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Tin Whiskers
A "New" Problem

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Lead-Free Movement Background

- **The negative effects of excessive amounts of lead (Pb) on the human body and the environment are well documented**
  - Must be ingested or inhaled
  - U.S. EPA limits
    - Air not to exceed 1.5 micrograms per cubic meter (1.5 µg/m^3) averaged over 3 months
    - Drinking water not to exceed to 15 µg per liter
    - Lowest lethal doses reported for lead compounds are around 200 milligrams/kg

- **The effects of low dosage of lead (Pb) on the human body and the environment are not well understood**

Lead-Free Movement Background

- **In 1985, the Swedish government enacted the Chemical Products Act based on the "Precautionary Principle"**
  - Precautionary Principle: "When an activity raises threats of harm to human health or the environment, precautionary measures should be taken *even if some cause-and-effect relationships are not fully established scientifically."*

- **There is no evidence linking the lead used in electronics manufacturing and products with any harm to humans or the environment**
  - Electronics industry uses less than 0.5% of the world's lead consumption

There are a host of issues associated with lead-free

Lead-Free Movement Background

- **Fears over *Perceived* harm from lead precipitated legislative action in Europe and Japan**
  - Ban on lead (and other substances) scheduled to take effect in **July 2006**

- **Commercial electronic component suppliers are responding to their main market: the commercial electronics industry**
  - Using pure tin plate surface finishes on commercial electronic components
    - Not compatible with most military and space mission requirements

There are a host of issues associated with lead-free

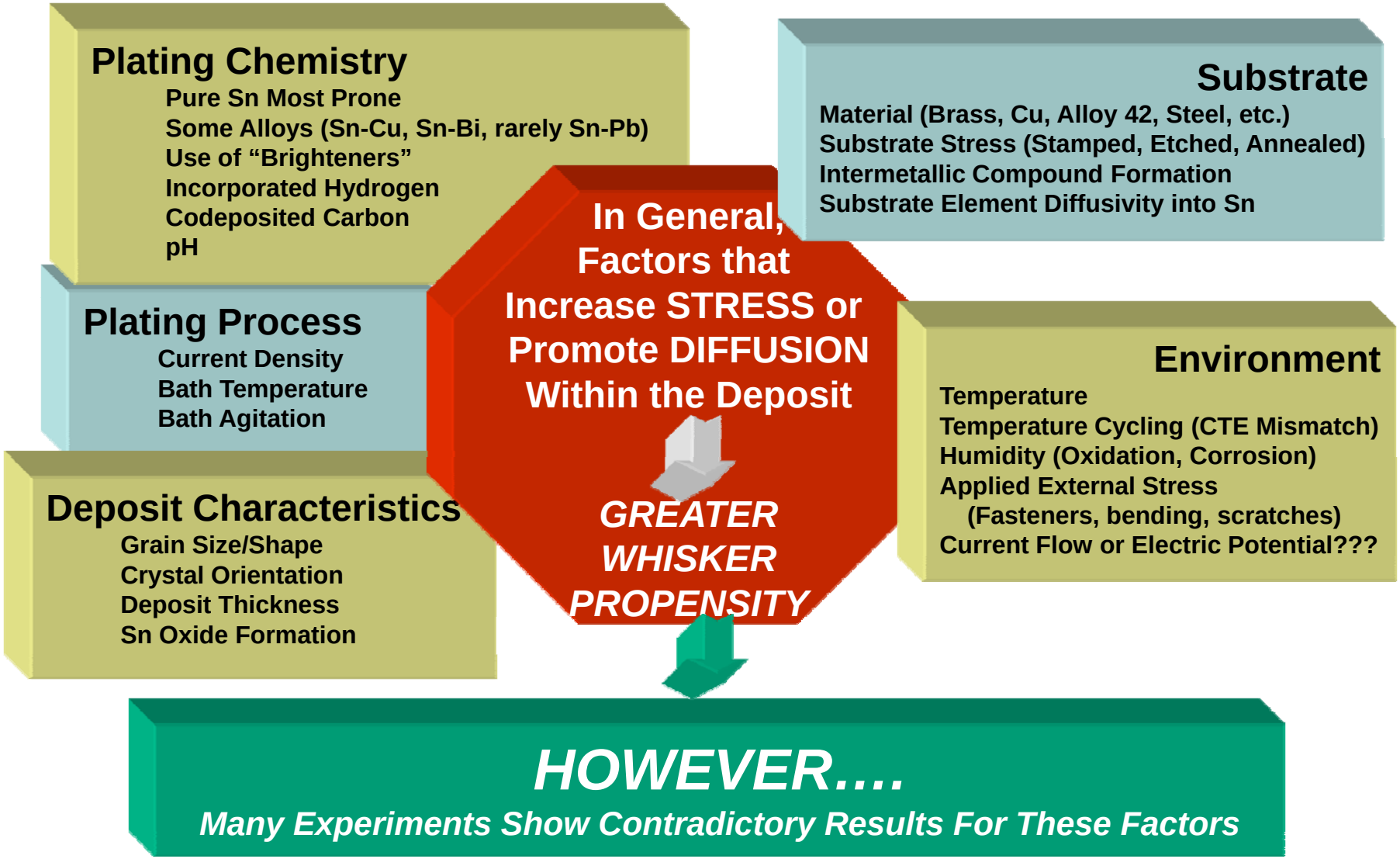
What Are Tin Whiskers?

- **Spontaneous, single crystal, hair-like growths from surfaces that use lead-free Tin (Sn) as a final finish**
  - Electrically conductive
  - May grow in days or years
  - Tin-plated electronic and mechanical parts (e.g., nuts, bolts) grow whiskers

On hybrid microcircuit lid

- Whisker growth mechanism still not fully understood after decades of study
  - Much conflicting experimental and documented evidence
- **No** effective and accepted tests to determine the susceptibility of platings to whisker
- **No** mitigation technique guarantees protection against whisker formation except the addition of 3% or more of lead to tin

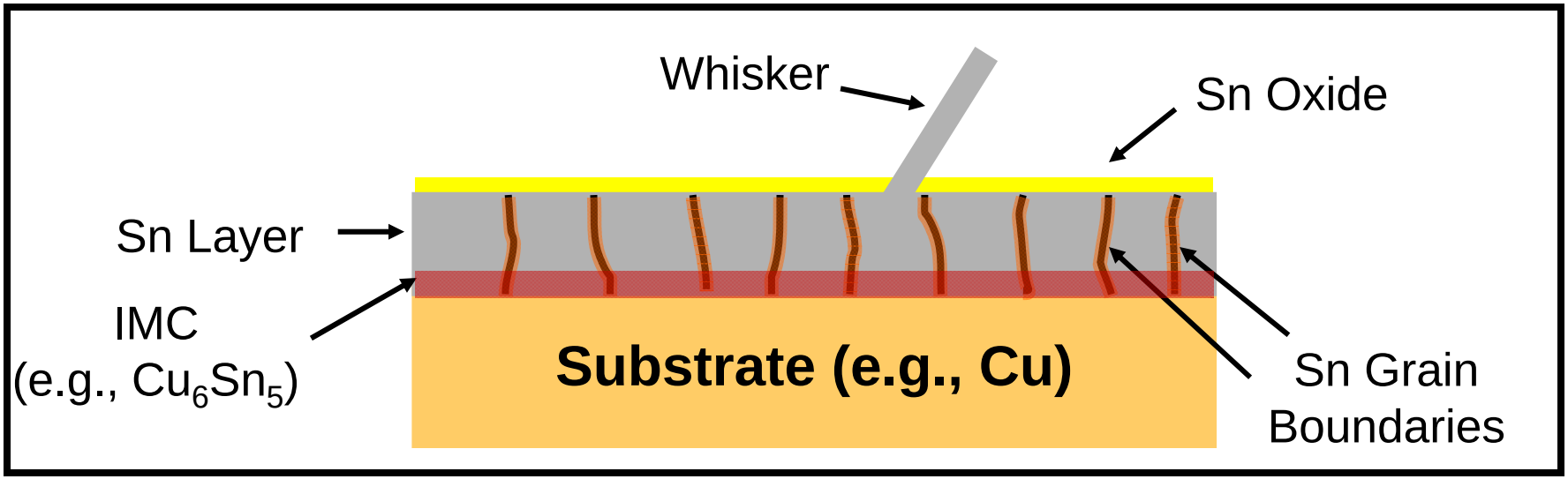
What Causes Tin Whiskers?



Courtesy of Jay Brusse, NASA GSFC

One Model for Whisker Growth Mechanism

1. Substrate elements (e.g., Cu, Zn) diffuse into Sn along grain boundaries
2. Intermetallic Compound (IMC) may form preferentially in grain boundaries
3. As a result, stress builds in Sn layer
4. To relieve stress, whiskers EXTRUDE through ruptures in Sn oxide

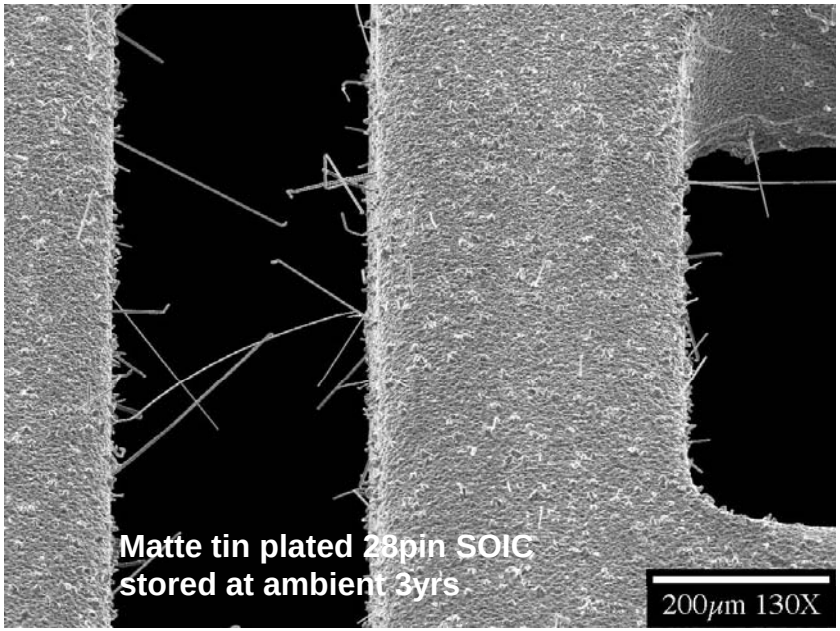


Courtesy of Jay Brusse, NASA GSFC

Dormant missiles particularly vulnerable

Why an Issue Now?

- Smaller circuit geometries
  - Whiskers can now easily bridge between contacts
  - Adjacent whiskers can touch each other
  - Broken off whiskers can bridge board traces and foul optics



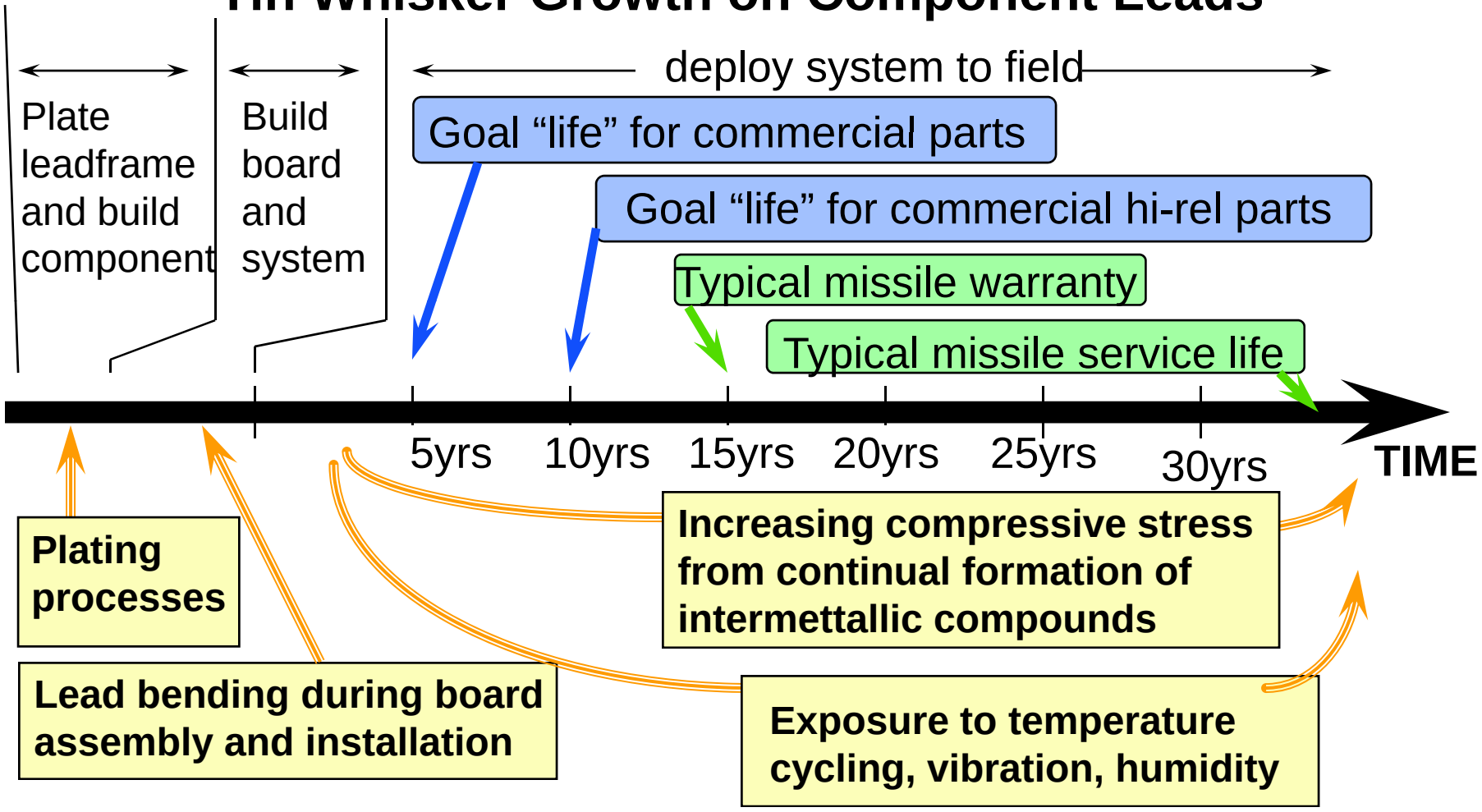
- Lower voltages
  - Whiskers can handle tens of milliamps without fusing
- Manufacturers rapidly going to “green” materials
  - Pure tin plate included
  - Some changes made without notice

Photo Courtesy Peter Bush, SUNY

Tin Whisker Failure Mechanisms

- Stable short circuit in low voltage, high impedance circuits where current insufficient to fuse whisker open
- Transient short circuit until whisker fuses open
- Plasma arcing in vacuum potentially most destructive - whisker can fuse open but *the vaporized tin may initiate a plasma that can conduct over 200 amps!* Atmospheric conditions with additional voltage/current may also experience whisker induced arcs
- Debris/Contamination: Whiskers or parts of whiskers may break loose and bridge isolated conductors or interfere with optical surfaces

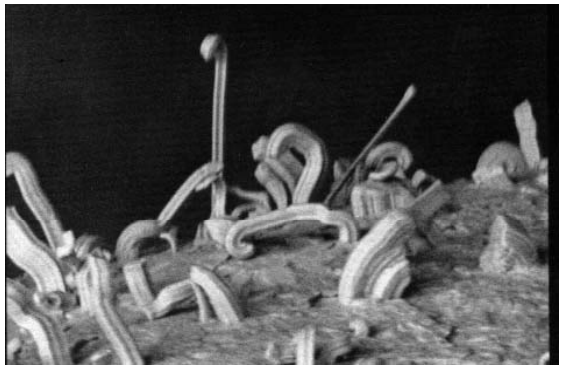
Stress Inputs vs. Time
Tin Whisker Growth on Component Leads



Courtesy Bill Rollin CALCE Tin Whisker Group

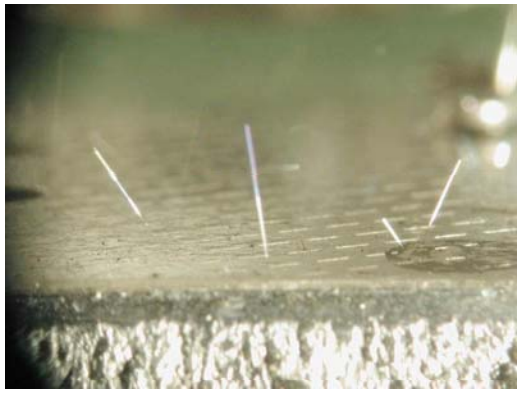
Tin Whisker Example

Tin Whisker Examples



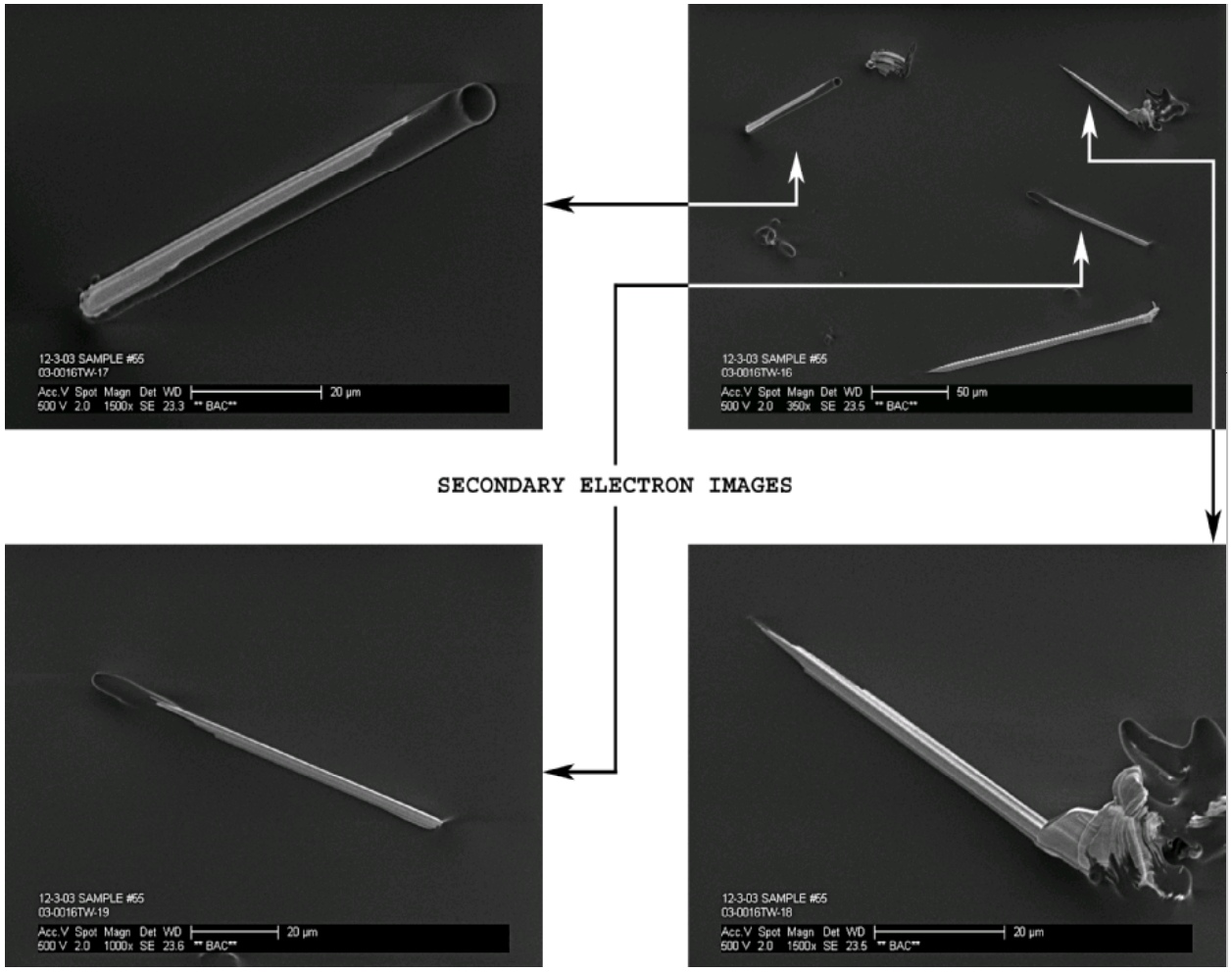
Growing on capacitor

On relay hook terminal



On relay armature

Tin Whisker Examples

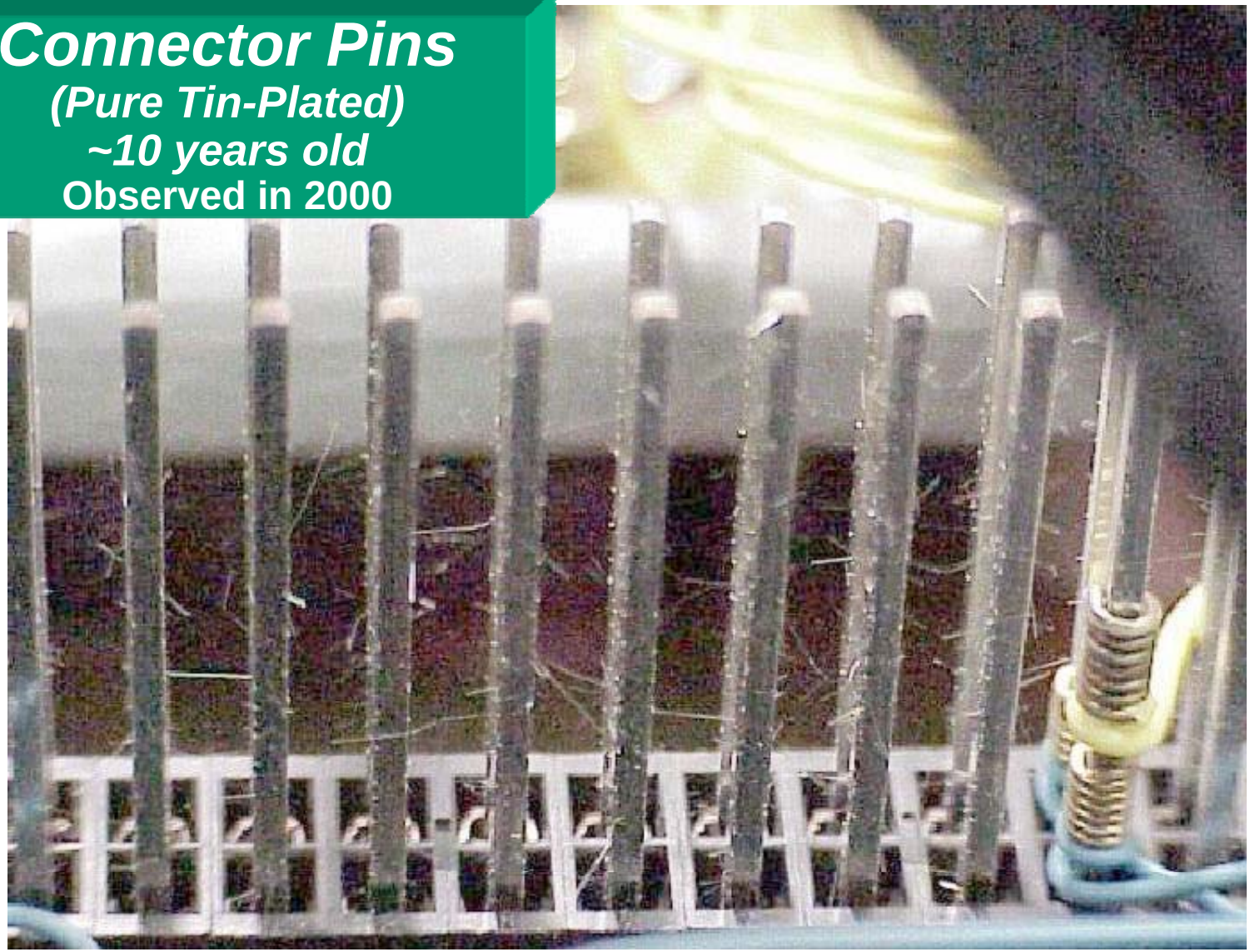


Whiskers penetrating acrylic conformal coating

Courtesy of Tom Woodrow, Boeing

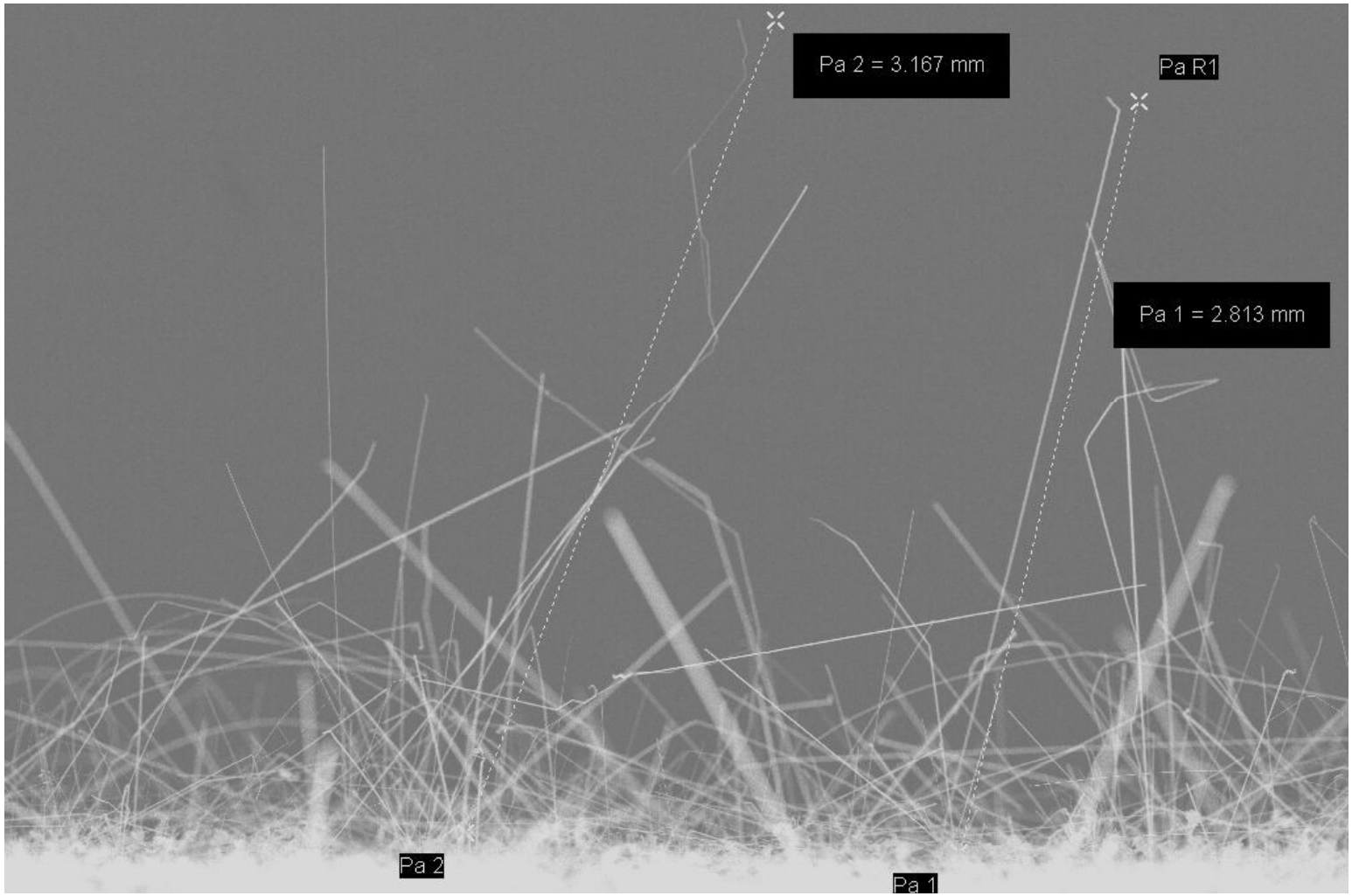
Tin Whisker Example

Connector Pins
(Pure Tin-Plated)
~10 years old
Observed in 2000



http://www.geindustrial.com/pm/support/dls/dlssb01.pdf

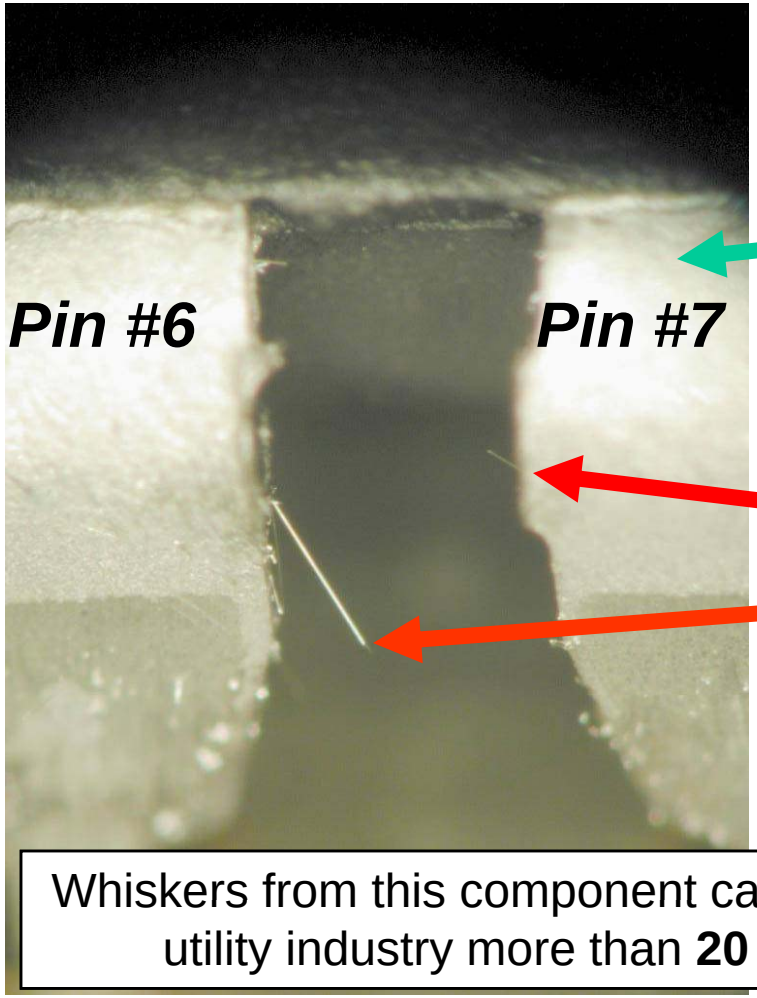
Tin Whisker Example



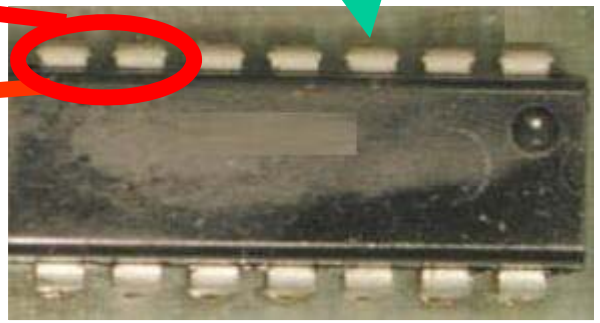
Tin Whisker “Forest” on test coupon in CALCE Tin Whisker Group’s collaborative test

Courtesy Bill Rollins CALCE Tin Whisker Group

Documented Failure: Tin Whisker Shorting



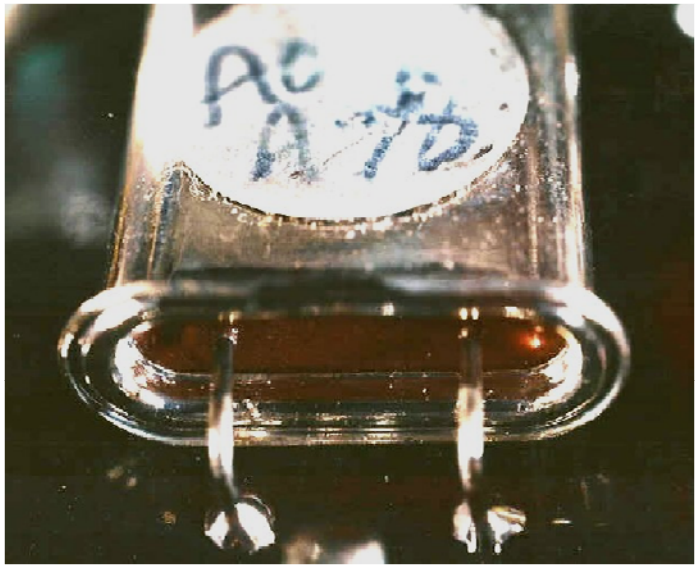
Microcircuit Leads
("Matte" Tin-Plated)



Whiskers from this component caused a FAILURE in the electric power utility industry more than **20 YEARS** after fielding the system

Courtesy of NASA GSFC

TIN WHISKER FAILURE ON OSCILLATOR

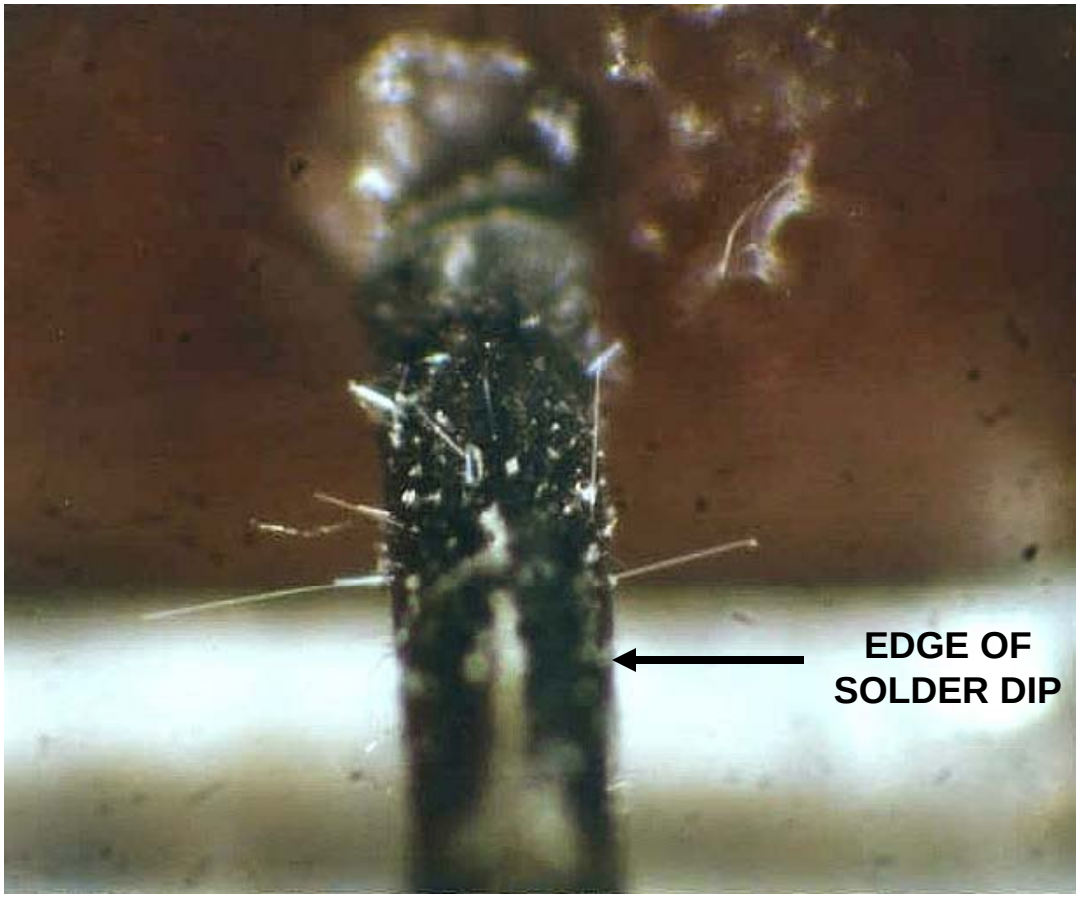


THRU HOLE OSCILLATOR.

LEAD DIAMETER 18 MILS.

BRITE TIN FINISH LEADS AND CASE.

SOLDER DIPPED WITHIN 50 MILS OF GLASS SEAL AND HAND SOLDERED TO PWB.



TIN WHISKER GROWTH NOTED FROM SEAL TO ABOUT 20 MILS FROM EDGE OF SOLDER COAT. ELECTRICAL FAILURE WAS TRACED TO A 60 MIL WHISKER THAT SHORTED LEAD TO CASE.

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

Documented Tin Whisker Failures

- Weapon systems that were built between 1985 and 1992 have had documented tin whisker failures
  - Failure rates varied from 1% to 10%
  - Manufacturers of microcircuits/semiconductors **BEGAN** shifting to pure tin in 1996-97
- 6 Satellites: partial or complete loss (Galaxy – 3, Solidaridad 1, Direct TV3, and HS 601) 1998-2002
- Airborne radar systems

	Year**	Application	Industry	Failure Cause	Whiskers on?
22	2000	Commercial Satellite #5	Space (Complete Loss)	Tin Whiskers	Relays
23	2000	Power Mgmt Modules	Industrial	Tin Whiskers	Connectors
24	2001	Commercial Satellite #6	Space	Tin Whiskers	Relays
25	2001	Space Ground Test Eqpt	Ground Support	ZINC Whiskers	Bus Rail
26	2001	Nuclear Power Plant	Power	Tin Whiskers	Relays
27	2001	Hi-Rel	Hi-Rel	Tin Whiskers	Ceramic Chip Caps
28	2002	Commercial Satellite #7	Space	Tin Whiskers	Relays
29	2002	Military Aircraft	Military	Tin Whiskers	Relays
30	2002	Electric Power Plant	Power	Tin Whiskers	Microcircuit Leads
31	2002	Hospital Computer Center	Medical	ZINC Whiskers	Floor Tiles
32	2002	Govt Computer Center	Commercial	ZINC Whiskers	Floor Tiles
33	2002	E-Comm. Comp Center	Commercial	ZINC Whiskers	Floor Tiles
34	2002	Library Computer Center	Public Service	ZINC Whiskers	Floor Tiles
35	2002	GPS Receiver	Aeronautical	Tin Whiskers	RF Enclosure
36	2002	MIL Aerospace	MIL Aerospace	Tin Whiskers	Mounting Hardware (nuts)
37	2002	Commercial Electronics	Power Supply	ZINC Whiskers	Mounting Hardware
38	2003	Commercial Electronics	Telecom	Tin Whiskers	RF Enclosure
39	2003	Telecom Equipment	Telecom	Tin Whiskers	Ckt Breaker
40	2003	NASA Data Center	Ground Support	ZINC Whiskers	Floor Tiles
41	2003	Missile Program "E"	Military	Tin Whiskers	Connectors
42	2003	Missile Program "F"	Military	Tin Whiskers	Relays

Courtesy of Jay Brusse, NASA GSFC

Projected Impact

- **Double-digit percentage failure rates are probable if action is not taken**
  - Based on documented tin whisker failures on China Lake Weapons Department systems that used limited amounts of tin plating
    - Failures may occur within weeks or years
    - Items in dormant storage particularly vulnerable

There are situations where failure is not an option

The Need for Speed

- **The pure tin problem is with us now!**
  - Many programs struggling with tin problems today
  - Pure tin being used despite prohibitions
  - Most decisions are to “use-as-is”
    - Tin plated items incorporated into systems
    - Items essential for system functionality
- **Suppliers shifting to tin plating at an increasingly rapid rate**
  - By Summer 2004 it will be difficult to find anything else from some suppliers

Status of Tin Control and Mitigation Activities

- **Commercial electronic component suppliers are responding to their main market : the commercial electronics industry**
  - Using pure tin plate surface finishes on commercial electronic components
    - Not compatible with most military and space mission requirements

Component Suppliers Offering Both Pure Tin and Tin-Lead Surface Finishes

Courtesy Bill Rollins CALCE Tin Whisker Group

February 2004

Dec. 2002: 6 companies	Atmel	Agilent Tech	International Resistor
	IDT **	Catalyst Semi	Lelon Electronics
May 2003: 17 companies	Altera	Central Semi	NEC **
	Motorola	Cirrus Logic	Panasonic
	National Semi	Fairchild **	Rohm
	Kemet **	General Semi	Temic
	Alegro	Hitachi**	Tyco
Sept. 2003: 29 companies	Logic Devices	Maxim	Vishay Semi **
	Micron Tech	Microchip Tech	VLSI Tech
	Vishay/Dale **	Mini-Circuits	
	STMicro	Nichilon**	
Feb. 2004: 46 companies	Cypress **	Simtek	
	Micrel **	AMI	
	Phillips	Analog Devices	
	AMD**	Clare	
	ON Semi **	EPCOS AG	
	AVX**	Infineon	
	Linear Tech	International Rectifier	

** Companies planning to drop some of their tin-lead product lines

Developer View of Tin Issue

- **Contracts often specify - No Sn, No Zn**
  - Zn is an issue for mechanical hardware
  - Rare Exceptions were handled on a case-by-case basis by “specialists”
- **The case-by-case approach is rapidly becoming unworkable**
  - Exceptions that occurred 1-2 times/year are now encountered 3-4 times/week
  - Real flooding of assessments anticipated soon
  - Absolute bans not compatible with reasonable cost and schedule needs for most systems

Courtesy of Dave Pinsky, Raytheon, member CALCE Tin Whisker Group

How Developer Decisions are Made Today

- Tradeoffs are currently made based upon many reasons, some good, some not so good, and most non-standardized
  - Organizations that have suffered from previous bad experiences with tin whiskering tend to take a more conservative approach
  - Organizations experiencing serious cost and schedule pressures tend to take a more liberal approach
- The result is that the matching of mitigation strategies to actual operational requirements is less than optimal
  - Unnecessary costs are incurred by excessive mitigation
  - Unnecessary risks are incurred by insufficient mitigation

Those who have experienced failures are the most concerned and active

Courtesy of Dave Pinsky, Raytheon, member CALCE Tin Whisker Group

Informal Survey of Tin Control/Mitigation Activities

- **Major Aerospace Companies**
  - Generally are very active in tin prevention and mitigation
  - Coordinated by senior management
  - Prohibit use whenever possible
  - Take action to mitigate when pure tin must be used
  - Participate in industry forums and seminars

Those who have experienced failures are the most concerned and active

Informal Survey of Tin Control/Mitigation Activities

- **Major Commercial Systems Manufacturers**
  - Recognize there are risks but allow pure tin with some restrictions (e.g.,reflow or anneal, matte tin)
  - No mitigation on assembled boards
  - Request exemptions whenever possible

Concern but little management action

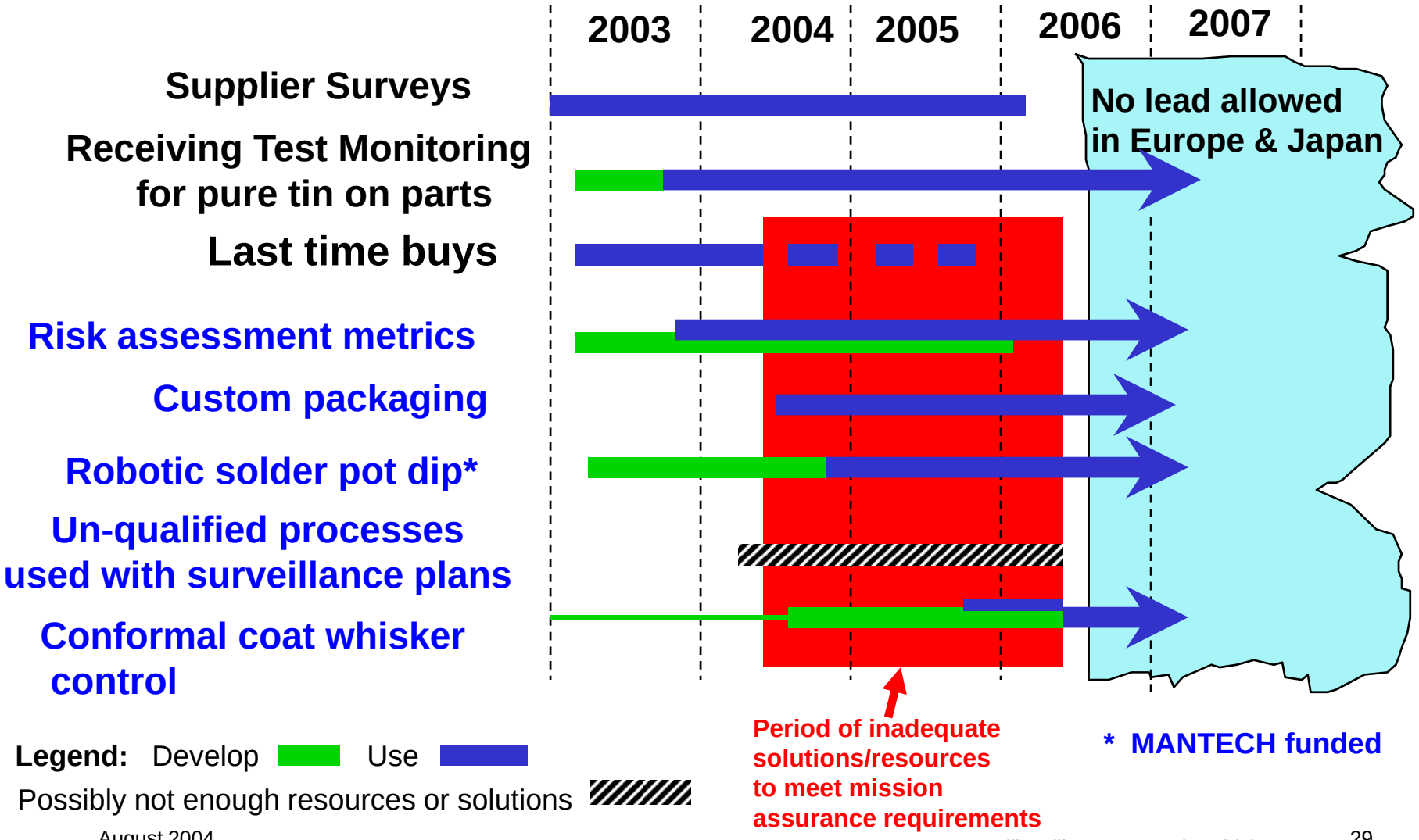
Standards Position on Tin Plating

- **EIA GEB2 "Reducing the Risk of Tin Whisker-Induced Failures in Electronic Equipment"**
  - Still in development
  - It is not a mandate
  - It does not contain any requirements

- **Most standards support EEU requirements on lead restriction**
  - Not concerned with the negative impacts of lead elimination

Timeline for Tin Whisker Risk Mitigation

TIN AVOIDANCE & TIN ADAPTATION



August 2004

Mitigation Techniques

1. Matte tin (tin with a dull low gloss finish and larger grain size) is more resistant to whiskering than bright tin. It can still grow whiskers.
2. Annealing tin can reduce the stresses in plating that contribute to whisker growth. The benefits are limited and only short term.
3. Robotic solder dipping with tin-lead solder is a solution for some but not all components. Components must be handled carefully to avoid damaging them during the process.
4. Conformal coatings can be applied but their success is very dependent on the coating material, thickness, and application process. This complex topic requires further investigation.
5. Stripping the finishes and replating with lead-tin solder is possible but requires extra handling and exposure of finished parts to corrosive materials. This sets the stage for corrosion related issues.

None of these are proven to provide the required degree of protection for high reliability equipment.

Suggested Short Term Actions

- Provide formal education on tin whiskers and related lead-free issues
- Audit manufacturing operations to define levels of exposure
- Audit of existing hardware to understand level of exposure and degree of risk
- Establish incoming inspection procedures using X-ray fluorescence (XRF) or Energy Dispersive X-ray (EDX) to positively verify composition of incoming materials
- Issue policy guidelines regarding tin use and mitigation techniques
- Develop conformal coating whisker mitigation techniques

Suggested Longer Term Actions

- **Establish a Lead-free Team to:**
  - Measure exposure
  - Coordinate avoidance and mitigation efforts
  - Develop and implement appropriate language for contracts and other documents
  - Provide on-going education
  - Participate in the Tin Whisker Group
  - Provide senior management with progress reports and risk assessments
- **Develop and implement an ongoing audit program to monitor and report the status of supplier tin mitigation efforts**

Suggested Longer Term Actions

- **Be hesitant in adopting lead-free technologies and processes**
- **Provide support to develop effective manufacturing processes for tin whisker mitigation and other lead-free issues**
  - Conformal coating should be a first priority
- **Encourage federal legislation to protect critical manufacturing technologies**
- **Build surveillance units to monitor critical hardware containing tin plating where normal inspection and/or testing tin whiskers are impossible**

Recommended Guidelines

- **AVOID PURE TIN PLATED MATERIALS**
  - Alloys of tin and lead are acceptable only where the alloy contains a minimum of 3% lead by weight
- **PERFORM POST PROCUREMENT VERIFICATION THAT PURE TIN PLATING HAS NOT BEEN SUPPLIED**
  - Contractual prohibitions and/or a supplier's certification are insufficient control mechanisms
  - Independent verification of all products is necessary

Recommended Guidelines

- **WHEN PURE TIN PLATED MATERIALS ARE THE ONLY OPTION**
  - Application specific factors may be used to assess the risk of whisker-induced failures and aid in making "use as-is" or "repair/replace" decisions
    - Some factors include: circuit geometries, voltages, base metal, conformal coating, environmental life cycle, mission criticality, mission duration, collateral risk of rework, schedule, and cost
  - Mitigation techniques can reduce the level of risk
    - **No single mitigation technique is applicable or effective for all situations**
    - **Further development is needed !**

There is no one solution for all tin plate applications

Information Sources

- **NASA Goddard Space Flight Center basic Info/FAQ**

  http://nepp.nasa.gov/whisker/background/index.htm

- **UMD CALCE**

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

Brief History of Lead-Free Movement

Industry Lead Consumption

Product	Consumption (%)
Storage Batteries	80.81
Paints, Ceramics, Pigments, Chemicals	4.78
Ammunition	4.69
Sheet Lead	1.79
Cable Covering	1.40
Casting Metals	1.13
Brass / Bronze Billets and Ingots	0.72
Pipes, Traps, Extruded Products	0.72
Solder (Excluding Electronic Solder)	0.70
Electronic Solder	0.49
Miscellaneous	2.77

Source: Advancing Microelectronics, September/October 1999. p. 29

End of Presentation