

Lead-free Electronics

Impact for Space Electronics

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Overview

- **Background**
- **Technical Implications**
- **Challenges**
- **Whiskers**
- **Tin Pest**
- **NASA Pb-free Policy**
- **Issues Encountered**
- **Mitigation Strategies Conclusions**



Background

- **The European Regulations known as RoHS, the Restrictions on the use of Hazardous Substances, were adopted in February of 2003 and took effect on July 1, 2006**
- **Amongst other materials , RoHS severely restricted the use of lead (Pb) in electronics in items sold within the European Union**
- **Although RoHS is European, it has affected the world market, most commercial electronic items are now advertised as Pb-free**
- **The US is not directly covered by RoHS and neither are space applications, even in Europe**



The Technical Implications

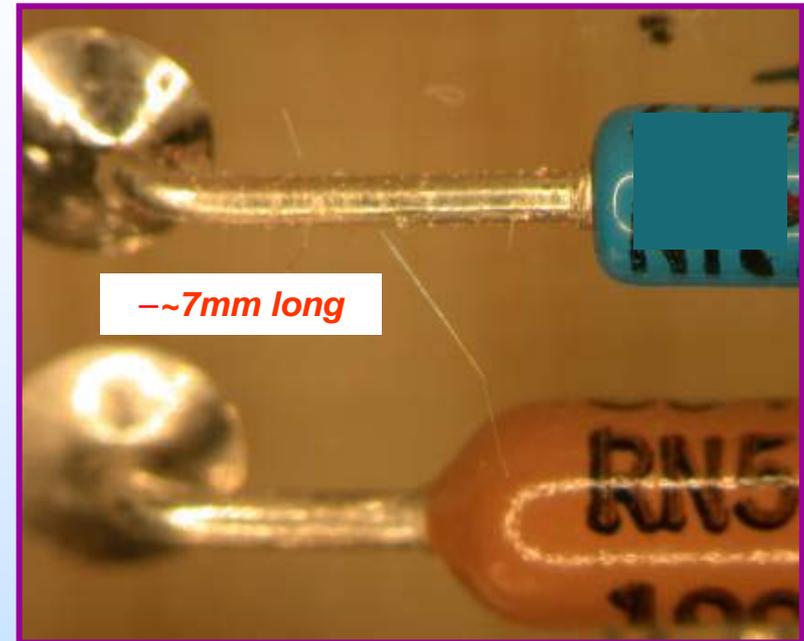
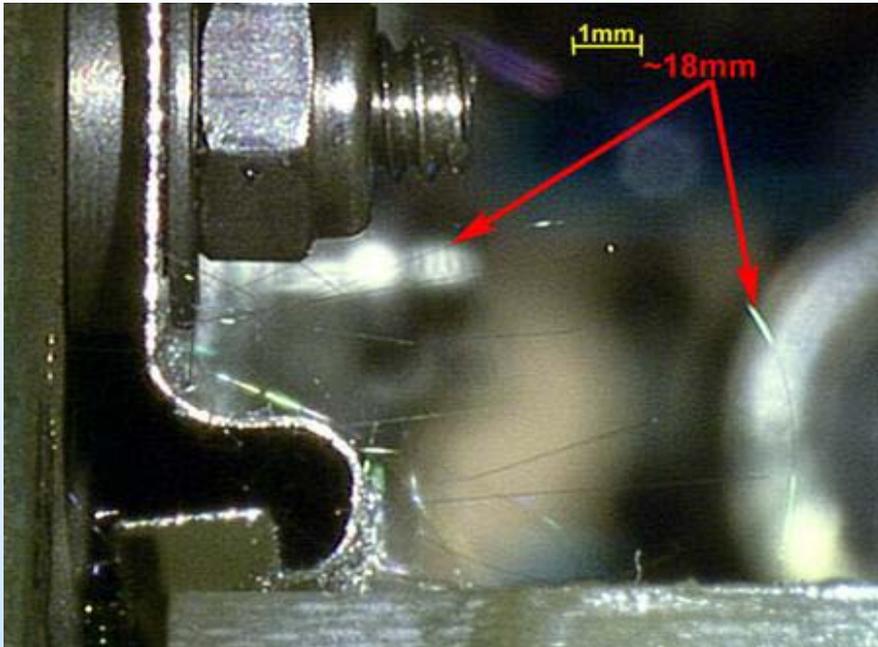
- **Pb is used as a constituent in solder alloys used to connect and attach electronic parts to printed wiring boards (PWBs)**
- **Similar Pb bearing alloys are electroplated or hot dipped onto the terminations of electronic parts to protect the terminations and make them solderable**
- **Changing to Pb-free solders and termination finishes has introduced significant technical challenges into the supply chain**
- **Tin/lead (Sn/Pb) alloys have been the solders of choice for electronics for more than 50 years**
- **Pb-free solder alloys are available but there is not a plug-in replacement for 60/40 or 63/37 (Sn/Pb) alloys, which have been the industry workhorses**



The Challenges

- **Pb-free solder alloys:**
 - Most are multi-element, 3 or more metals
 - The most popular alloys are based on Tin (Sn) Silver (Ag) and Copper (Cu) and are known as SAC
 - Many SAC based alloys are available with subtle differences in composition, intended to produce properties similar to or better than Sn/Pb
 - Physical properties of most SAC alloys are cause for concern
- **Pb-free termination finishes:**
 - Again there is no one replacement for Sn/Pb
 - Tin is the preferred choice for high volume commercial but tin is prone to “whiskering”
 - Tin Pest formation can be a problem below 13°C
 - Gold can be a good if expensive choice for space applications, when available, and if properly handled to avoid embrittlement form Sn/Au intermetallic formation

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

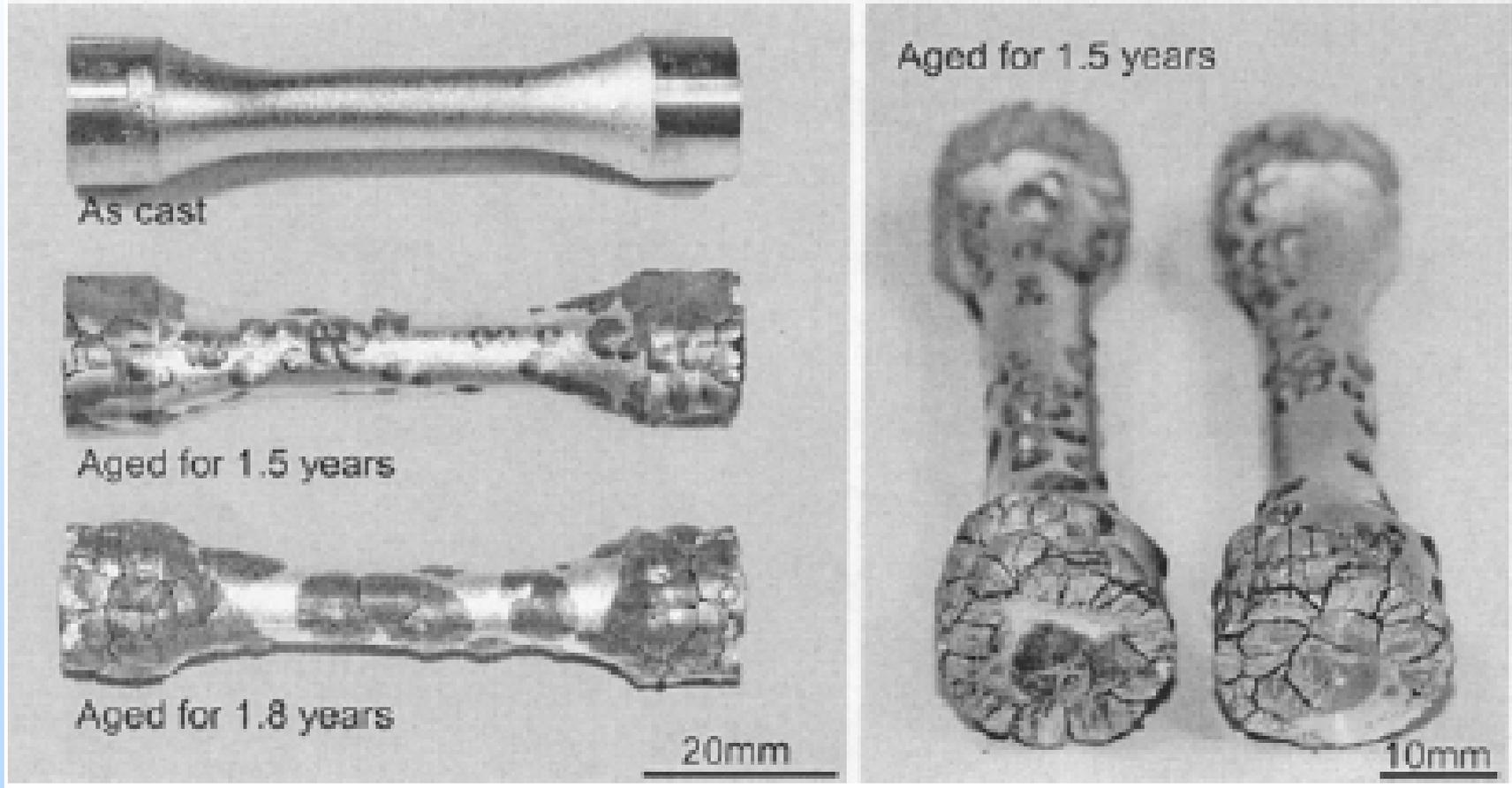


All These Sn-X Alloy Systems Have at Least One Documented Case of Whisker Growth

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*

Tin Pest





The NASA Pb-free Policy

- Policy is contained in NPD 8730.2, NASA Parts Policy, 11/3/08
- Requires traditional tin-lead solders except when justified by technical need (eg. high melt point)
 - Approved GEIA-STD-0005-1 plan to define rules and controls
 - SAC and other “new” alloys require exceptional rationale
- Require all tin-based platings and protective finishes to have $\geq 3\%$ Pb content (No pure tin) unless :
 - A persuasive rationale is provided
 - Tin whisker (and tin pest when applicable) mitigation strategy is supported by data and approved by NASA
 - GEIA-STD-0005-2, “Control Level 2C” = tin ID’d by part number, maybe Level 2B (ID by part type) for higher risk apps.

BUT implementation will not be that simple



So What is Pure Tin?

- **Some Specifications and Standards Say <97% Tin**
 - NASA wants the other 3% minimum to always be Pb
- **Measurement methods are not “pin-point” accurate**
 - Only chemical methods give 1 decimal place %
 - XRF studies show significant equipment variation
- **Granular structure of tin-lead can lead to large variations in apparent composition when illuminated with a small spot size (EDS)**
 - Checking multiple sights and averaging can overcome this but might then fail to detect genuine tin rich areas
- **Calibration standards are needed**
- **JEDEC JC13.1 has developed a standard Pb measurement test method JESD213 for XRF**
- **A similar test method is needed for EDS but numerous technical and practical issues to be overcome**

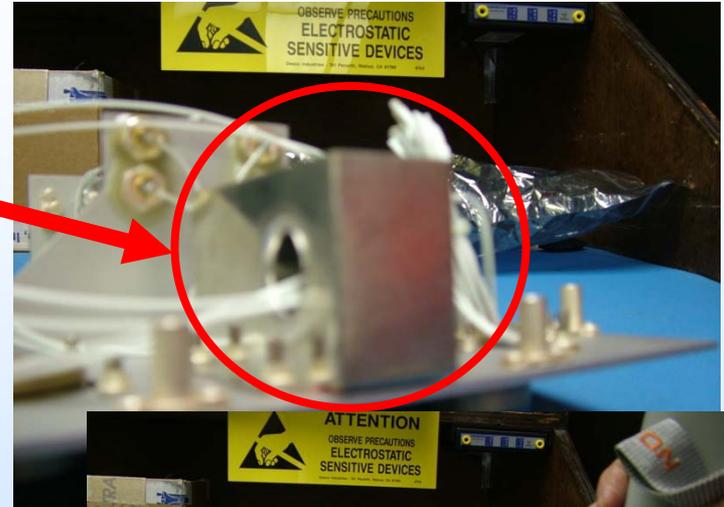


Issues Encountered

- **Parts built with tin-based Pb-free solders for years**
 - Example High Temp Solders (Sn-Ag, Sn-Sb, etc.)
 - Acceptance at part level risks precedence for board level
 - Can require mitigation for external uses BUT internal to a part?
 - We know little about whisker risk from these alloys
 - Tin pest risk is low for most
- **Incoming Surveillance for Prohibited Materials is NOT “Plug and Play”**
 - Standard Reference Materials are Needed
 - Equipment selection is critical (Navy “XRF shootout”)
 - XRF can be quick but EDS needed to resolve marginal results
 - EDS is costly and difficult, tends to resolve tin or lead but not both simultaneously
 - Operator Training is ESSENTIAL!!!
 - GIDEP documents B6K-P-07-01 and LL-U-07-024

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%
- **XRF penetrated to the base metal**
- **Inadequate Training Resulted in**
 - Contractor Incorrectly “Accepting” a Pure Tin Plated Component

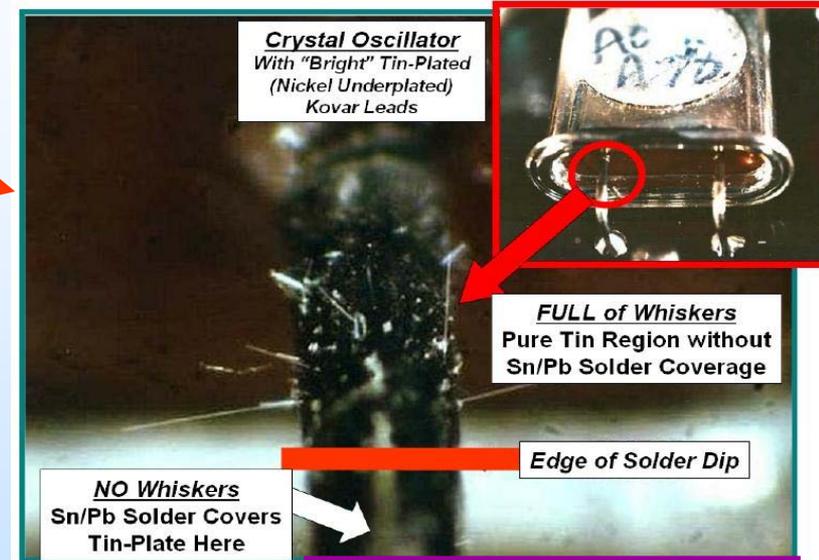


–Test Standards, Reference Material Standards And Training are NEEDED

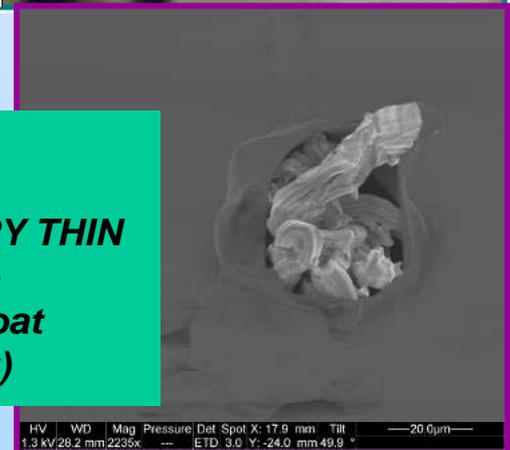
Pure Tin Mitigation Strategies

- GEIA-STD-0005-2, Level 2C requires >1 mitigation strategy for a good reason:

- Hot Sn/Pb solder dip
 - Seems to suppress
 - Not always effective
- Nickel underplate
 - 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)



Much More Work Needed



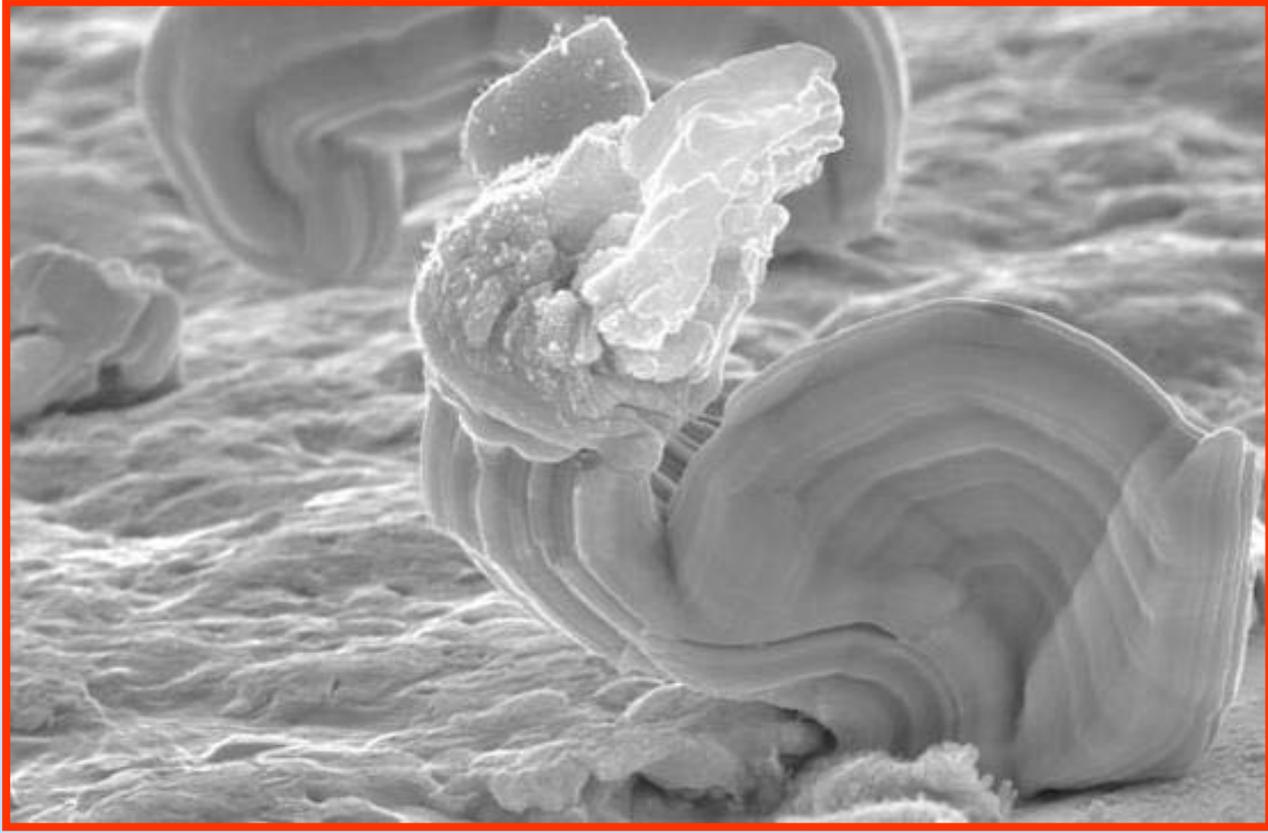
Conclusions

- **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
- **All spaceflight entities need a Pb-free policy**

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



Cute Whiskers



“Not So” Cute Whiskers



<http://nepp.nasa.gov>