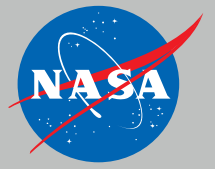

Developing a NASA Lead-free Policy for Electronics

Lessons Learned

Presentation to TRISMAC 2008

ESA/ESTEC Noordwijk, The Netherlands
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Overview

- The Current Situation
- The Concerns
- GEIA Documents
- Making a Policy
- Issues Encountered
- Pure Tin Mitigations
- Conclusions

Our Current Situation

- A Comprehensive NASA "Agency Level" Policy for Pb-Free Electronics Does Not Exist Today
- Some Aspects of a Pb-Free Policy are Implied by NASA Workmanship Standards and NASA Field Center Parts Selection Standards
  - Preferred solders such as Sn60 and Sn63
  - Avoidance of pure tin surface finishes
- However, Without a Solid Over - Arching Policy, Errors and Chaos Can be Expected

Examples of Existing NASA Requirements

- **NASA Workmanship Standard 8739.3, Soldered Electrical Connections**
  - *Solder used for tinning and solder connections shall conform to ANSI/J-STD-006 … solder shall be either SN60 or SN63*
  - *Use of high temperature solder alloy is permitted (e.g., SN96AG04A)*
  - *The type of … high temperature solder shall be specified on the engineering documentation*
  - *The use of any other solder compositions and forms shall require the approval of the procuring NASA Center*
  - [STANDARD NOW MANDATORY BUT USE IS NOT ESTABLISHED]
- **NASA GSFC EEE-INST-002 EEE Parts Selection Std**
  - *Materials … due to the risk of whisker growth that can lead to short circuit conditions, pure Tin, Cadmium and Zinc shall not be used as a final finish on EEE parts.*
  - [This is a NASA Standard BUT not used Agency-wide (mainly by GSFC)]
    - Most NASA Centers have parts documents with similar requirements

Tin Whiskers Are Real

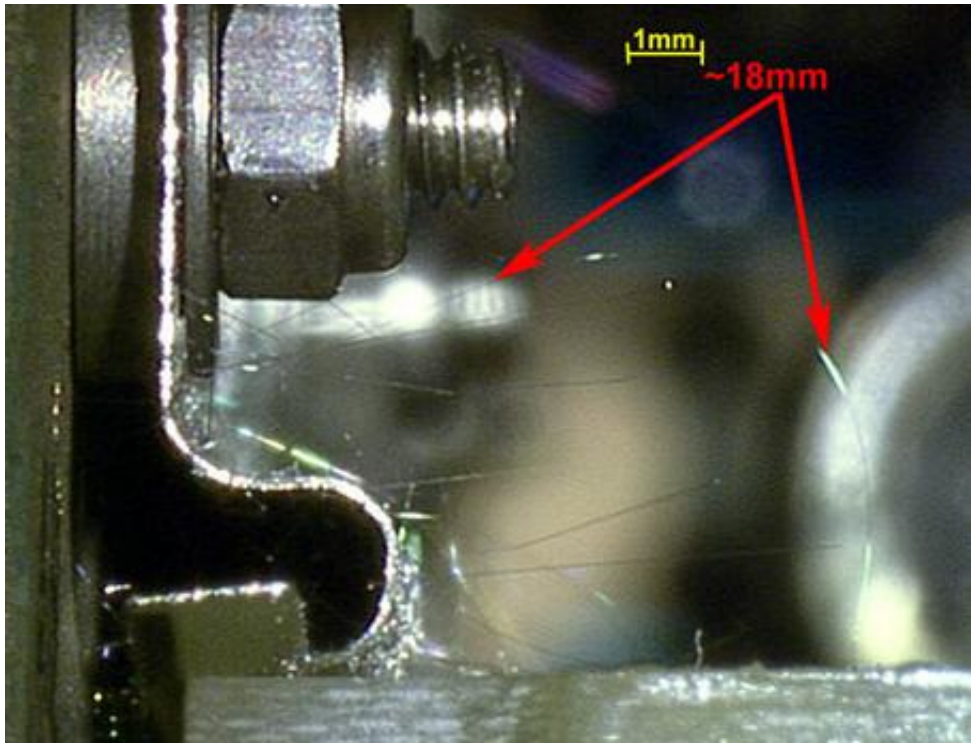


Photo Credit: James D. Stewart,
M&P Failure Analysis Laboratory
The Boeing Company Logistics Depot

Space Shuttle OV105 Card Guide

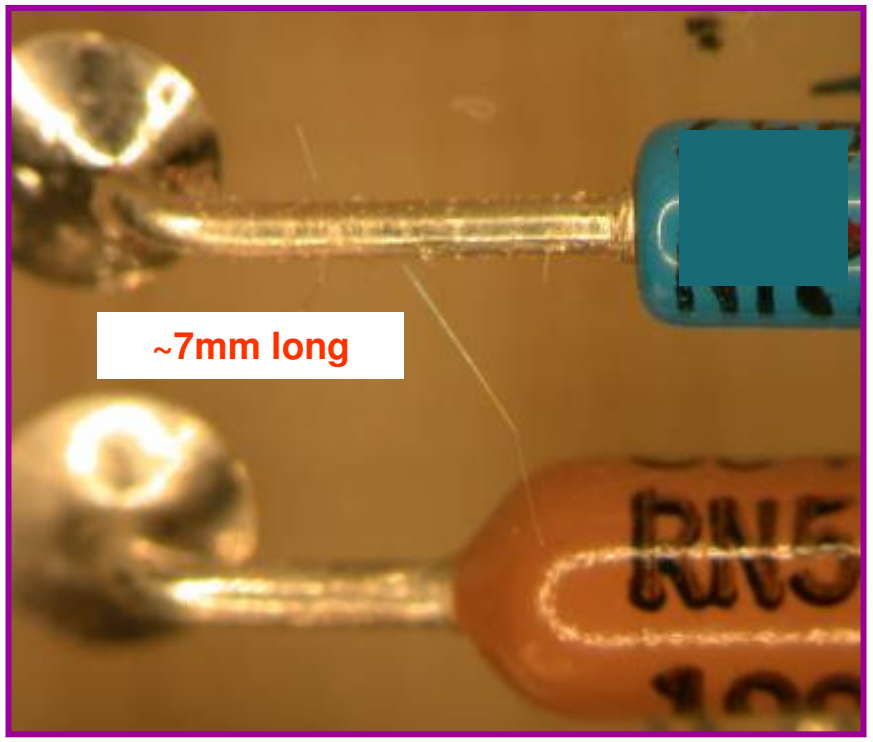
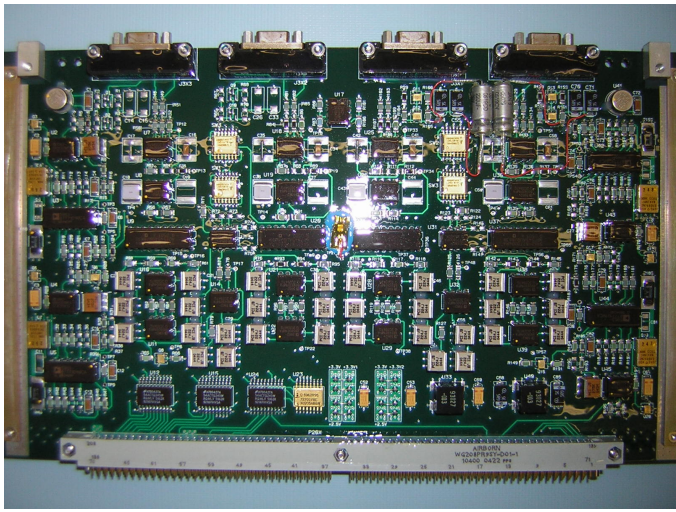


Image Courtesy of: T. Riccio (STPNOC)

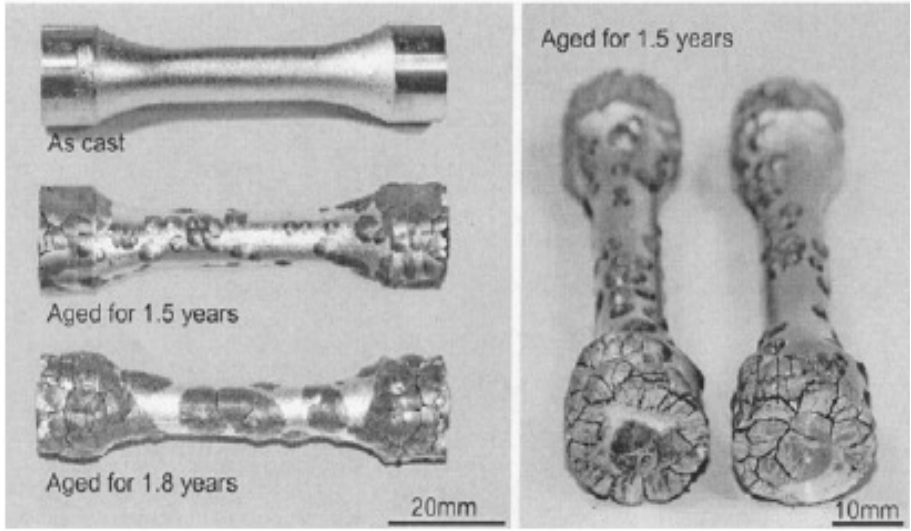
Nuclear Power Plant Electronics, Diode Leads

Trend Observed – The Older the Hardware, the Longer the Whiskers. In Both Cases, the Hardware is ~20 years old

NASA Policy – A Straightforward Task?



- Looked simple, the problems are known:
  - Lead-free (Pb-free) solders
    - ➤ Unknown reliability, especially over the long term
    - ➤ Unknown risk of heat damage to EEE parts
  - Pb-free platings and surface finishes
    - ➤ Risk of whiskers from tin-based materials
    - ➤ Risk of tin pest for pure tin at cold temperatures (+13˚C to ≤ -40˚C)
- The solutions are also known
  - Avoid the use of Pb-free solders
  - Avoid Pb-free, tin based platings
- Implementation tools are available
  - The GEIA 0005 standards

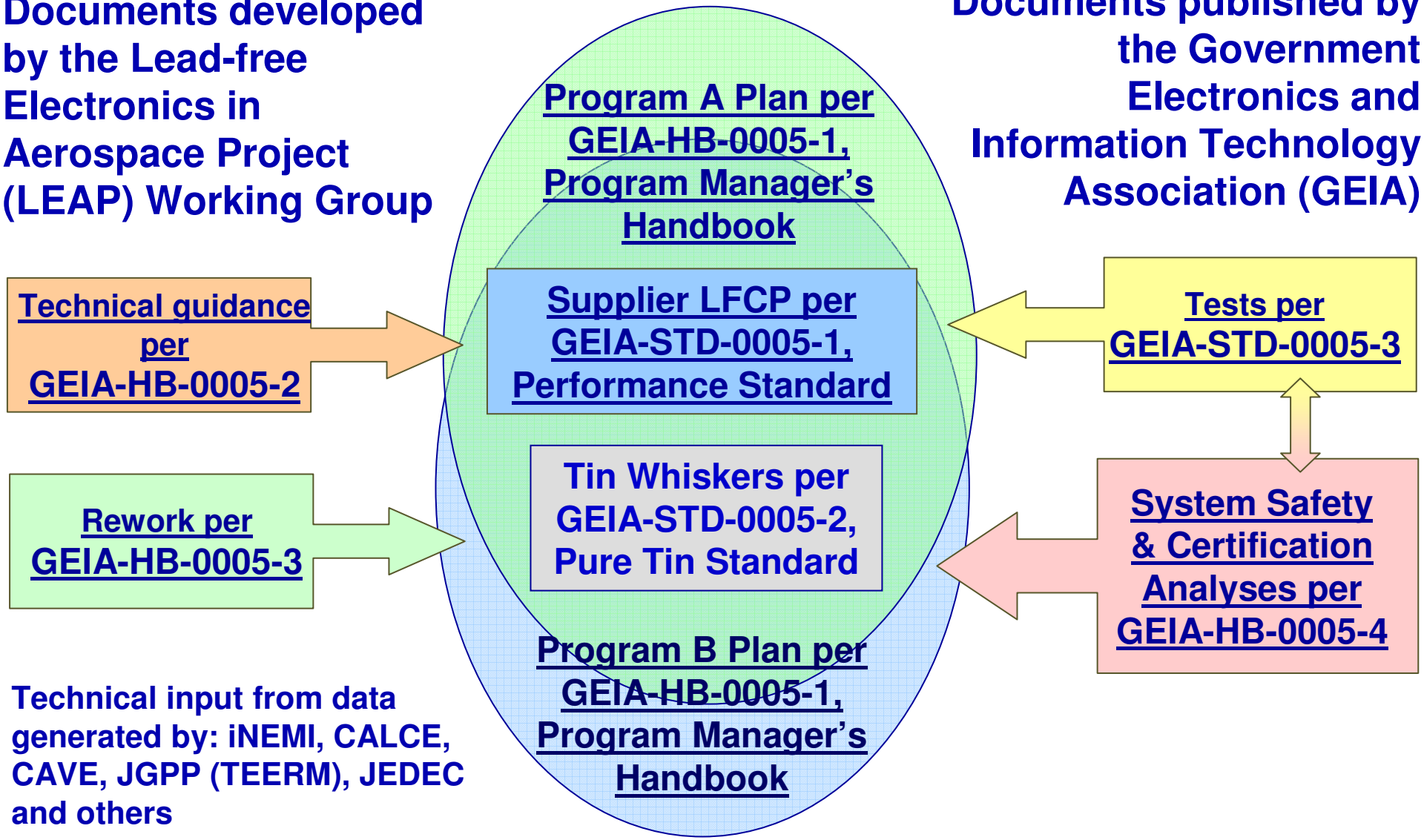


Tin Pest

The GEIA 5000 Series Documents

Documents developed by the Lead-free Electronics in Aerospace Project (LEAP) Working Group

Documents published by the Government Electronics and Information Technology Association (GEIA)



Technical input from data generated by: iNEMI, CALCE, CAVE, JGPP (TEERM), JEDEC and others

Status of GEIA 5000 Documents

Document Number	Released / Title / In Ballot	GEIA Publication Date
GEIA-HB-0005-1	Program Management/ Systems Engineering Guidelines for Managing the Transition to Lead-free Electronics	2Q 2006
GEIA-HB-0005-2	Technical Guidelines for Aerospace Electronic Systems Containing Lead-free Solder and Finishes	3Q 2007
GEIA-STD-0005-1	Performance Standard for Aerospace and High Performance Electronic Systems Containing Lead-free Solder	2Q 2006
GEIA-STD-0005-2	Standard for Mitigating the Effects of Tin Whiskers in Aerospace and High Performance Electronic Systems	2Q 2006
GEIA-STD-0005-3	Performance Testing for Aerospace and High Performance Electronics Containing Lead-free Solder and Finishes	2008
GEIA-HB-0005-3	Rework and Repair Handbook for Aerospace and High Performance Electronic Systems Containing Heritage SnPb and Lead-Free Solder and Finishes	2008
GEIA-HB-0005-4	Impact of Lead Free Solder on Aerospace Electronic System Reliability and Safety Analysis	2008

The Simple Policy

- Require traditional tin-lead solders for all electronic assembly except when justified by technical need (such as a high melt point)
  - Approved GEIA-STD-0005-1 plan to define rules and controls
  - SAC and other “new” alloys require special and exceptional rationale
- Require all tin-based platings and protective finishes to have a minimum of 3% Pb content unless:
  - A persuasive rationale is provided
  - Tin whisker mitigation strategy is supported by data and approved by NASA
  - GEIA-STD-0005-2, “Control Level 2C” because traceability is required by part number, however Levels 2A and 2 B may be allowed with procuring activity approval
  - Use GEIA-HDBK-0005-1 for guidance

BUT we learned it is not that simple

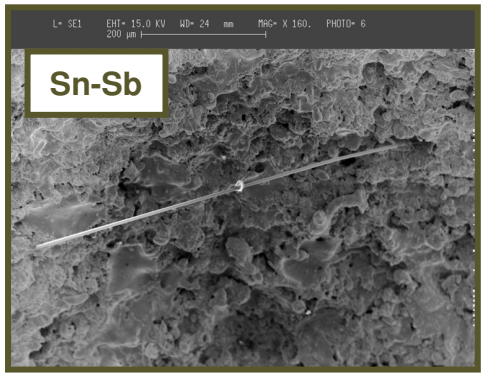
Summary of GEIA-0005-2 Tin Control Levels

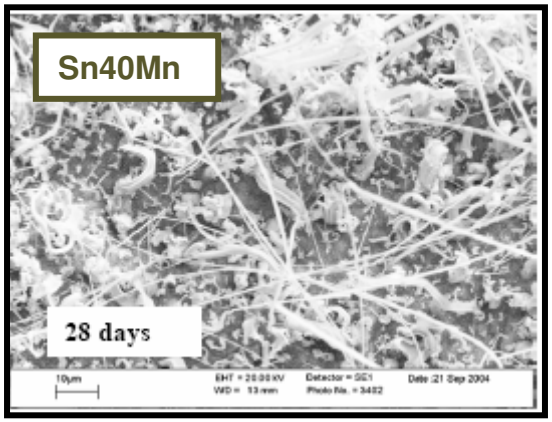
Level	Documentation of Tin Usage	Detection and Control	Mitigation	Risk Analysis
1 Don't Care	Supplier: General info on finishes used	None	None	None
Decreasing Tolerance for Tin ↓ 2A	Supplier: General info on finishes used Customer: List any apps where tin prohibited	None	None except report any instances where used in analysis	Show meets performance even with whiskers or because of mitigation
2B	Supplier: List families, general apps Customer: List any apps where tin prohibited	Sampling plan for materials check recommended	At least two mitigation methods recommended	Application tolerance or mitigation success at family level
2C	Supplier: Detailed listing of all uses Customer: List any apps where tin prohibited	Sampling plan agreed between supplier and customer	At least two mitigation methods required	Application tolerance or mitigation success at instance level
3 NO TIN	Supplier: Results of lot screening for tin	≥ 1 sample/lot must be tested for tin	None, N/A	None, N/A

Issues We've Encountered Along the Way

- We are encountering EEE parts that have been built using tin-based Pb-free solders for years
  - Example High Temp Solders (Sn/Ag, Sn/Sb, etc.)
  - If we openly accept their use at the part level, we are vulnerable to challenges to use them at the board level
  - We can require mitigation strategies for external uses but what about when used internal to a part?
  - What do we really know about "whiskers" from these alloys?
- Surveillance for Prohibited Materials is NOT "Plug and Play"
  - Standard test methods are needed
  - Calibration standards are needed
  - Operator training is ESSENTIAL!!!
  - Analysis companies are frustrated by inaccuracies and uncertainties
- Mitigation Strategies
  - No single approach, in fact all current options have weaknesses

Some Tin Alloys That Have Grown Whiskers*





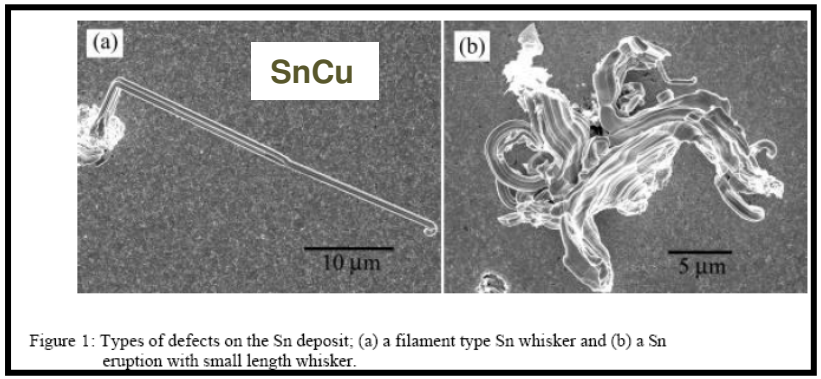


Figure 1: Types of defects on the Sn deposit; (a) a filament type Sn whisker and (b) a Sn eruption with small length whisker.

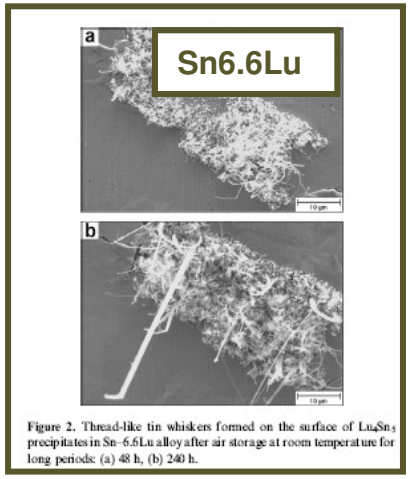


Figure 2. Thread-like tin whiskers formed on the surface of Lu_2Sn_5 precipitates in Sn–6.6Lu alloy after air storage at room temperature for long periods: (a) 48 h, (b) 240 h.

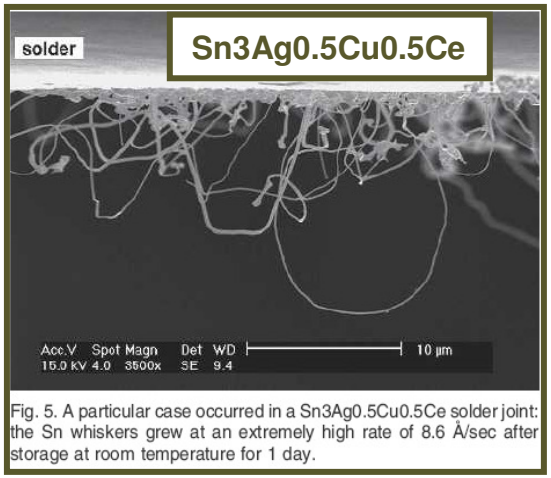
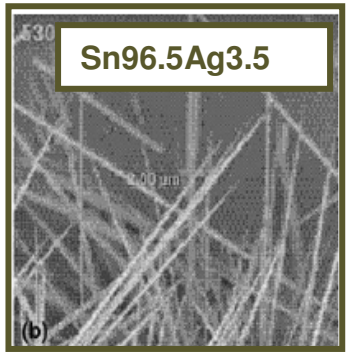


Fig. 5. A particular case occurred in a Sn3Ag0.5Cu0.5Ce solder joint: the Sn whiskers grew at an extremely high rate of 8.6 Å/sec after storage at room temperature for 1 day.



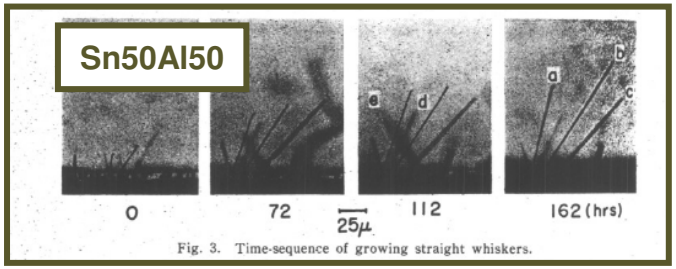
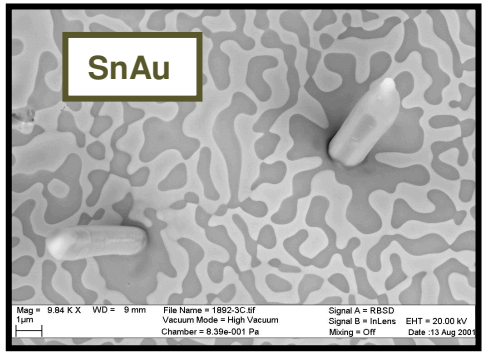


Fig. 3. Time-sequence of growing straight whiskers.



*Citations at end of Presentation

All These Sn-X Alloy Systems Have at Least One Documented Case of Whisker Growth

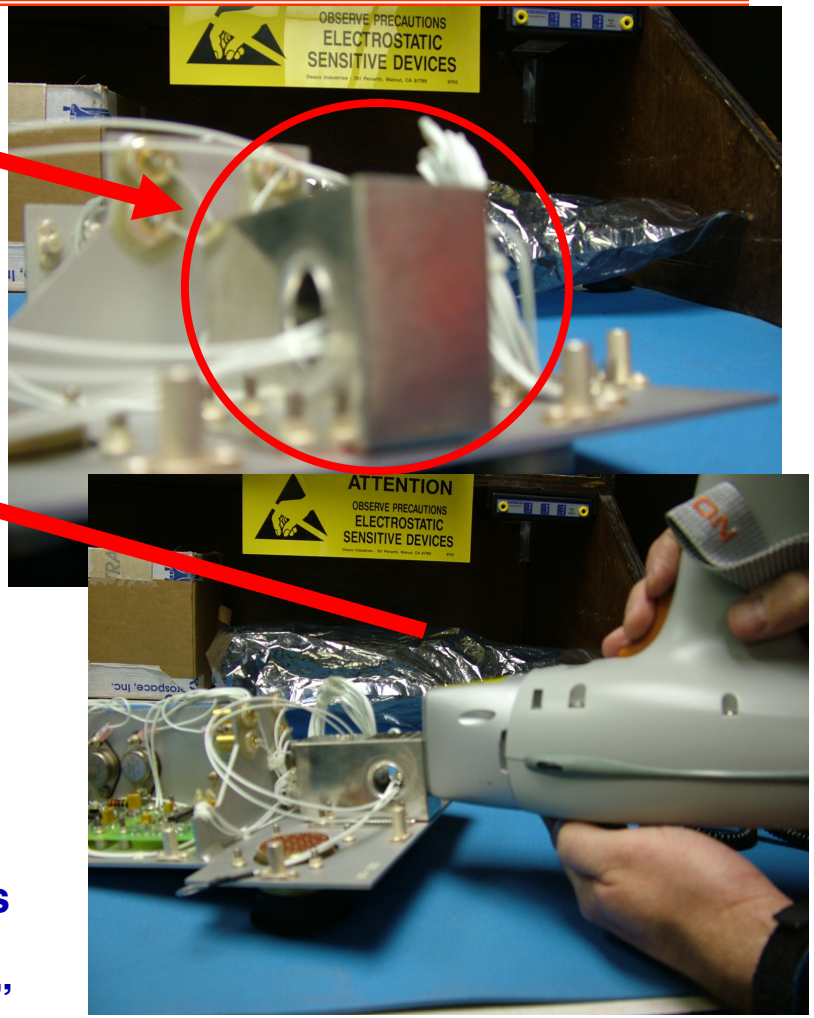
	Alloy System	Empirical Evidence for Whisker Tendencies
1.	Sn	Lots of Data – Significant Whisker Tendencies
2.	Sn-Pb	Lots of Data – Greatly Reduced Whisker Tendencies
3.	Sn-Ag	Minimal data – "Maybe" High Temp Application Makes Worse
4.	Sn-Au	Few Experiences Citing Whiskers
5.	Sn-Al	1 Study – Lots of whiskers
6.	Sn-Bi	Minimal data
7.	Sn-Cu	Some data – suggests increased whisker tendency
8.	Sn-Lu	Only 1 Study – Significant Whisker Tendency
9.	Sn-Mn	Only 1 Study – Significant Whisker Tendency
10.	Sn-Sb-X	Few Observations –Film Caps & High Temp Solder Applications
11.	Sn-Ag-Cu	Minimal Data – 1 Field Concern Not in Public Domain
12.	Sn-Ag-Cu-Ce	Only 2 Studies – Significant Whisker Tendency

Key:

Ag = Silver
Al = Aluminum
Au = Gold
Bi = Bismuth
Ce = Cerium
Cu = Copper
Lu = Lutetium
Mn = Manganese
Sb= Antimony
Sn = Tin
X = any element

Materials Analysis Tools are NOT "Plug and Play"

- Component: Current Sensor
  - "Pure Tin" Final Finish
  - Nickel Underplate
  - Brass Package (Cu-Zn)
- Portable XRF Analysis Results
  - *Sn – 9.05%*
  - Ni – 23.68%
  - Cu – 52.88%
  - Zn – 12.20%
- Results were Improperly Interpreted
  - XRF penetrated to the base metal
  - User Interpreted the underplate and base metal as alloying constituents in the surface plating
- Inadequate Training Resulted in
  - Contractor Incorrectly "Accepting" a Pure Tin Plated Component Because Their XRF Analysis Showed Sn content << 97%
  - Contractor Declared Results were "Repeatable" (But they were repeatably WRONG)



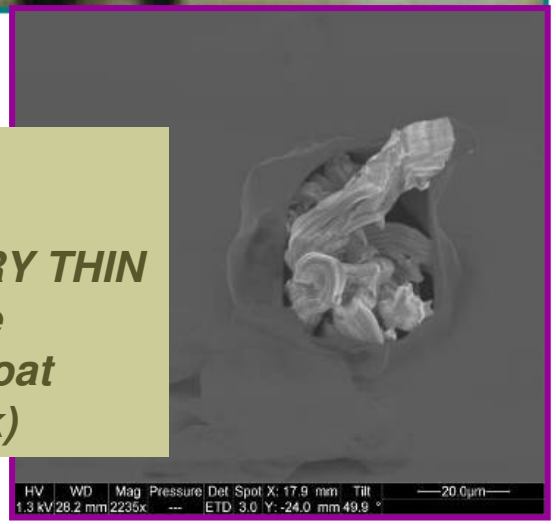
Calibration Standards, Standard Procedures And Training are NEEDED

Determining What is NOT Pure Tin

- Current Specifications and Standards Say <97% Tin
  - NASA wants the other 3% minimum to be Pb
- XRF measurement systems and methods are not “pin-point” accurate; they have a tolerance
  - Assays showing elemental contents to even one decimal place are bogus, none of the systems in common use have this accuracy
- Granular structure of tin-lead can lead to large variations in apparent composition when illuminated with a small spot size (EDS)
  - Checking multiple sites and averaging can overcome this but might then fail to detect genuine tin rich areas
- Calibration standards are needed
- JEDEC JC13.1 has task group developing a standard Pb measurement test method for MIL-STD-750 (transistors, diodes)
  - It is only looking at XRF
  - G12 is recommending a general JEDEC standard with technology specific detail in MIL-STDs 202, 750 and 883

Pure Tin Mitigation Strategies

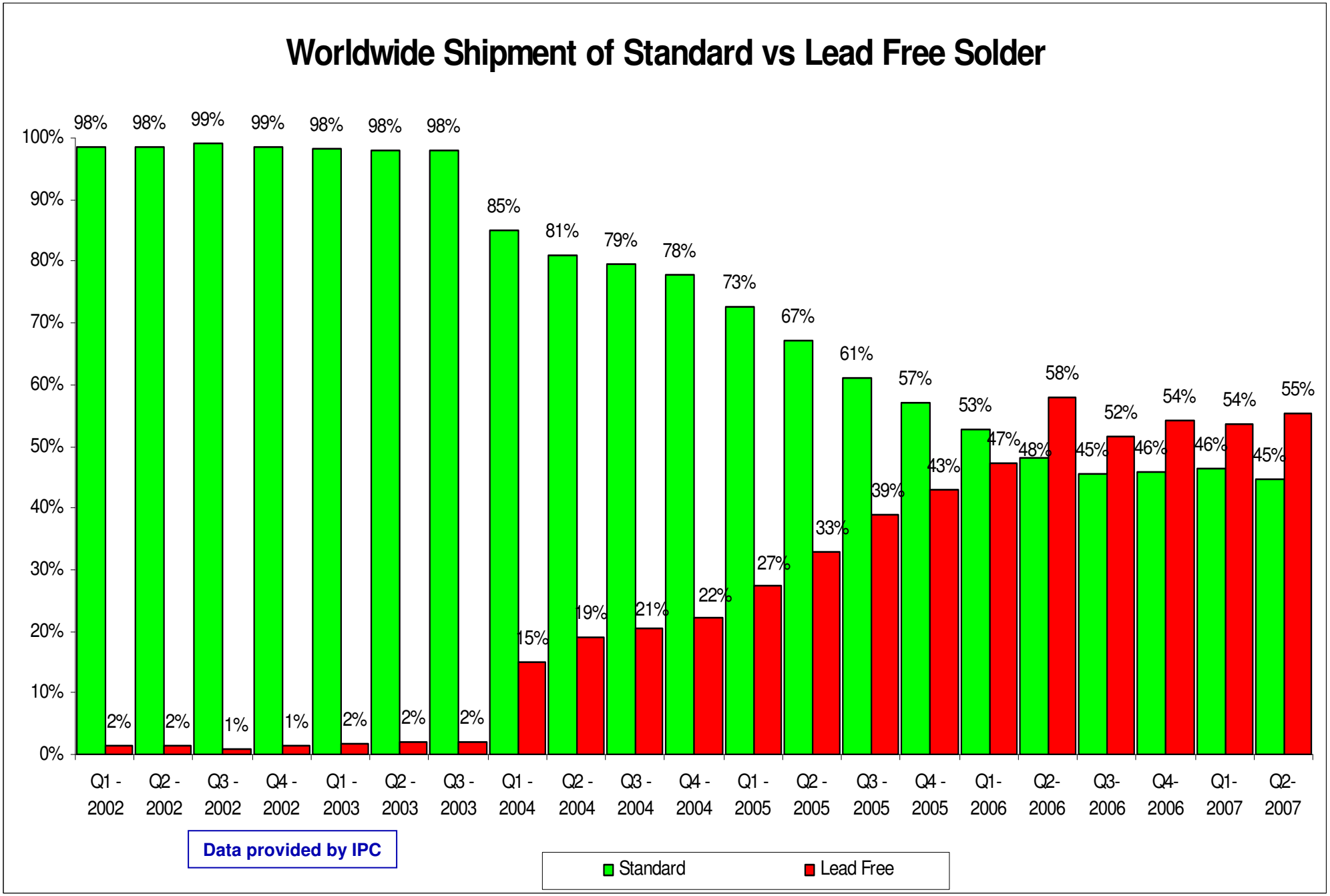
- GEIA-STD-0005-2, Level 2C requires at least two mitigation strategies for a good reason:
  - Hot Sn/Pb solder dip
  - Nickel underplate
    - Seems to suppress
    - Not always effective
  - Conformal Coat
    - Cannot cover everywhere
    - Don't want it under some parts
    - Holes and thin spots
  - Annealing
    - May have some benefit if done soon after plating
  - Reflow - ?
  - Dings and scratches can undo annealing and reflow benefits



Tin Whisker Pushing Out Through VERY THIN Polyurethane Conformal Coat (~2.5µM thick)

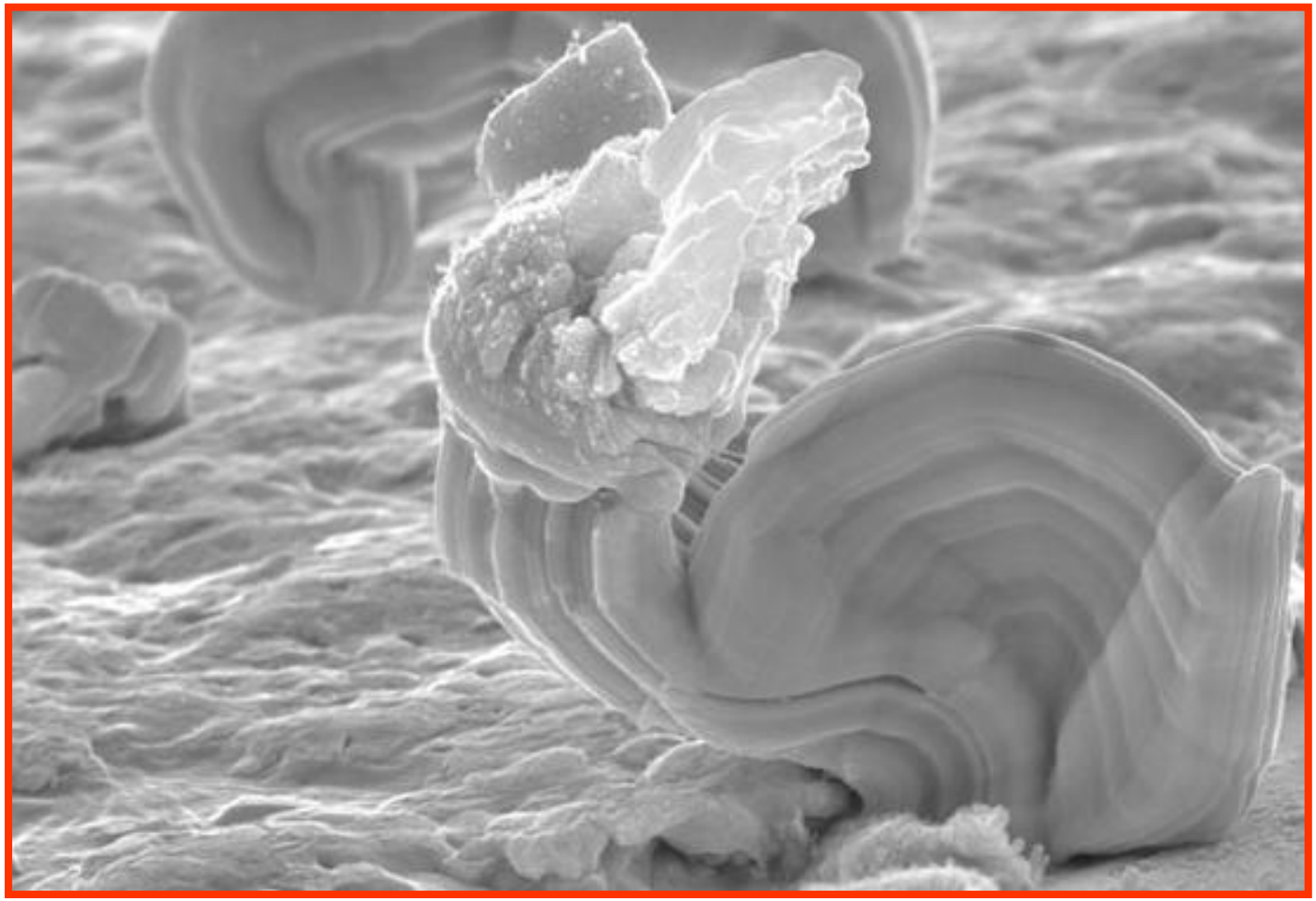
Conclusions

- NASA and other Aerospace enterprises can afford to wait to go Pb-free for solders
  - Let high volume commercial business debug the processes and select the solders
- More immediate action must be taken to avoid whisker surprises (and pest)
  - Any use of commercial parts risks exposure to pure tin termination finishes
- A Lead-Free Control Plan is needed even if the intent is to stay with leaded solder
  - The supplier documents the controls and mitigations they will use to meet the customer's requirements
- NASA needs a Pb-free policy soon

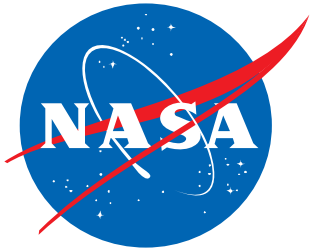

Worldwide Shipment of Standard vs Lead Free Solder
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
98% 98% 99% 99% 98% 98% 98%
85% 81% 79% 78% 73% 67% 61% 57% 53% 58% 52% 54% 54% 55%
2% 2% 1% 1% 2% 2% 2%
15% 19% 21% 22% 27% 33% 39% 43% 47% 48% 45% 46% 46% 45%
Q1 - 2002
Q2 - 2002
Q3 - 2002
Q4 - 2002
Q1 - 2003
Q2 - 2003
Q3 - 2003
Q1 - 2004
Q2 - 2004
Q3 - 2004
Q4 - 2004
Q1 - 2005
Q2 - 2005
Q3 - 2005
Q4 - 2005
Q1- 2006
Q2- 2006
Q3- 2006
Q4- 2006
Q1- 2007
Q2- 2007
Data provided by IPC
Standard
Lead Free

Tin and Other Metal Whiskers Website: http://nepp.nasa.gov/whisker/

Cute Whiskers



"Not So" Cute Whiskers


NASA