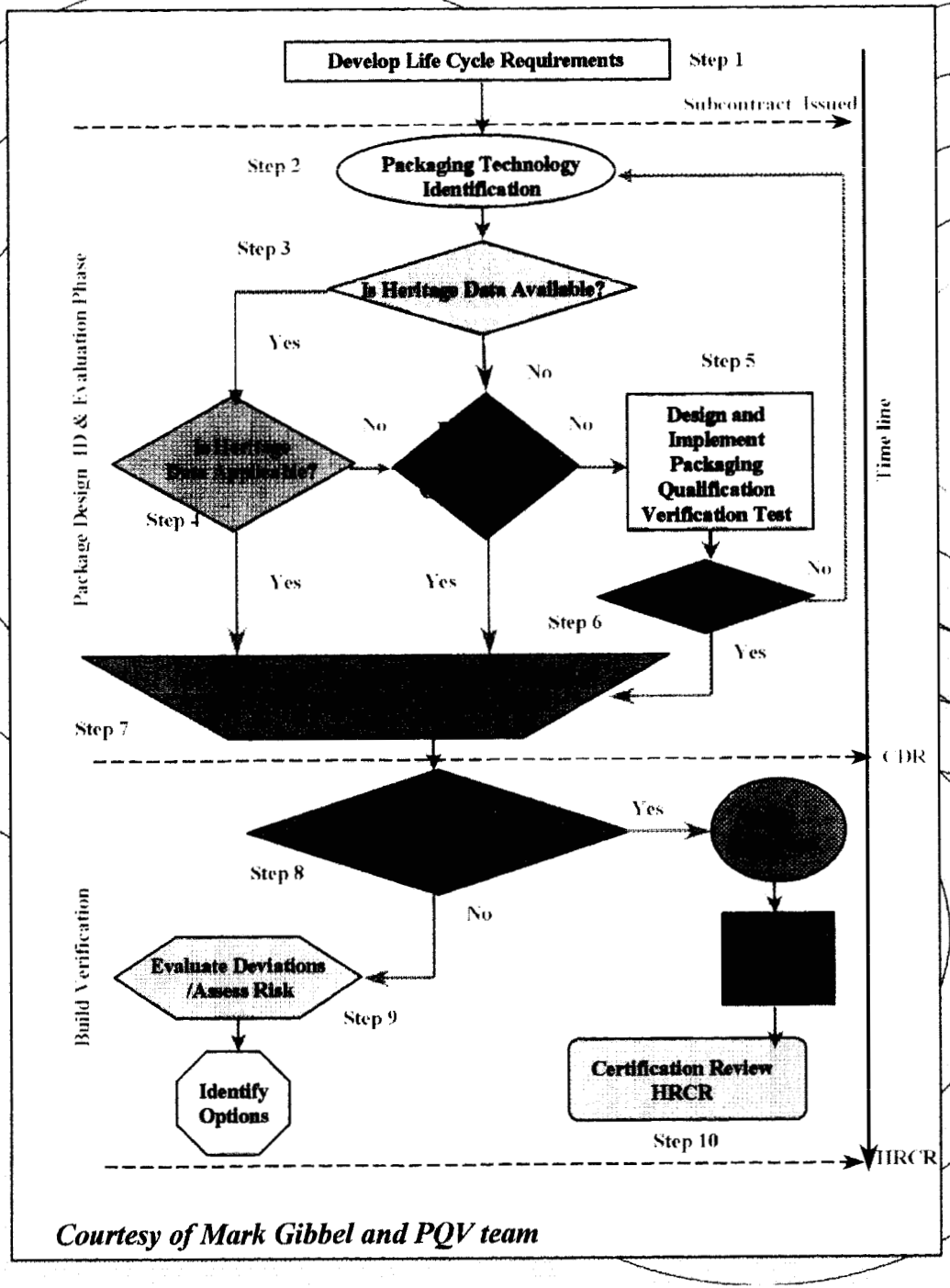
### Ground, Space, and Potential Stress

- Manufacture/fabrication, assembly, storage, handling, and operation (on ground)
- Manufacture/fabrication, assembly, storage, handling, transportation, launching, cruising, landing, and operation (on ground and in space)
- Loads/stress: Mechanical shock, vibration, temperature, thermal cycling, thermal shock, thermal gradients, power cycling (current and voltage), humidity, contaminants, biological contaminants, Electromagnetics, radiation, etc.

# Package Qualification and Verification for JPL/NASA Projects



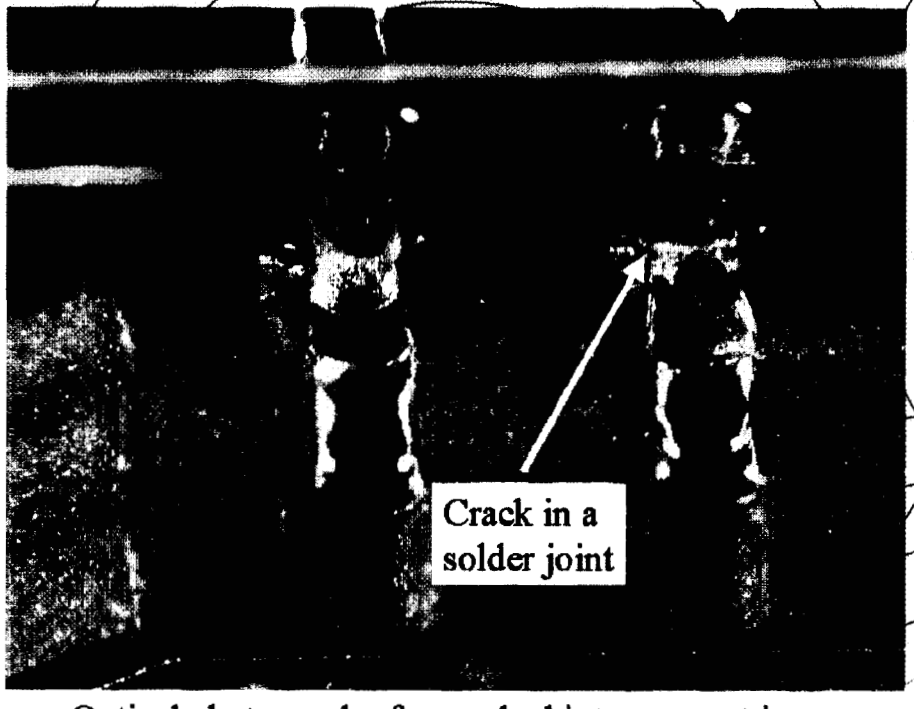
*Courtesy of Mark Johnson et al.,*




*Courtesy of Mark Gibbel and PQV team*

# Process flow for the packaging qualification verification (PQV) plan

# Package Qualification and Verification for JPL/NASA Projects




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

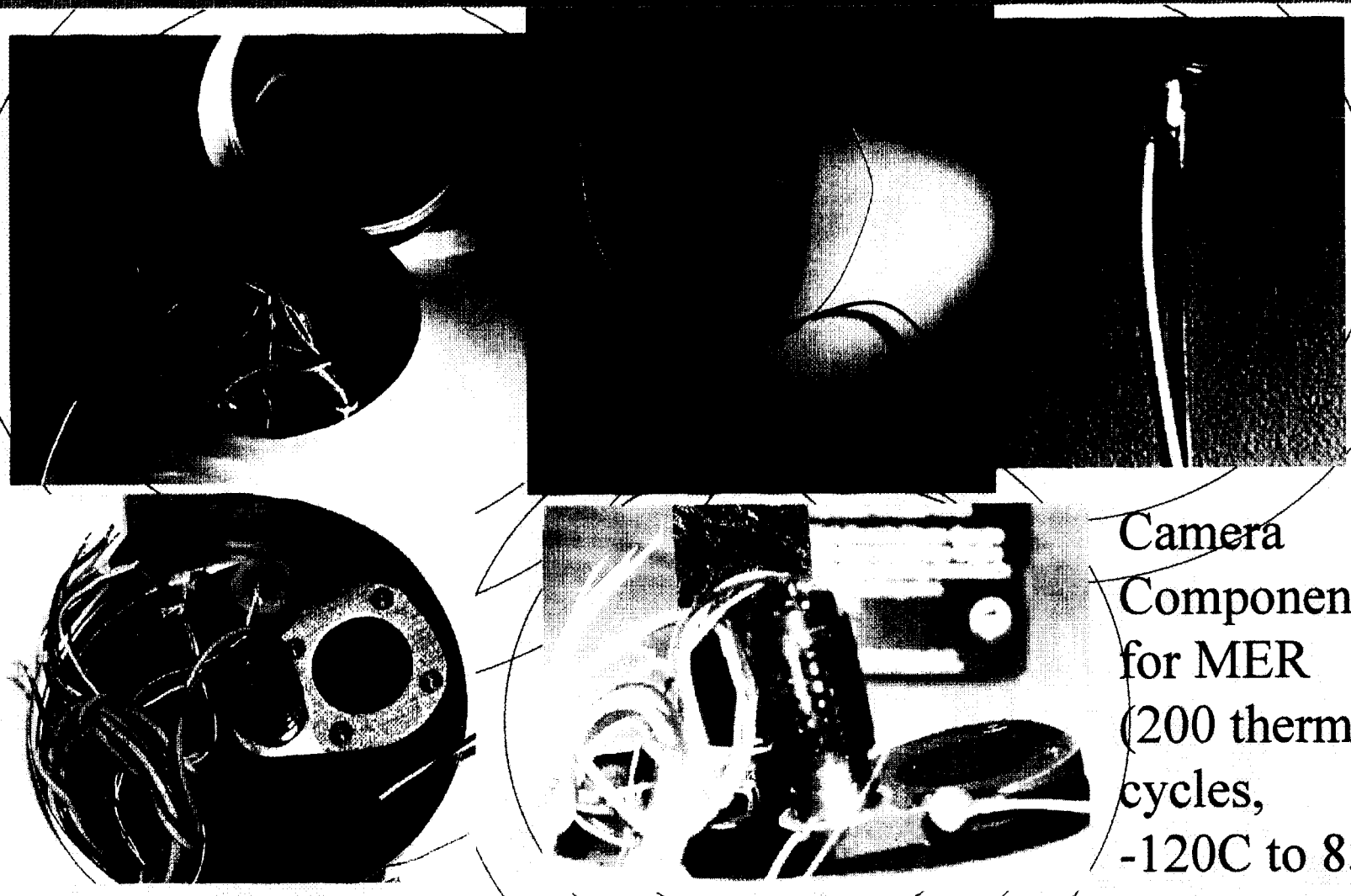
Sepa of solder joint after
cycles

ed haywire

## Camera Electronics Assembly for MER

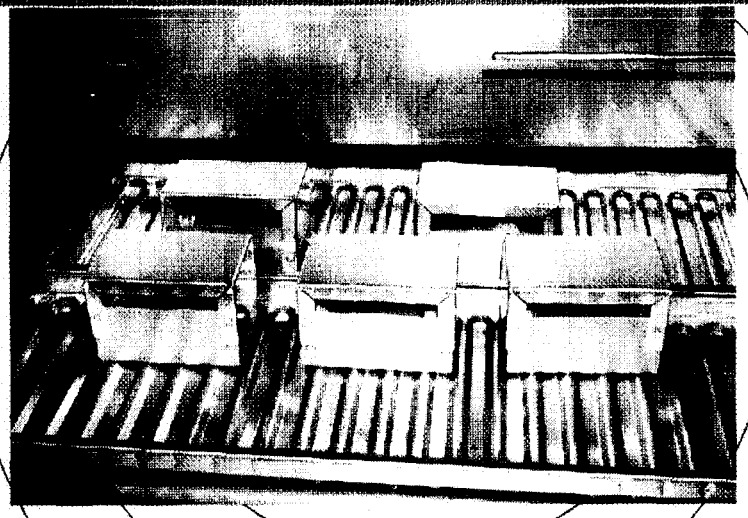
(200 thermal cycles, -120C to 85C)

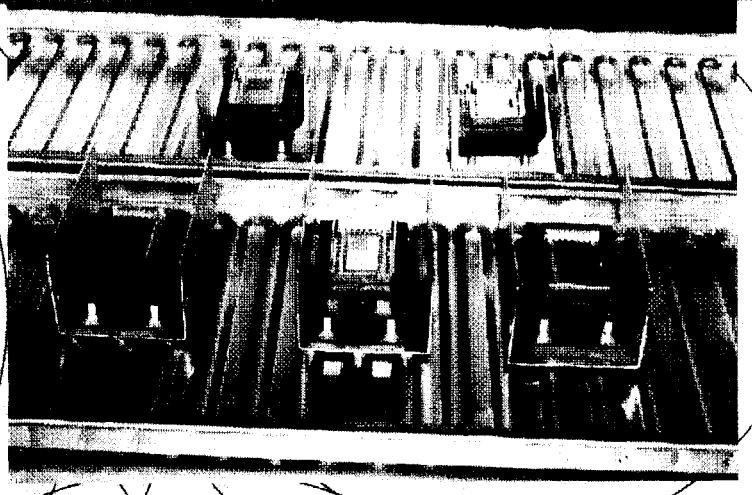
# Package Qualification and Verification for NASA Projects



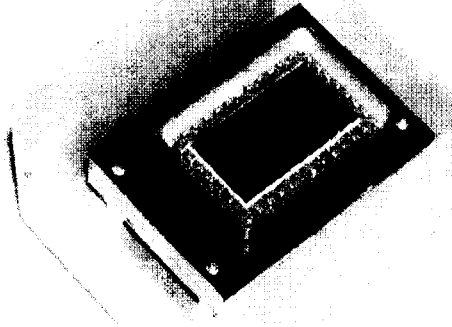
Camera Components for MER (200 thermal cycles, -120C to 85C)

# Package Qualification and Verification for NASA Projects

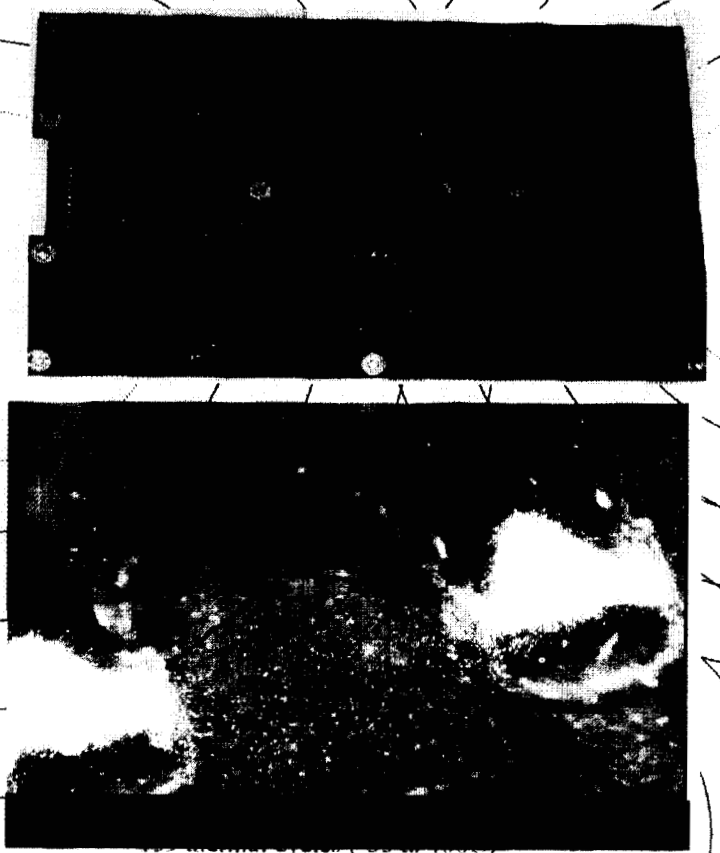




CCDs for Camera Assembly of MER
(10 thermal cycles,
-120C to 50C)

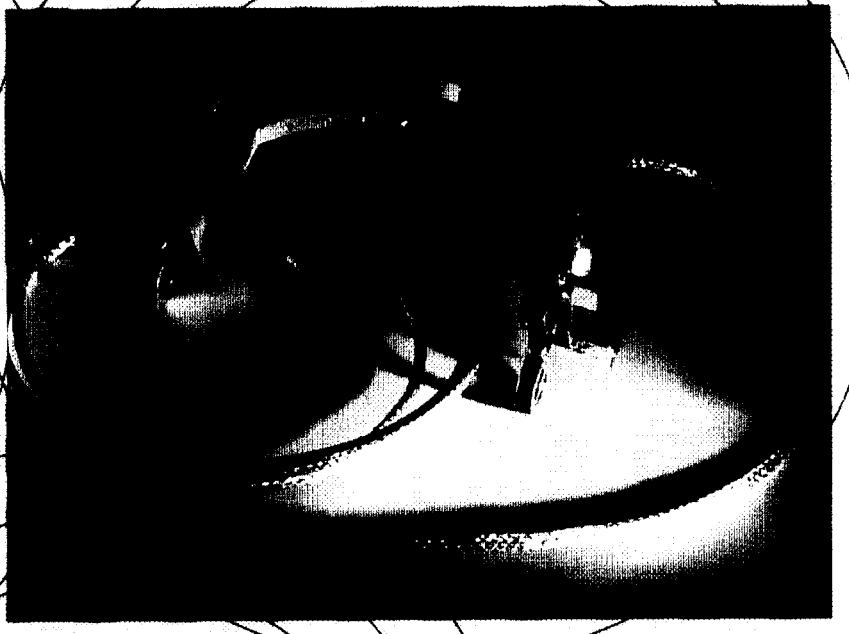


# Package Qualification and Verification for NASA Projects



Spectrometer electronic package for MER
(200 Thermal cycles, -55C to 100C)

# Package Qualification and Verification for JPL/NASA Projects

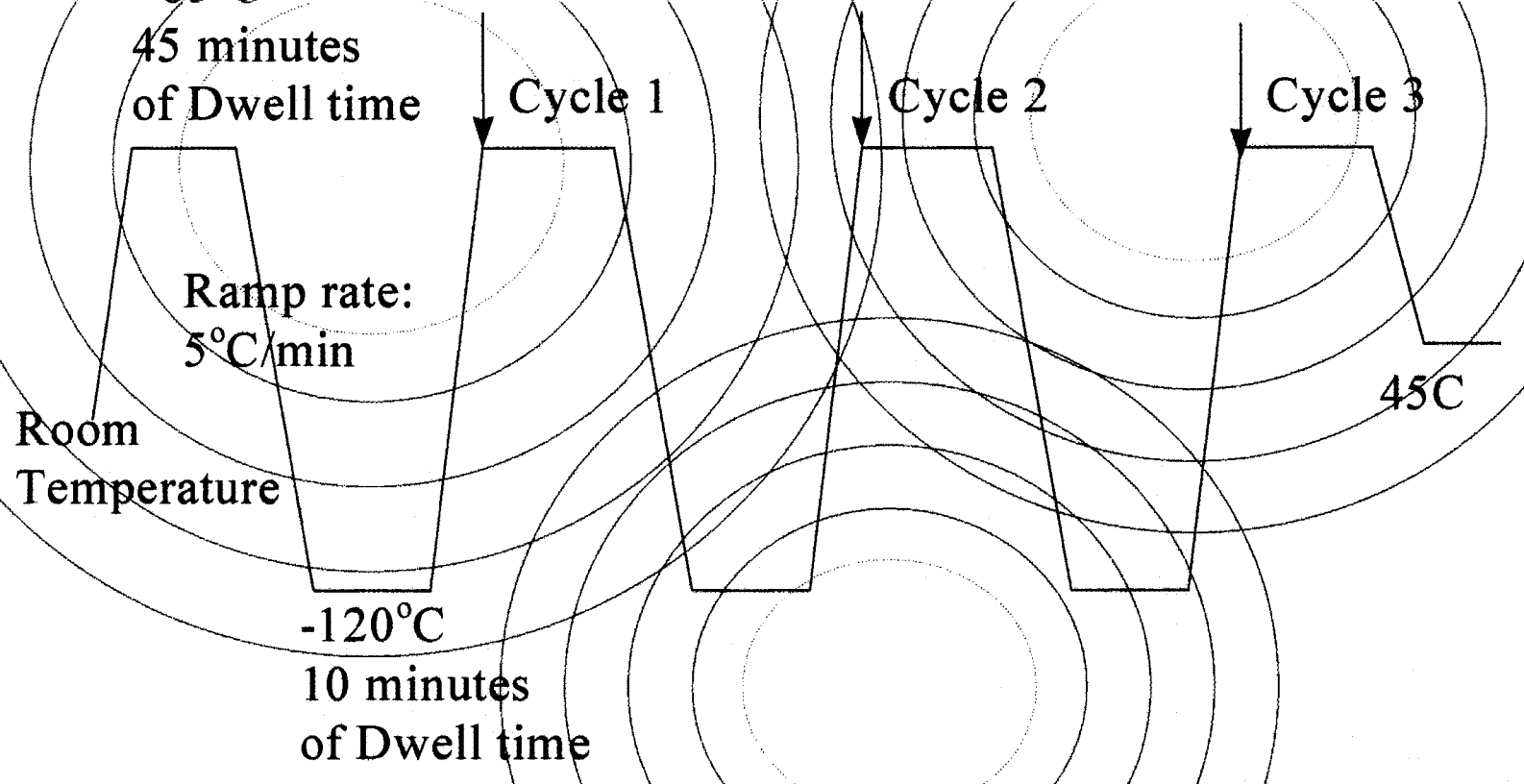


- Rock Abrasion Tool's Butterfly Switch (PQV test)
(270 thermal cycles, -120C to 85C)

*Steve Kondos and Don Sevilla's test (payload element)*

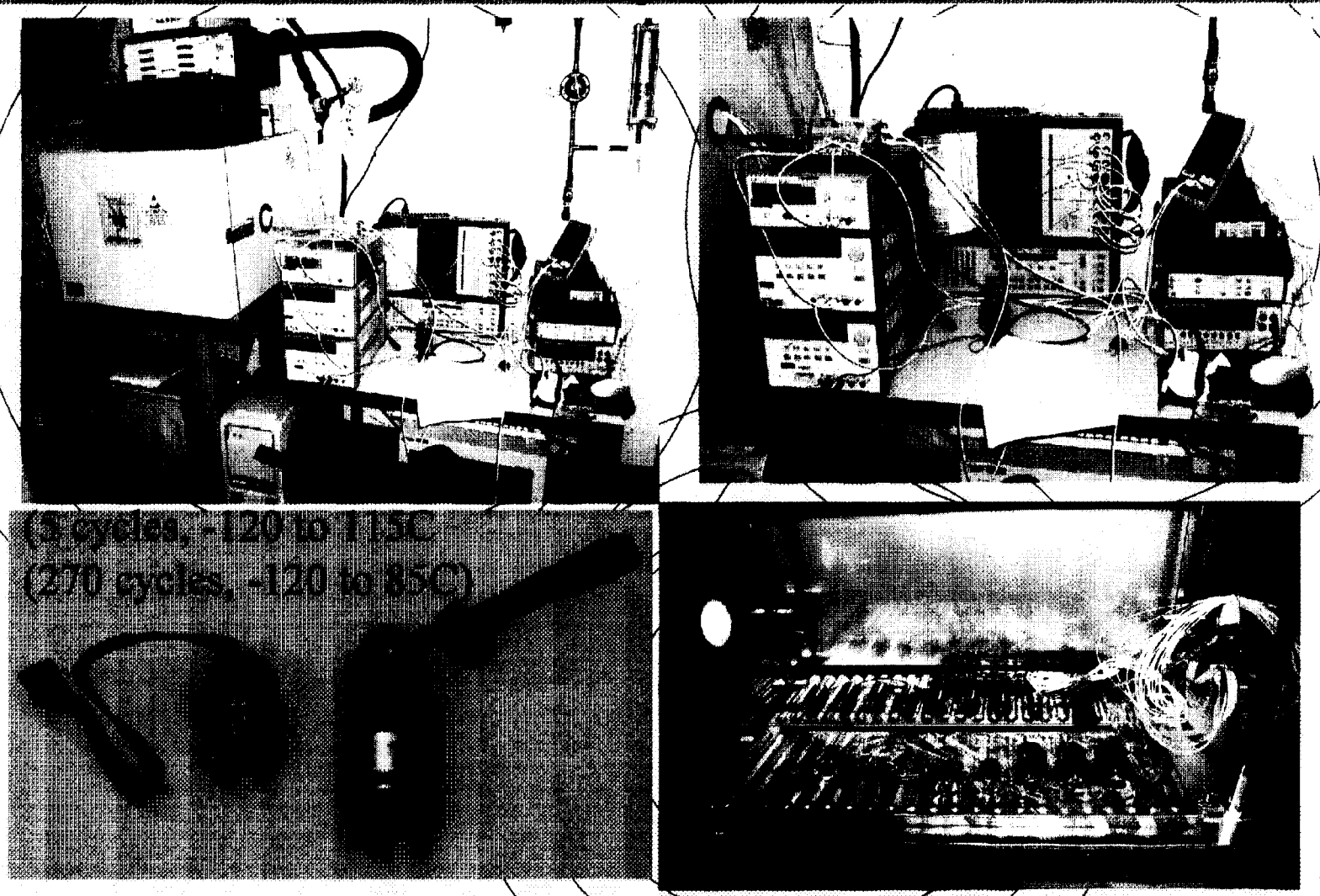
# Package Qualification and Verification for NASA Projects

JPL




**Temperature Profile 1: 270 cycles only**

# Package Qualification and Verification for NASA Projects



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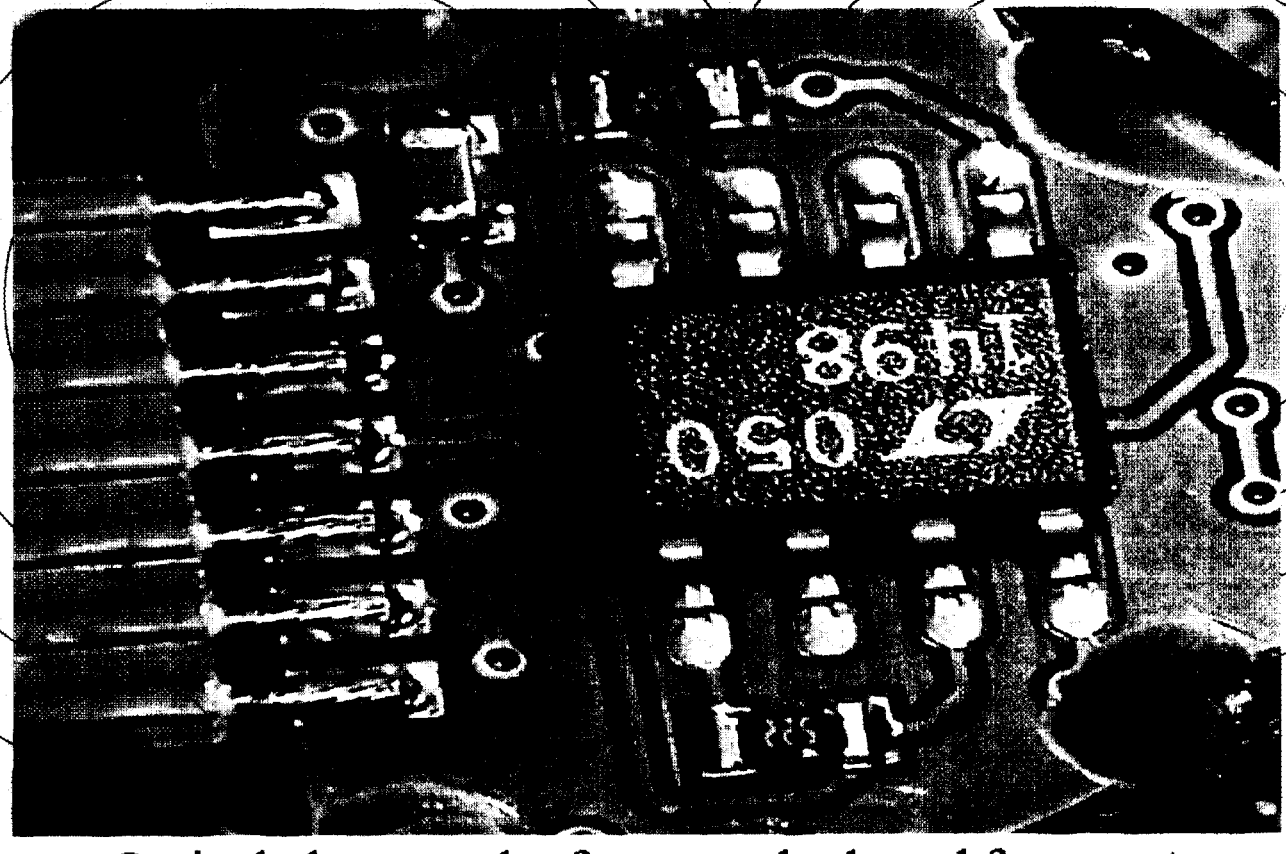
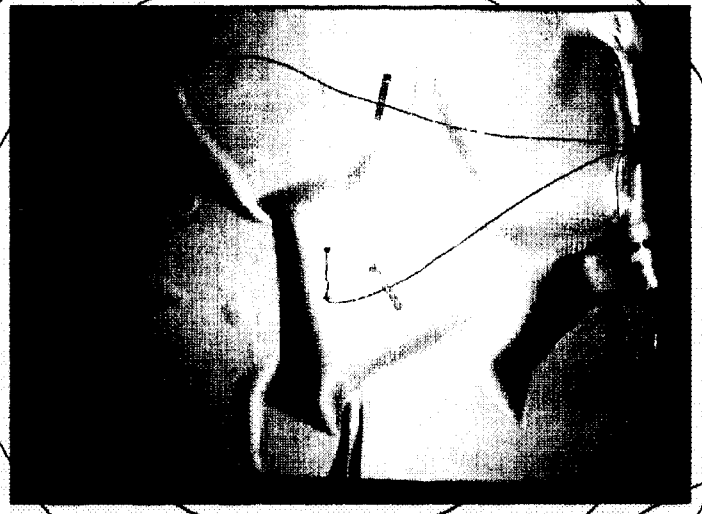
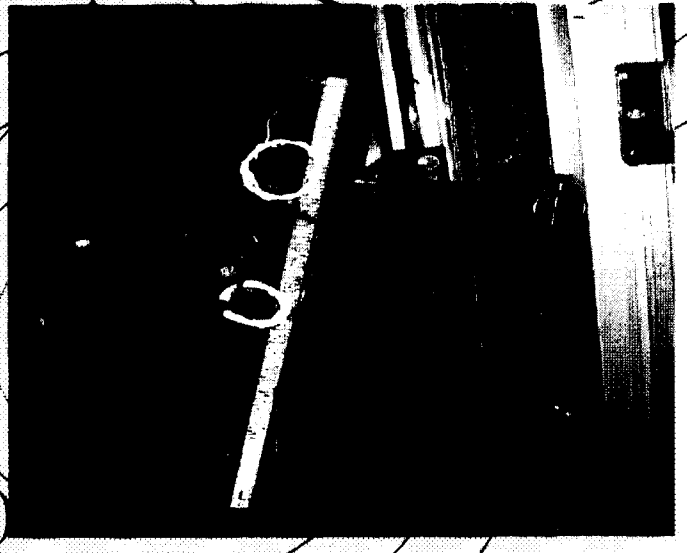



Optical photograph of an encoder board for a motor subjected to 200 thermal cycles (-120°C to 115°C) and 70 Cycles (-120°C to 85°C)

# Package Qualification and Verification for NASA Projects

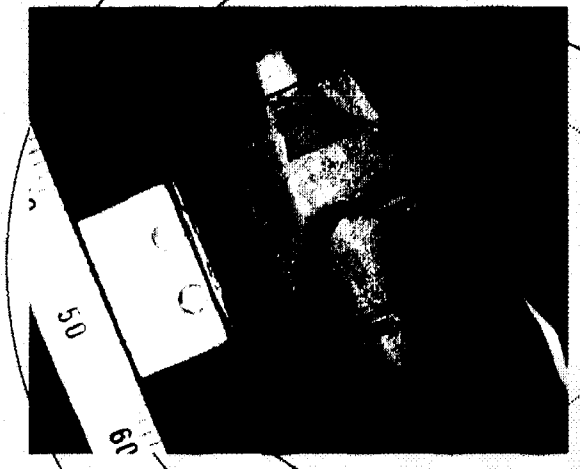


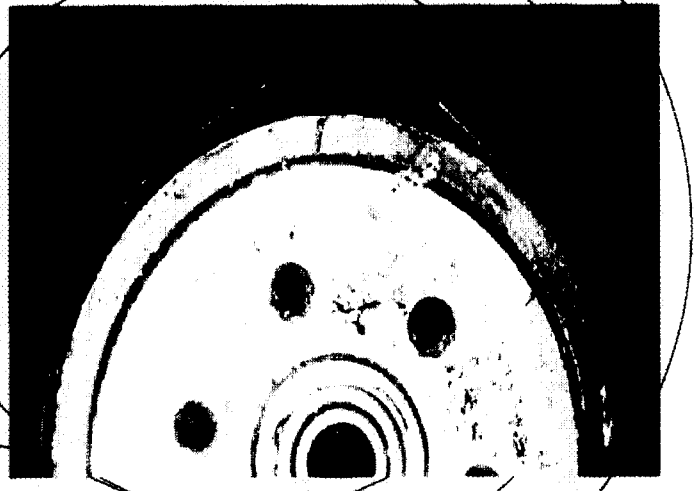


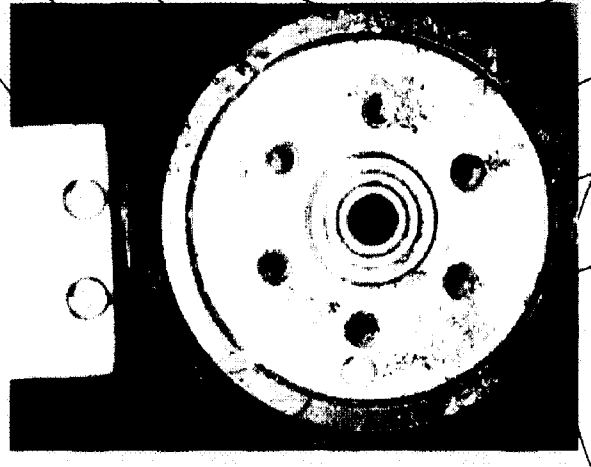
(270 cycles, -120C to 110C)

*Paul Stella/K. Boykins/Eric Sunada's test*

# Package Qualification and Verification for NASA Projects







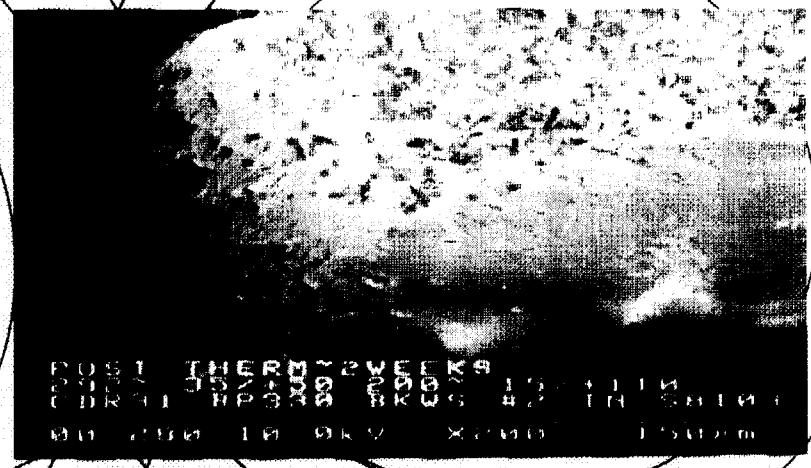
Thin Film Heater around the Motors

(315 cycles, -120C to 115C)



*Courtesy of Eric Sunada*

# Package Qualification and Verification for NASA Projects



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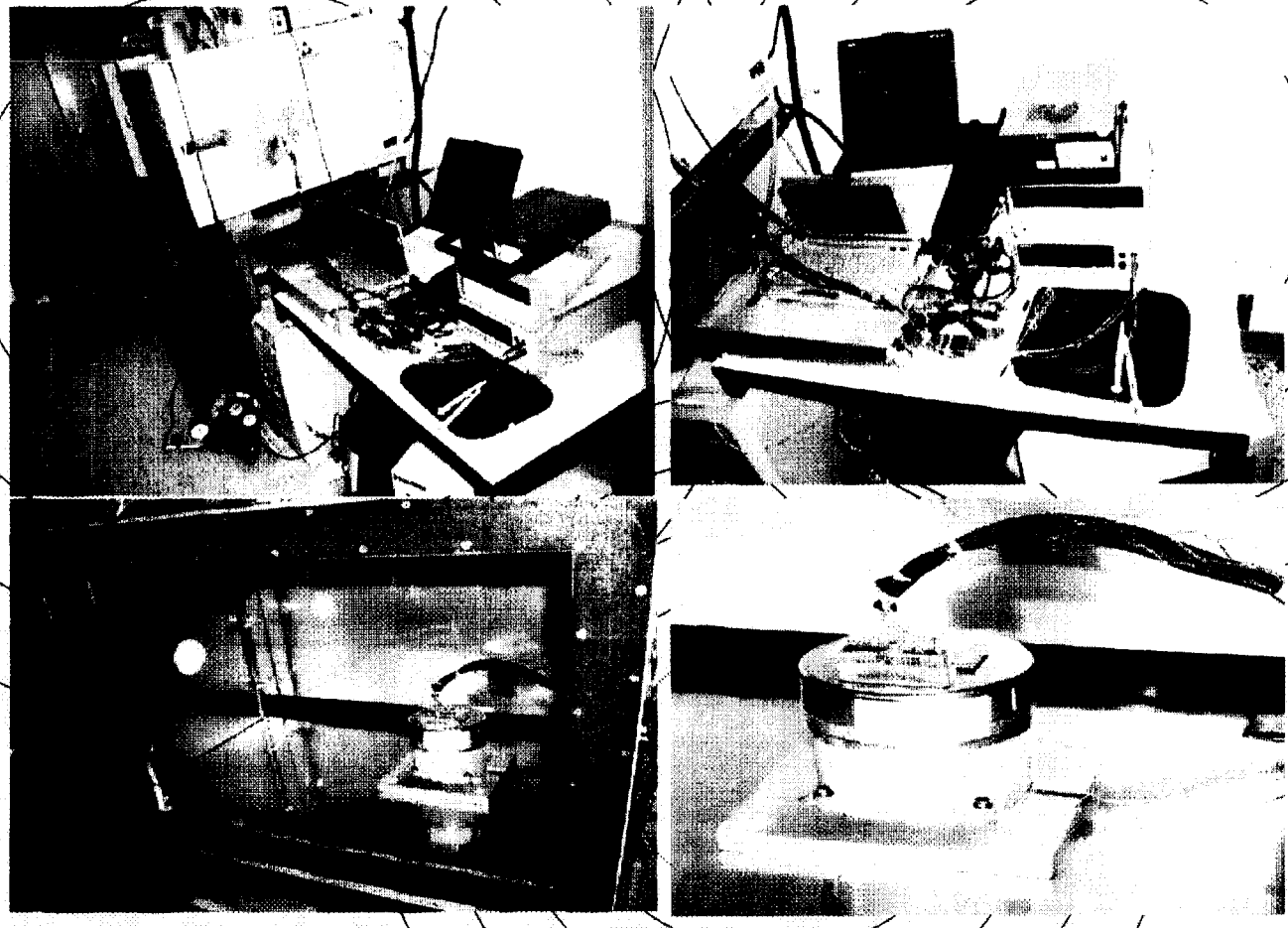
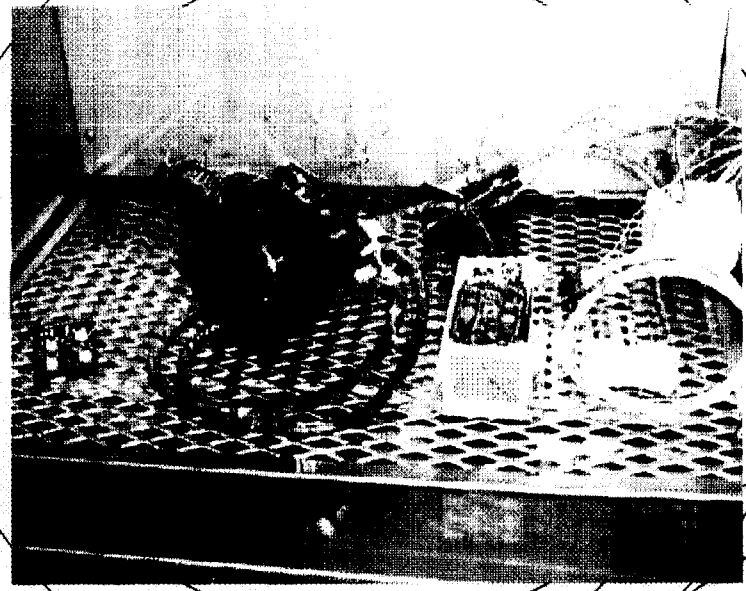
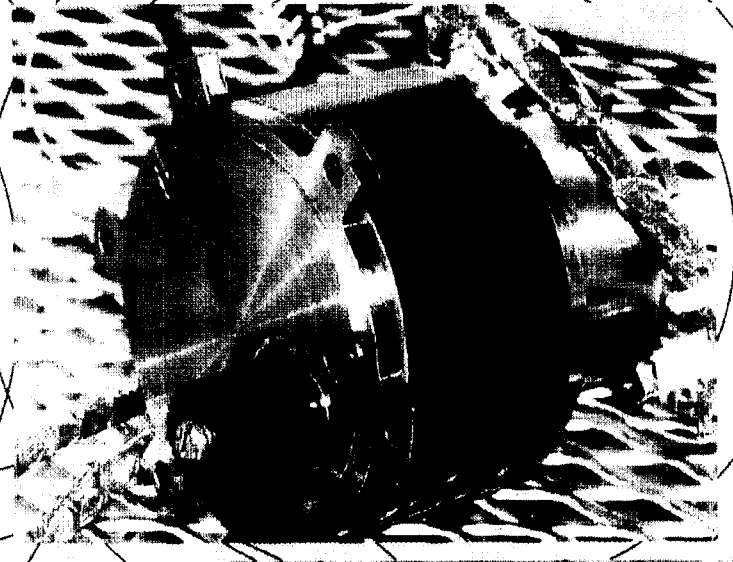


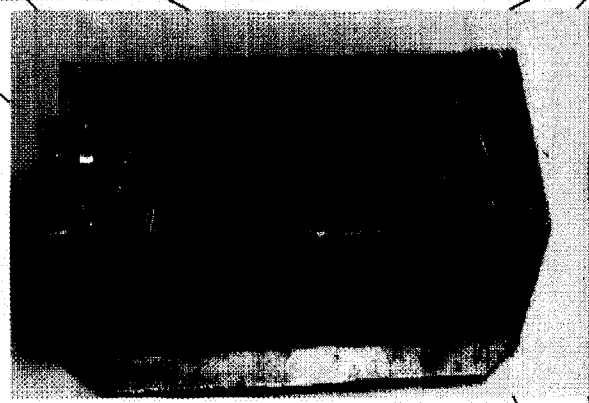
Inertial Measurement Unit for MER (220 thermal cycles, -54 to 71°C)

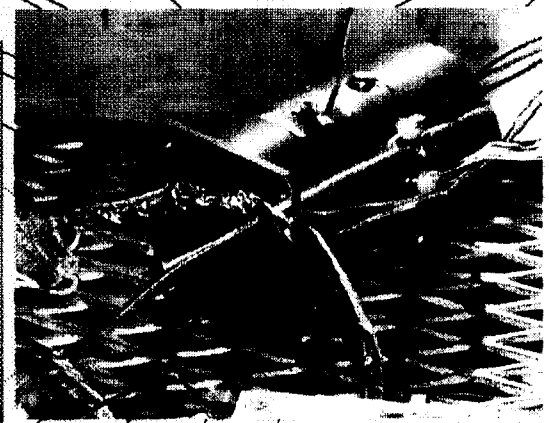
*Ed Litty and Ed Konefat's test*

# Package Qualification and Verification for NASA Projects



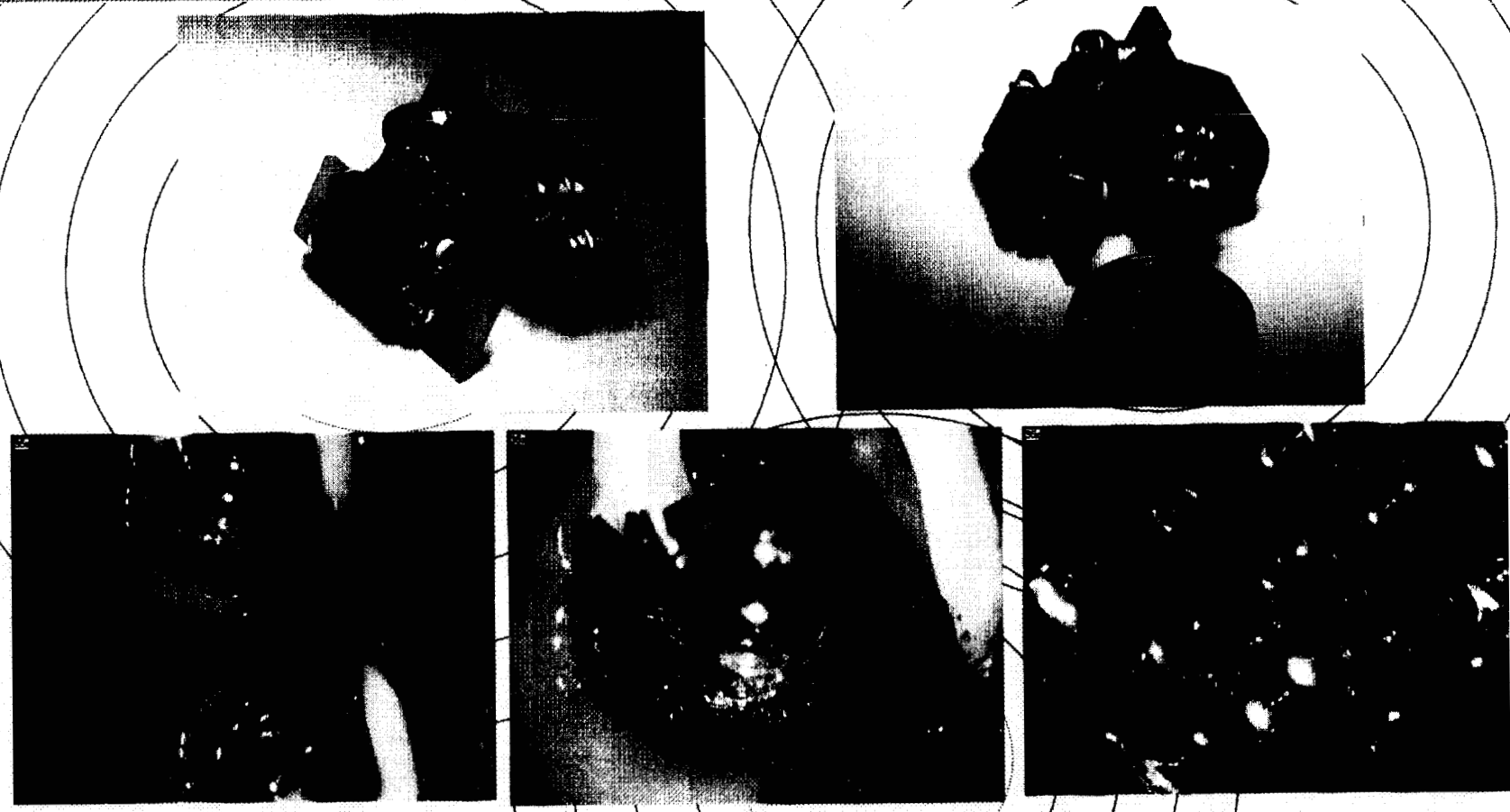






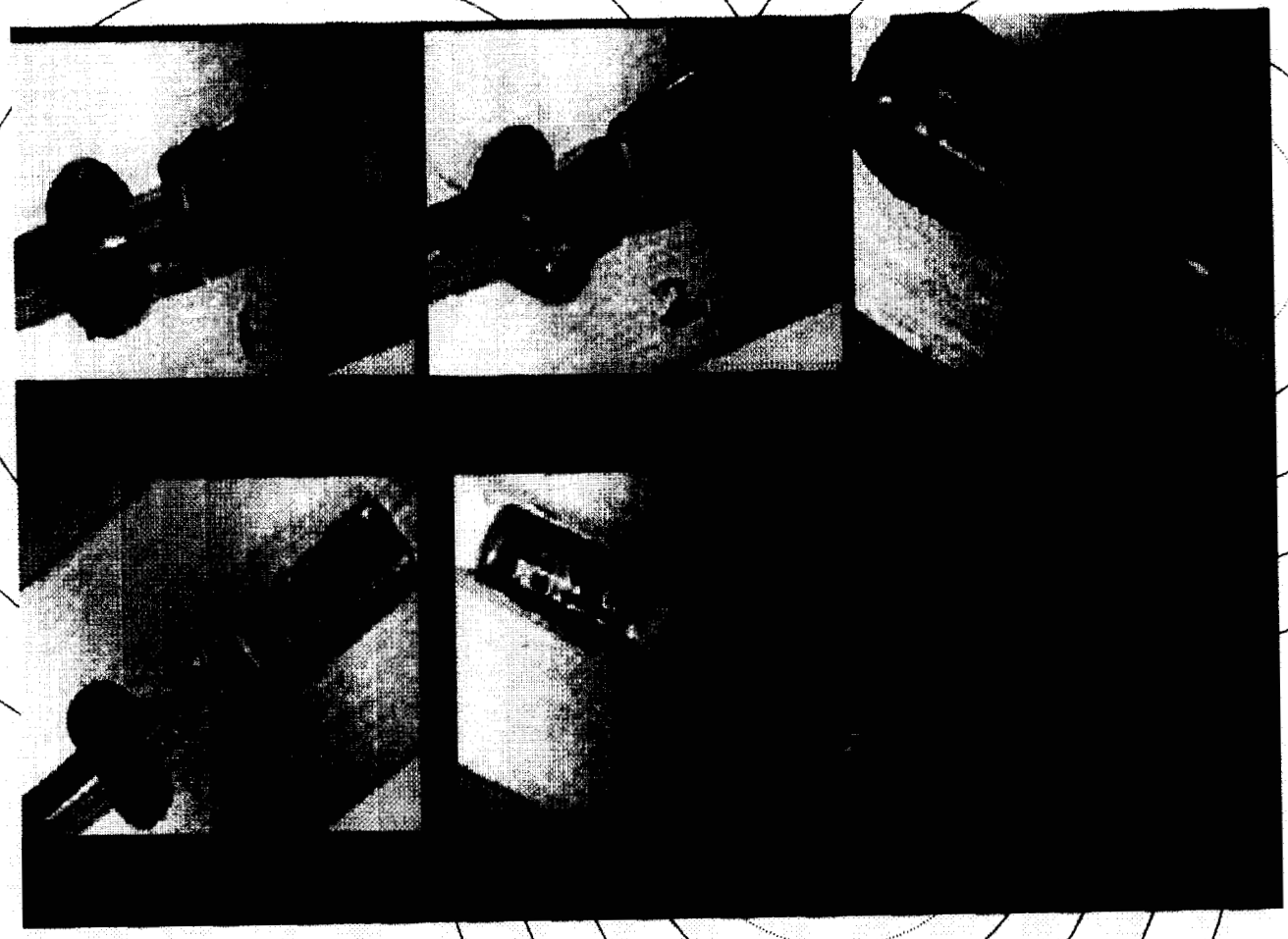
Brush-less motors (90 thermal cycles, -120 to 70C)

# Package Qualification and Verification for NASA Projects



SPG Fuse Plug (MER Terminal Board
(300 thermal cycles, -40°C to 50°C)

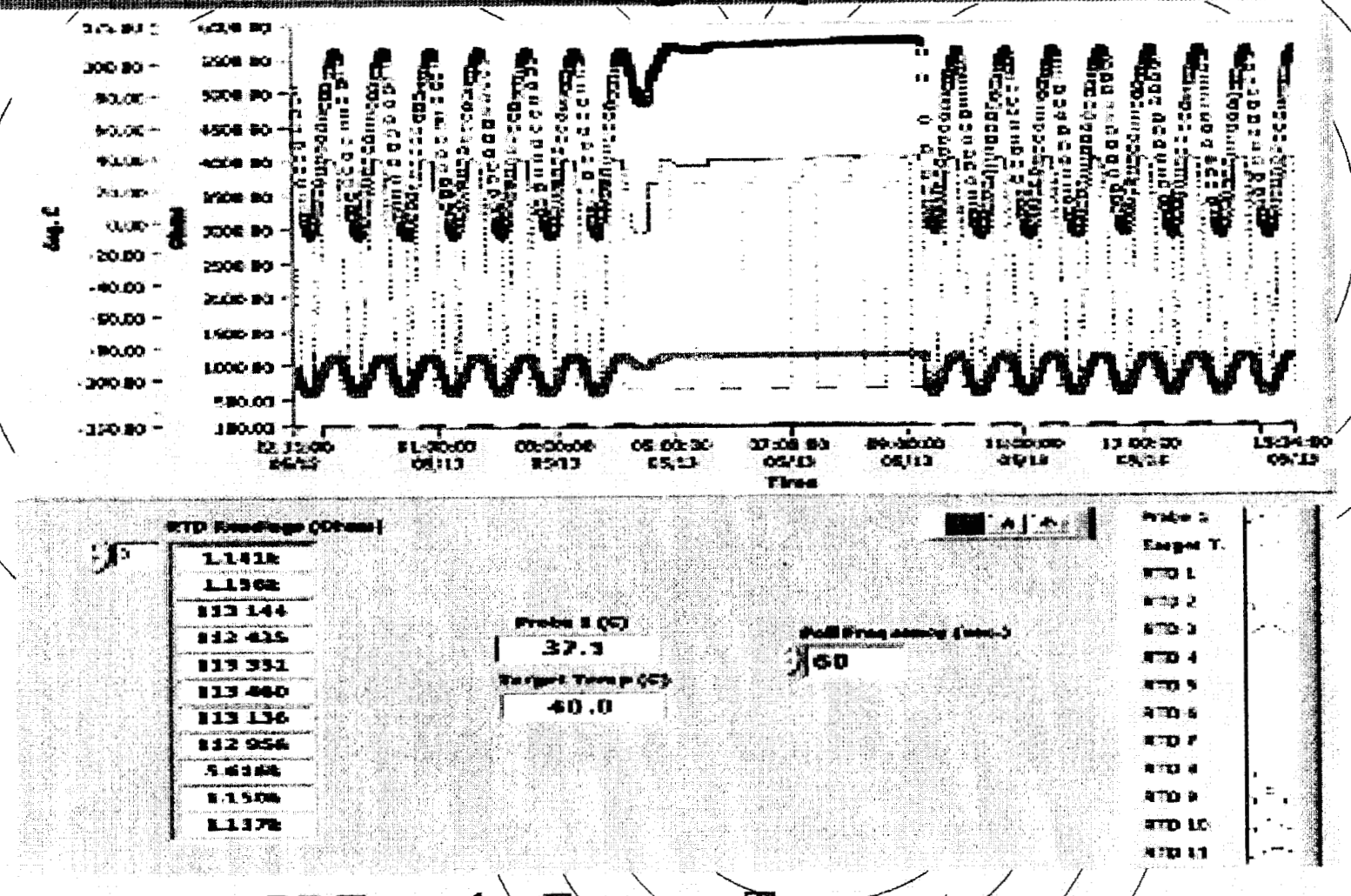
# Package Qualification and Verification for NASA Projects



PRTs tested under Extreme Temperatures

*Eric Sunada's test*

# Package Qualification and Verification for NASA Projects

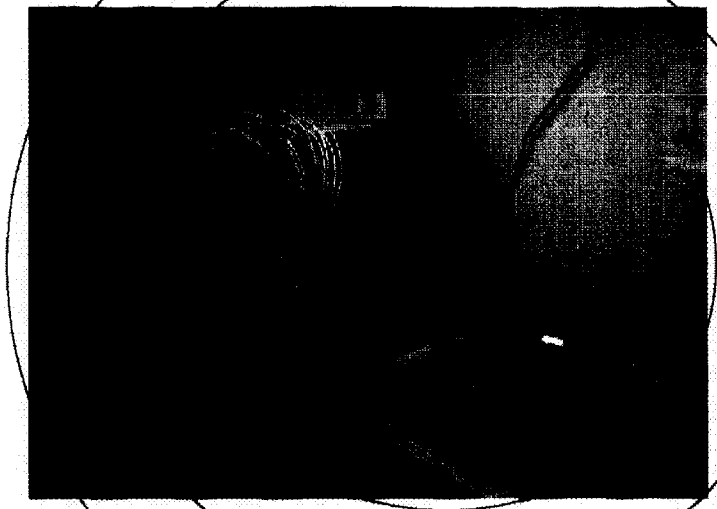


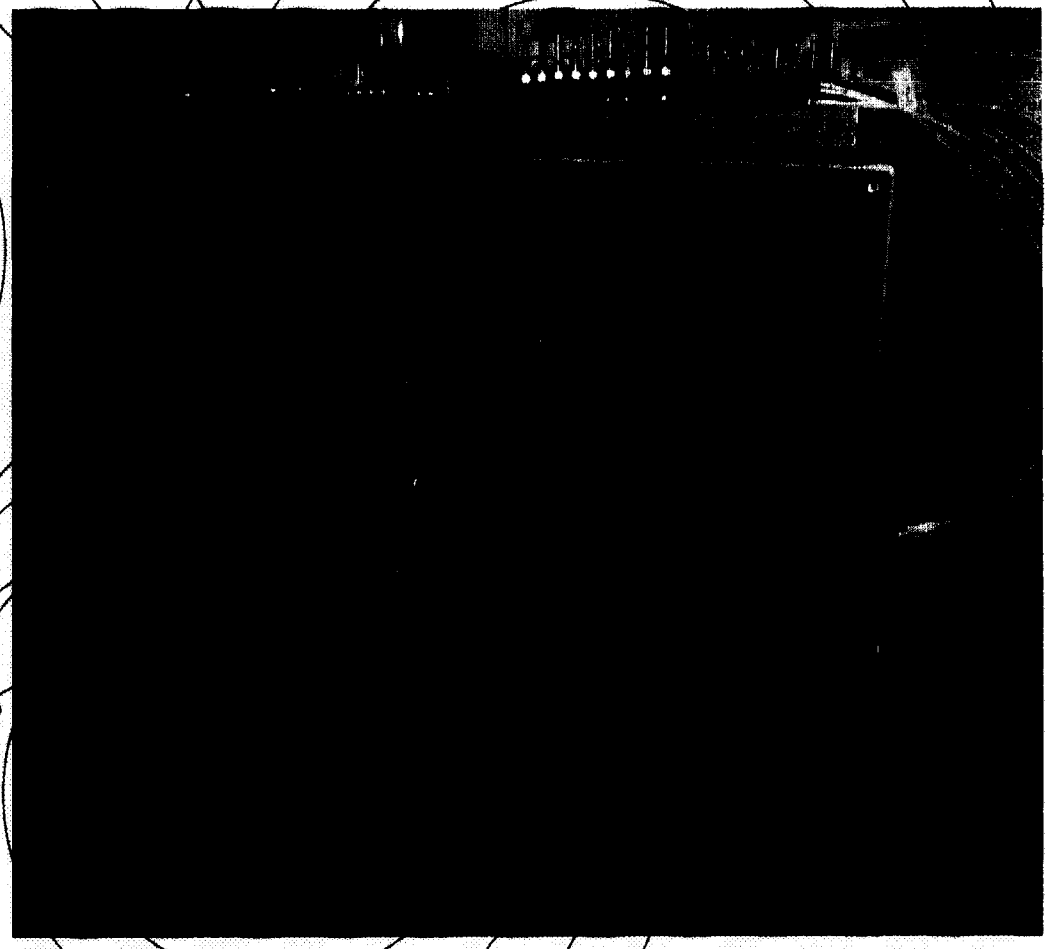

PRTs under Extreme Temperatures

# Package Qualification and Verification for NASA Projects

Grinding wheels (RAT) for MER
(-120°C to 55°C)

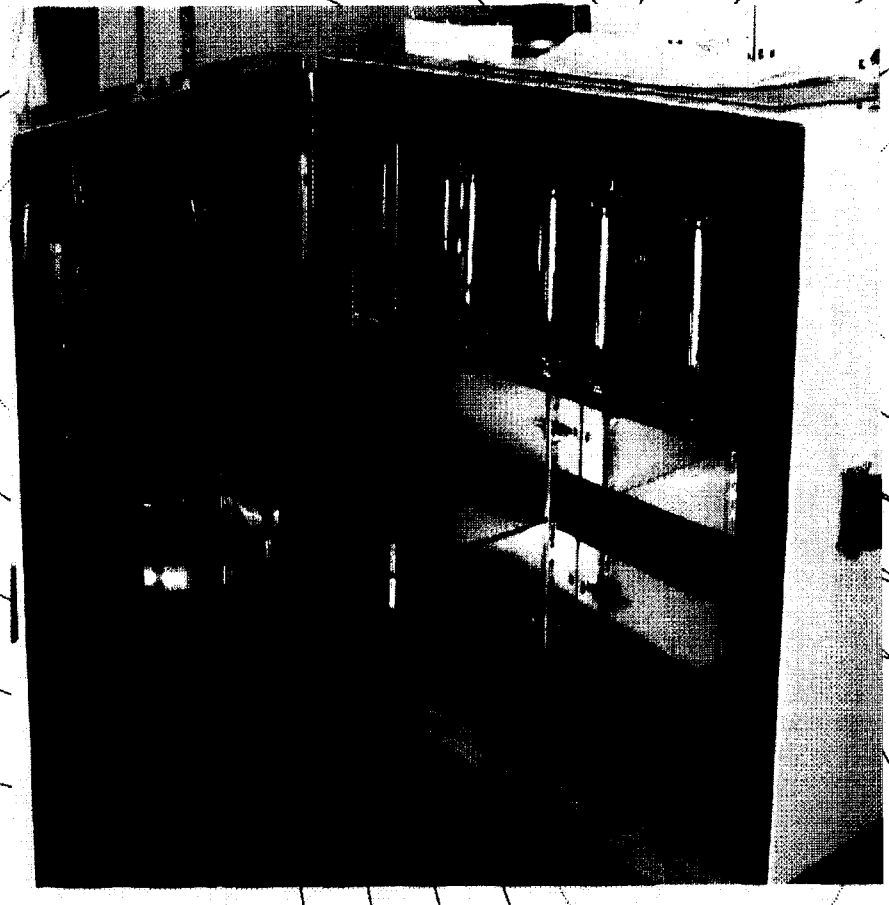
# Package Qualification and Verification for NASA Projects





LSD Potentiometers
Acceptance test (3 cycles,
-75C to 70C)

# Package Qualification and Verification for NASA Projects



Acceptance test of Air Bag Retraction Actuators (110 to –120C)

# Summary

PQV team has closely worked with MER CogEs, Project Managers, PEMs, Payload managers, Flight Systems Managers, etc. to address several issues associated with the packaging and PQV testing to address reliability and qualification.

Several Packaging Designs were tested with reference to PQV requirements of MER.

PQV tests have been conducted to enhance the assurance of the package designs and the test hardware for MER project.

Experimental long term thermal cycling performed in our laboratory using the various test articles for MER to address the critical hardware for MER project.

The experimental test data may be used as a heritage for future Mars/NASA projects.