Tin Whiskers: Reliability Risk That Adds a New Dimension to DMSMS

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Best Manufacturing Practices Center of Excellence

- Department of the Navy Manufacturing Technology Program
  - A National Center of Excellence
  - Approximately 45 People Augmented by More Than 150 Subject Matter Experts

- Heritage
  - Transition from Development-to-Production Templates (1985)
  - Industry Facility On-site Surveys (1985-Present)
  - Practical Engineering Guides for Managing Risk (1985-Present)
  - Support Military Acquisition Activities (1985-Present)
  - Program Manager's WorkStation (1993-Present)
  - Integrated Digital Environment Using Web Technologies (1996-Present)
  - Winner - Innovations in American Government Award (1998)
  - Winner - Vice President's Hammer Award (2000)

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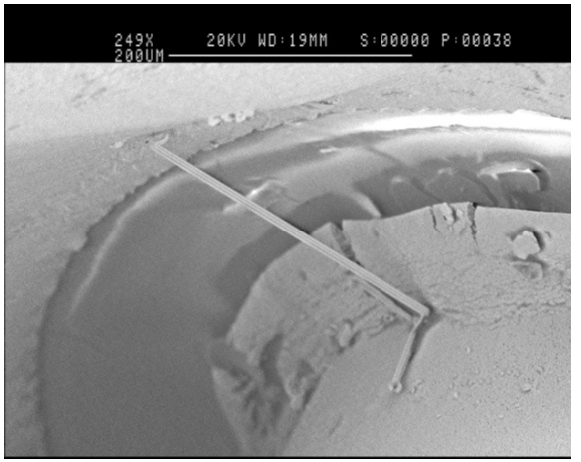
What Are Tin Whiskers?

- Single Crystal, Hair-like Growths from Surfaces that use **Lead-free Tin (Sn) as a Final Finish**
  - Electrically Conductive
  - May Grow in Days/Weeks/Years
  - Length: 1mm Typical; Some 10mm
  - Electrical, Electronic and Mechanical Parts



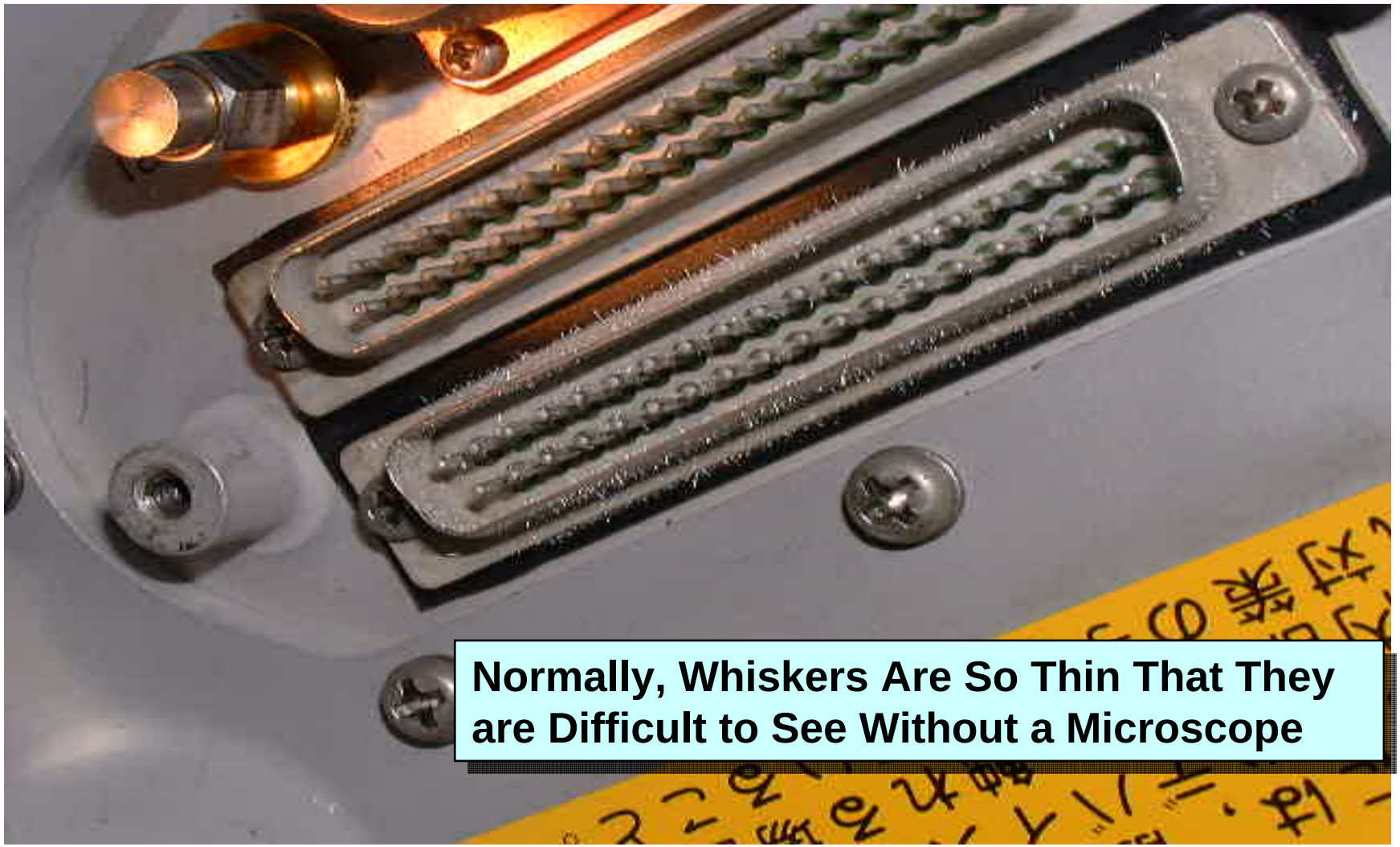
2004 short circuit failure on legacy missile accelerometer

- Growth Mechanism Still Not Fully Understood – Much Conflicting Data
- **No** Effective Tests to Predict Susceptibility
- **No** Mitigation Technique Guarantees Protection Required by DoD

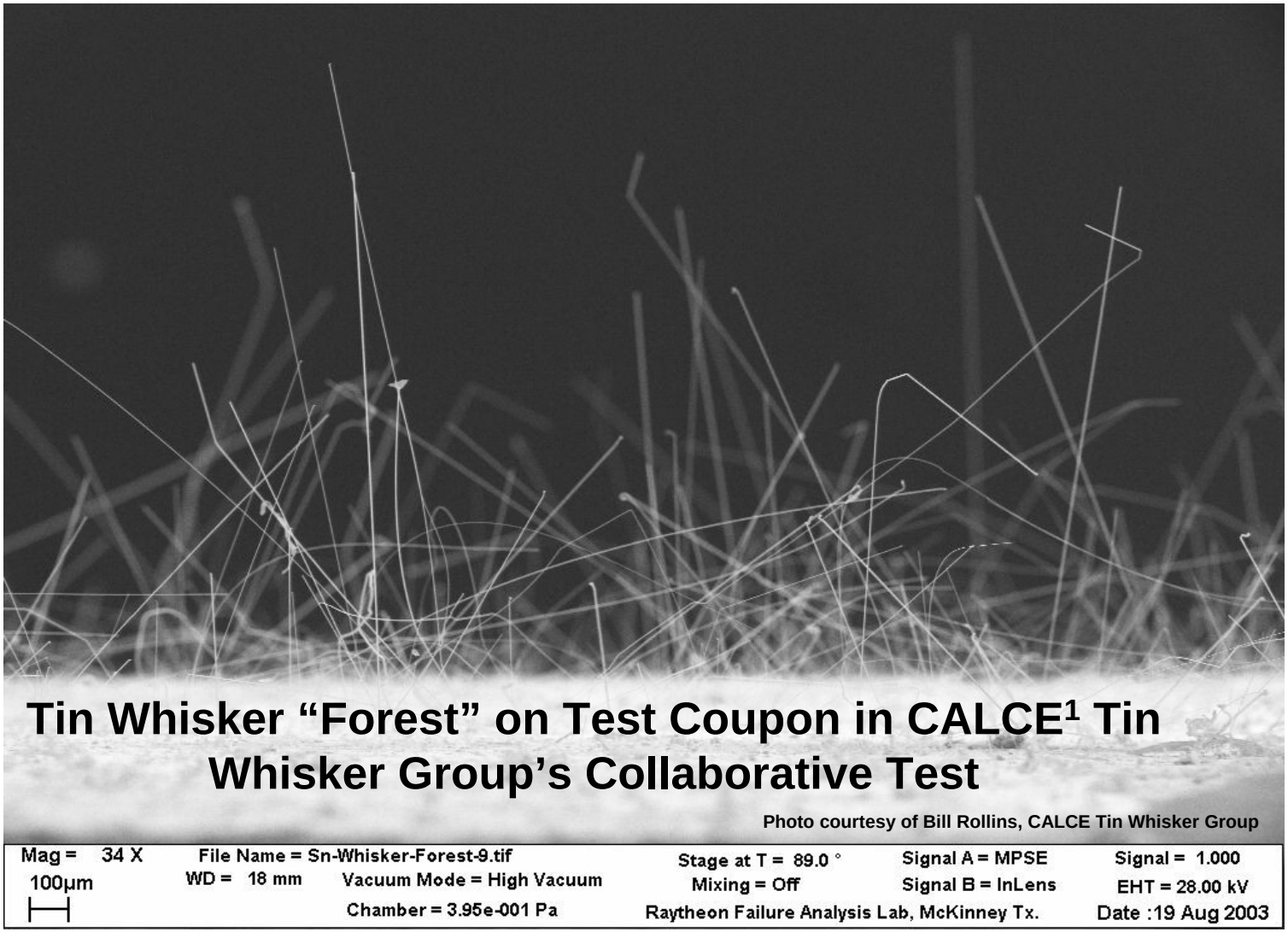
There is No One Solution for All Tin-Plate Applications

Photo Courtesy of CALCE Tin Whisker Group

Tin Whisker Example

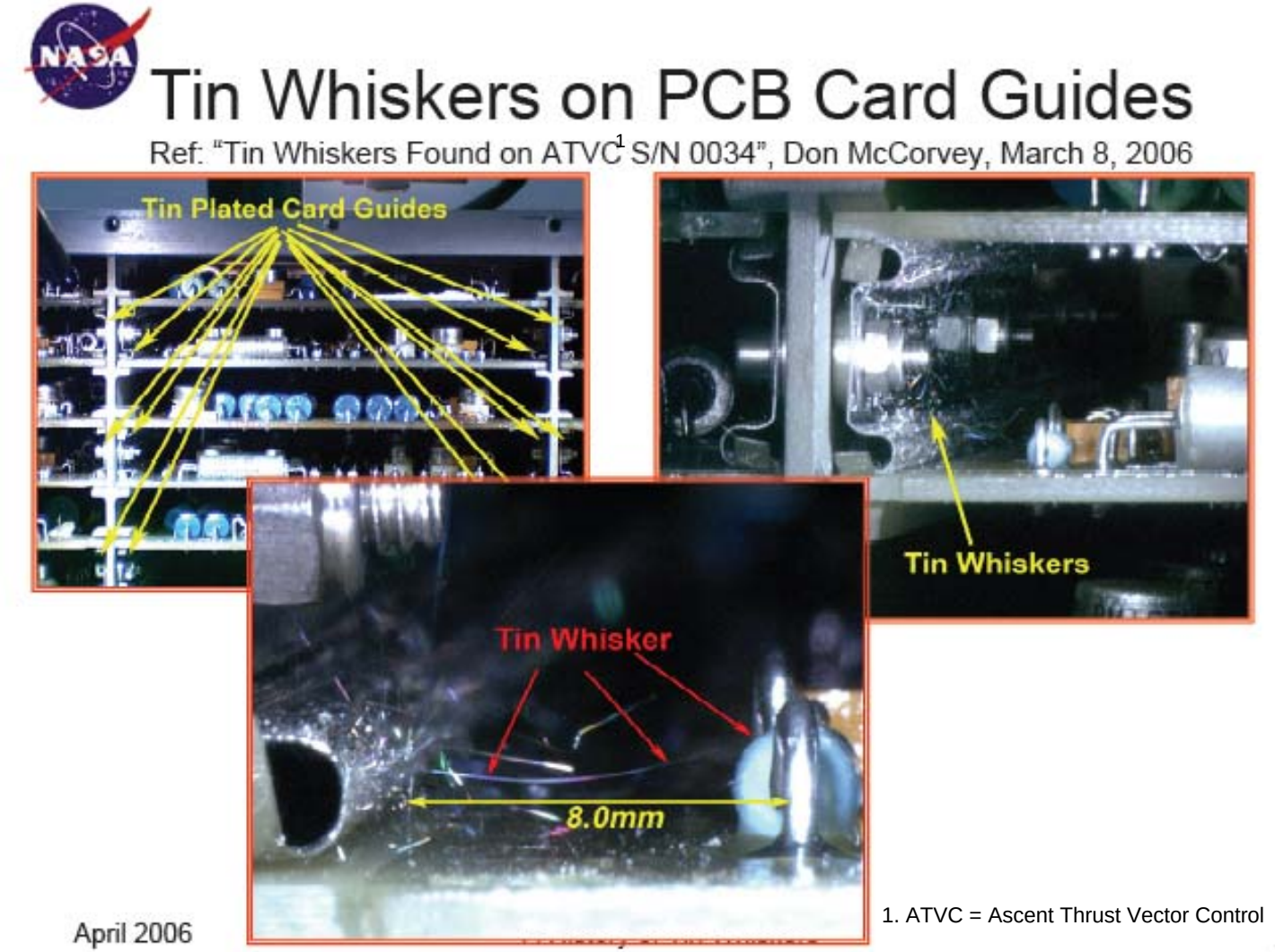


Tin Whisker Example



[1]Center for Advanced Life Cycle Engineering, University of Maryland

March 2006 - Tin Whiskers Found in Space Shuttle



1. ATVC = Ascent Thrust Vector Control

Ref: "Tin Whiskers: A History of Documented Electrical System Failures – A Briefing Prepared for the Space Shuttle Program Office," Dr. Henning Leidecker/NASA GSFC and Jay Brusse/QSS Group, Inc, April 2006

Why an Issue Now?

- Smaller Circuit Geometries
  - Whiskers Can Bridge Contacts
  - Adjacent Whiskers Can Touch
  - Broken Whiskers Can Bridge Board Traces, Foul Optics
- Lower Voltages – Whiskers Can Sustain Current

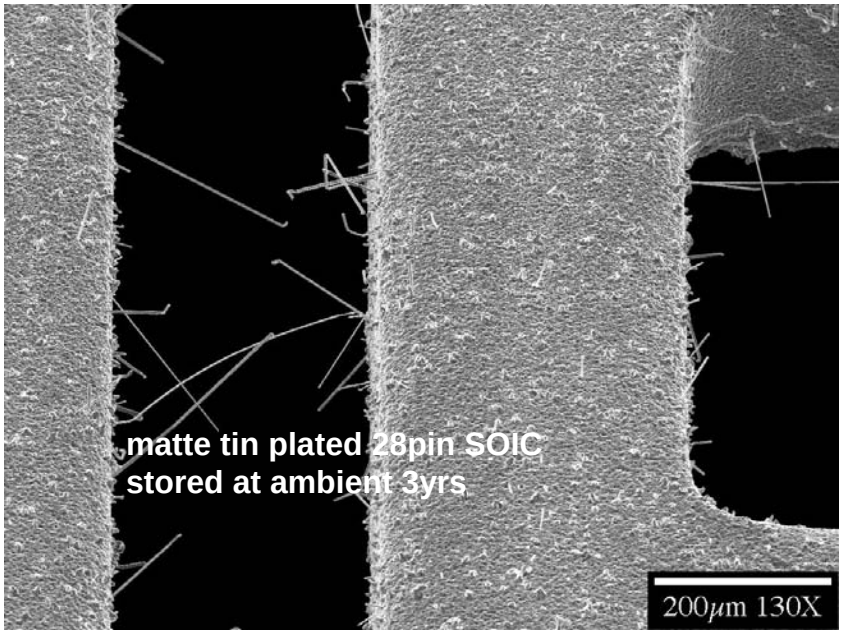


Photo Courtesy Peter Bush, SUNY

- Manufacturers Rapidly Going to 'Green' Materials
  - Compliance with European Union RoHS[1] Directive
  - Pure Tin Plate the Primary Finish of Choice
  - Some Changes Made Without Notice
  - Some Part Numbers Unchanged

[1]Restriction on Hazardous Substances

Tin Whisker Failure Mechanisms

- Stable Short Circuit in Low-Voltage Circuits
- Transient Short Circuit Until Whisker Fuses Open
- Plasma Arcing in Vacuum Potentially Most Destructive - *Vaporized Tin May Form a Plasma that Can Conduct Over 200 Amps!*
- Debris/Contamination: Whiskers May Break Loose and Cause Short Circuits or Interfere with Optical Surfaces
- High-Frequency Circuit Performance (6 Ghz Rf and Above)

Airworthiness Advisory AA-05-01, Lead-Free Solder

- Issued 2005 by the Aeronautical Systems Center (AFMC), Wright-Patterson AFB
- Purpose: "…provides information on the trend within the electronics…community toward the use of lead (Pb)-free solder. To date, no lead-free solders are known to have met the reliability requirements imposed upon military electronics…"
- Scope: "…applies to all USAF aircraft, manned and unmanned..."
- Guidance/Recommendations: **"**Until…a suitable, reliable, lead-free solder replacement is identified, all program managers should ensure their electronic equipment suppliers continue to provide items which meet all performance, compatibility, and reliability requirements.…"

Nuclear Reactor Shut Down by Single Whisker

GIDEP AAN-U-05-093 13 Sept 05: NRC NOTICE 2005-25: INADVERTENT REACTOR TRIP AND PARTIAL SAFETY INJECTION ACTUATION DUE TO TIN WHISKER

- 17 April, 2005 – Millstone Nuclear Generating Station experienced an unexpected safety injection actuation and reactor trip caused by a fault on a protection system circuit card
- Caused "…safety train actuation and reactor trip"
- A single tin whisker created a bridge (short circuit) between a diode and the output trace on a circuit card

Swatch Watch Failures

- Swatch Group Began RoHS Compliance Effort in 2003
- Implemented for Mass Production in 2005
- As of January 2006, 30% of Quartz Crystal Oscillators Had Tin Whiskers
- 5% (And Counting) Have Experienced Short Circuits
- Have Applied for RoHS Exemption

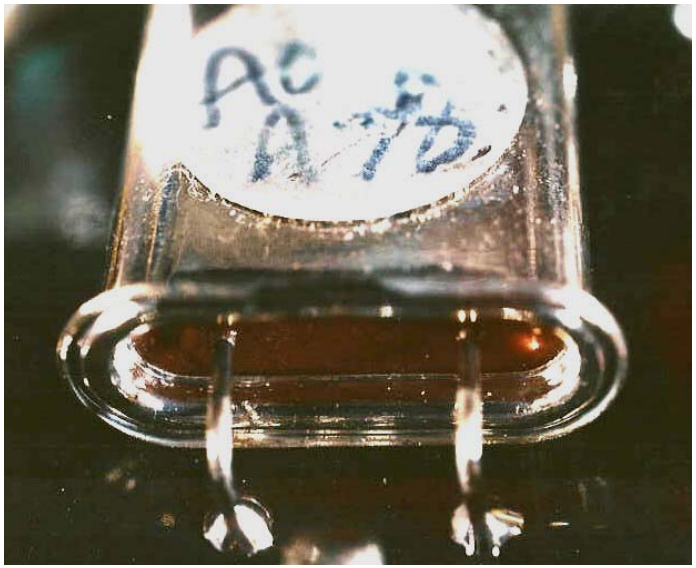
Complicating Factors

- Reliability the Issue, but No Quantifiable Means of Prediction (e.g., Cannot Predict MTTF/MTBF)
- COTS Assemblies (e.g., IMUs) - Little Control Over Design/Manufacturing Processes
- Risk Assessment Methodologies Still Being Developed
  - Whisker Mitigation Levels
  - Raytheon Risk Assessment Algorithm
  - CALCE calceWhiskerRiskCalculator
  - Tyco Risk Methodology
- Most Proposed Partial Mitigation Techniques Still Unproven/Unqualified

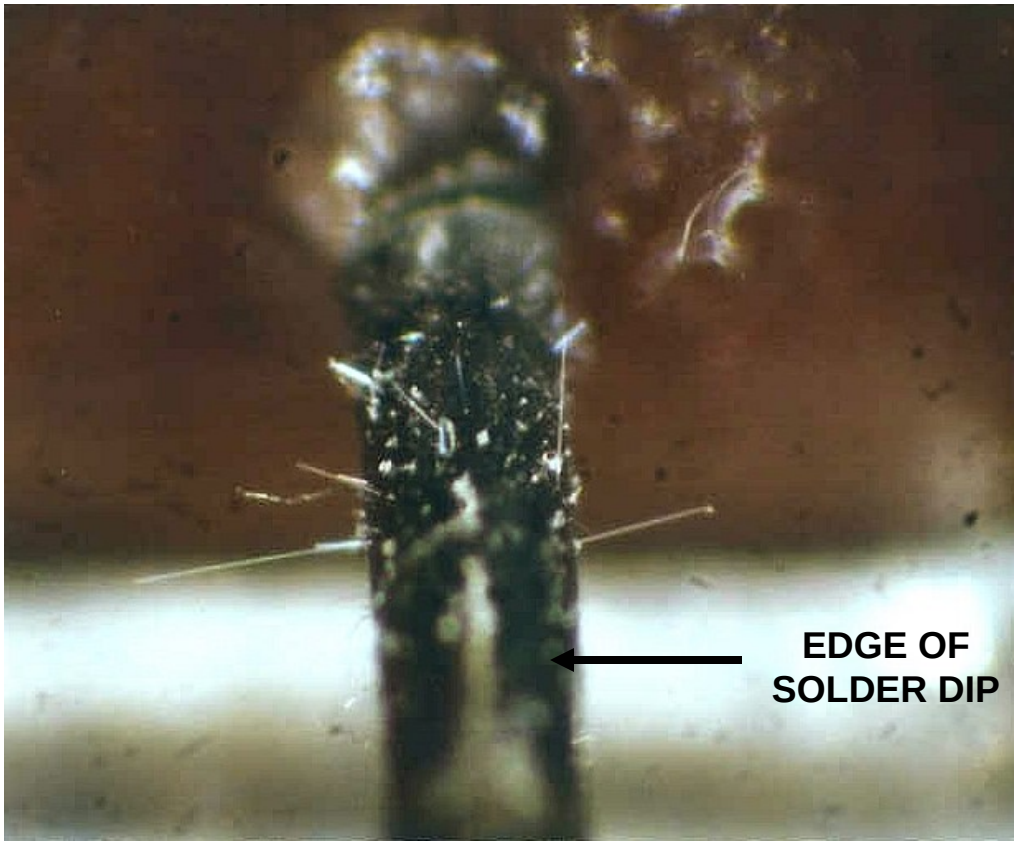
Solder Dipping Mitigation Technique

- Provides a Means of Mitigating Tin Whiskers on Many Component Types
- Replaces Tin (Sn) Finish with Tin-lead (Pb-Sn) Finish (Pb 3% Min)
- Robotic Process Preferred/Required for Fine-Pitch Parts
- Requires Careful Control of Dipping Time, Temperature, Angle, etc.
- Requires Complete Coverage to Ensure Effectiveness in HIREL Applications

Tin Whisker Crystal Solder Dip Failure



- **Through Hole Crystal**
- **Bright Tin Finish**
- **Manually Solder Dipped to within 50 mils of Glass Seal**

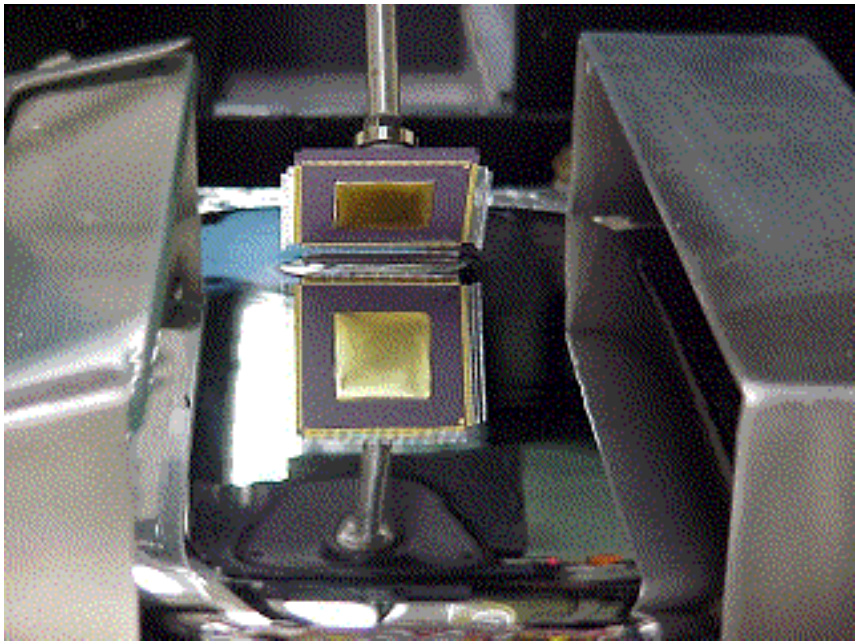


Tin Whisker Growth Noted from Seal to near Edge of Solder Coat. Electrical Failure Traced to a 60 mil Whisker that Shorted Lead to Case

NASA GSFC Tin Whisker Website
http://nepp.nasa.gov/whisker/

One Partial Solution: Robotic Solder Dip

- ONR ManTech Research Project: “The Use of Robotic Solder Dipping to Replace Electronic Part Surfaces Finishes of Pure Tin With a Tin-Lead Finish”
- Qualified a Number of Component Package Types for a Tailored Commercial Process for Robotically Refinishing Component Leads



Robotic Solder Dip Project Benefits

- Project Qualified a Tailored Commercial Process to Completely Replace Pure Tin with Tin-Lead
  - Usable for a Significant Number of Microcircuit Package Styles
  - Will Allow Use of Many Microcircuits Made Obsolete for HREL Users
  - Will Allow Many Programs to Avoid Redesigns/Production Interrupts
  - Can be Incorporated into Supply Chain Process Through Parts Suppliers/Distributors
- Some Component Package Styles Do Not Qualify
  - Existing ‘Advertised Mitigation Methods May Help but Most Offer Limited Protection
  - Conformal Coatings Offer Most Promise; New, Tougher Ones Need to be Developed

Information Sources

- NASA Goddard Space Flight Center Basic Info/FAQ

  http://nepp.nasa.gov/whisker/

- University of Maryland Center for Advanced Life-Cycle Engineering (CALCE)

  http://www.calce.umd.edu/lead-free/

- Project Report for ManTech Research Project S1057: Tin Whisker Mitigation - The Use of Robotic Solder Dipping to Replace Electronic Part Surfaces Finishes of Pure Tin With a Tin-Lead Finish

  http://www.bmpcoe.org/

- "Tin Whiskers: A New DMSMS Issue," DMSMS COE Newsletter, Vol 3, Issue 3, April 2005

  http://www.dmsms.org/

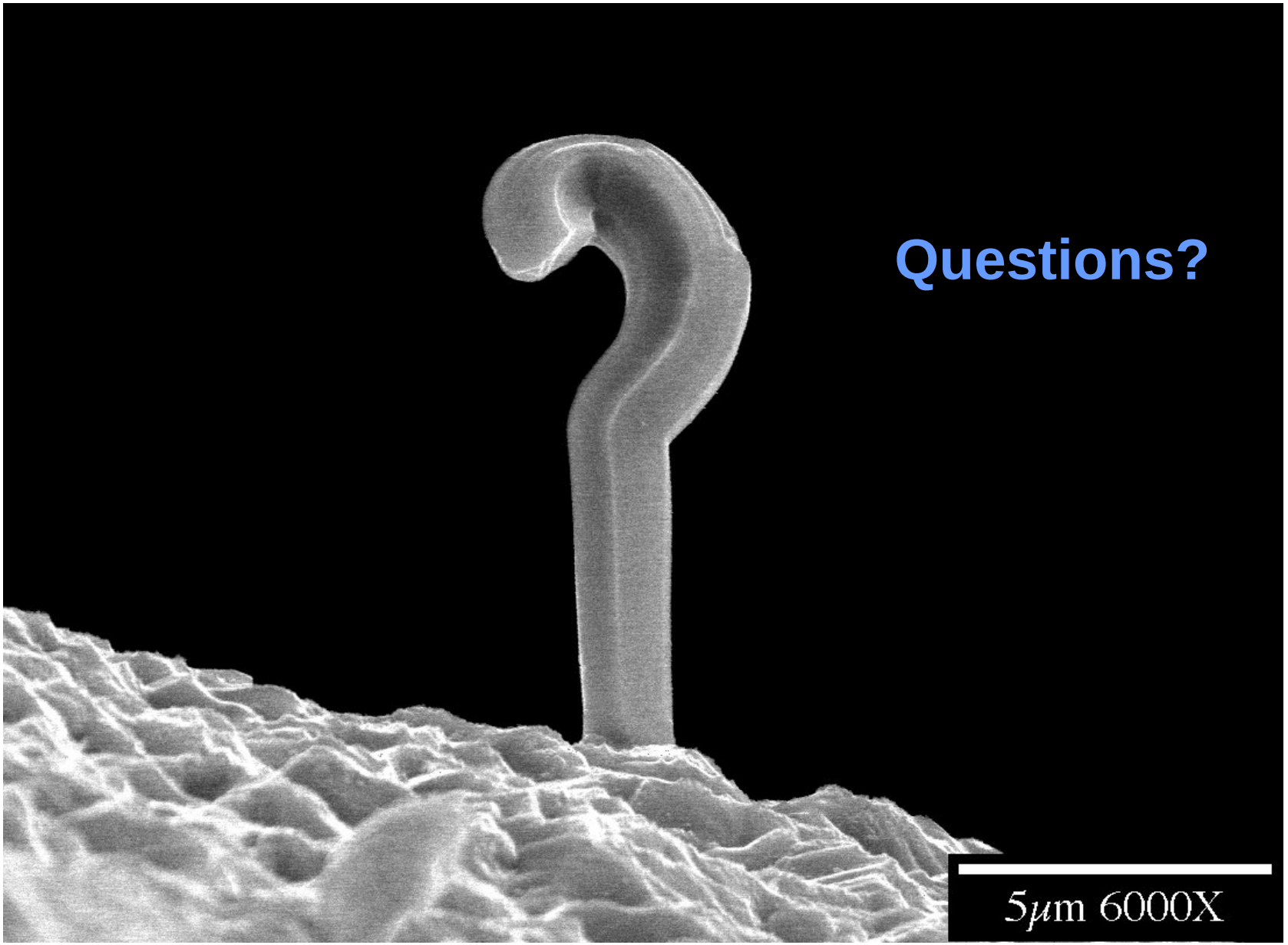


Photo courtesy of Peter Bush, SUNY at Buffalo

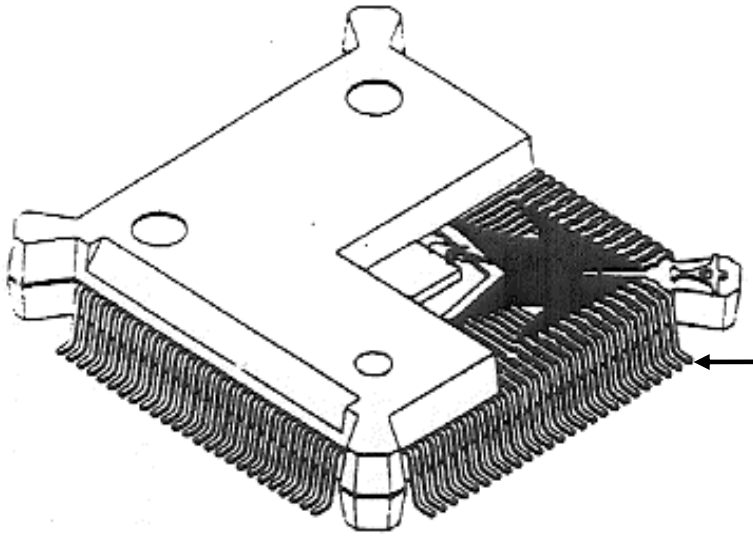
BACKUP

The Problem

- DoD Acquisition Programs are Increasingly Dependent on Commercial Electronic Parts and Assemblies - COTS
- The Commercial World is Going Lead-Free
- Lead-Free Products and Processes Pose a Host of Risks to Reliability — the Most Insidious is the Susceptibility to Growth of **Tin Whiskers**
- The Problem is Only Going to Get Worse
- High Reliability Systems Most Vulnerable
- Many Parts Will be Available but Unusable, and thus **'Obsolete'** for HIREL Systems
- Mitigation Techniques are Urgently Needed
- Robotic Solder Dip Provides One Technique for Many Electronic Package Types

The Solder Dip Technical Challenge

- Smaller Circuit Geometries
  - Partial Coverage
  - Solder Bridging
- Plastic Packages
  - Thermal Effects



Typical PQFP Lead Spacing
9 mil (229 micron)

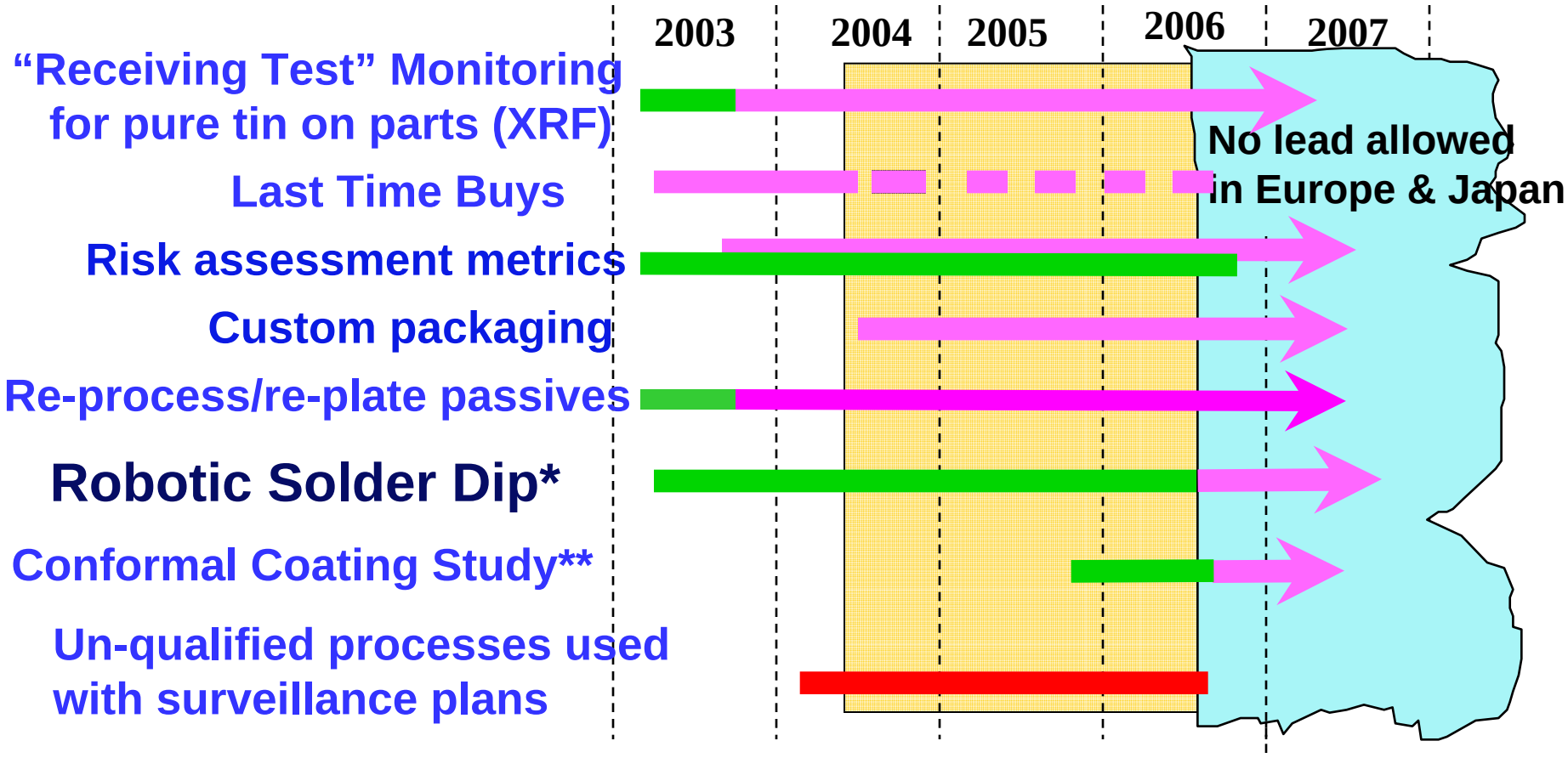
Typical Quad Flat Pack

Some Risks With Lead-free

- Tin whiskers
- Tin plague
- Major Difficulties in Parts Management
  - Mixing Tin-lead and Lead-free
  - Inability of Contractors to Know What Type Parts They are Getting
- Higher Soldering Temperatures – Potential Damage to Parts
- Mixed Technology Boards
  - Temperature and Thermal Expansion Mismatch Issues
  - Rework Issues
  - Cannot be Overemphasized

There are a Host of Issues Associated with Lead-free

Timeline For Tin Whisker Risk Mitigation Tool Development And Implementation



Missiles And Related Weapons Particularly Vulnerable

- Unique Vulnerability Factors
  - Components Not in Continuous Operation
  - Long Term Unobserved Dormant Storage
  - Diurnal Thermal Cycling
  - Transportation/Launch Vibe/Shock
  - Non Redundant Circuits/HW
- Other Factors
  - Generally No LRU
  - Generally No BIT to CCA Level
  - High Unit Cost (e.g., Trident, THAAD, SM-3, Nuclear Weapons)
  - Many Lives at Stake