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Lead-free Impact on DoD Programs

Michael Osterman, Ph.D.
osterman@calce.umd.edu

Center for Advanced Life Cycle Engineering
University of Maryland
College Park, MD 20742
(301) 405-5323
http://www.calce.umd.edu

Formed 1987

ISO 9001:2000 Certified, 1999

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What is CALCE?

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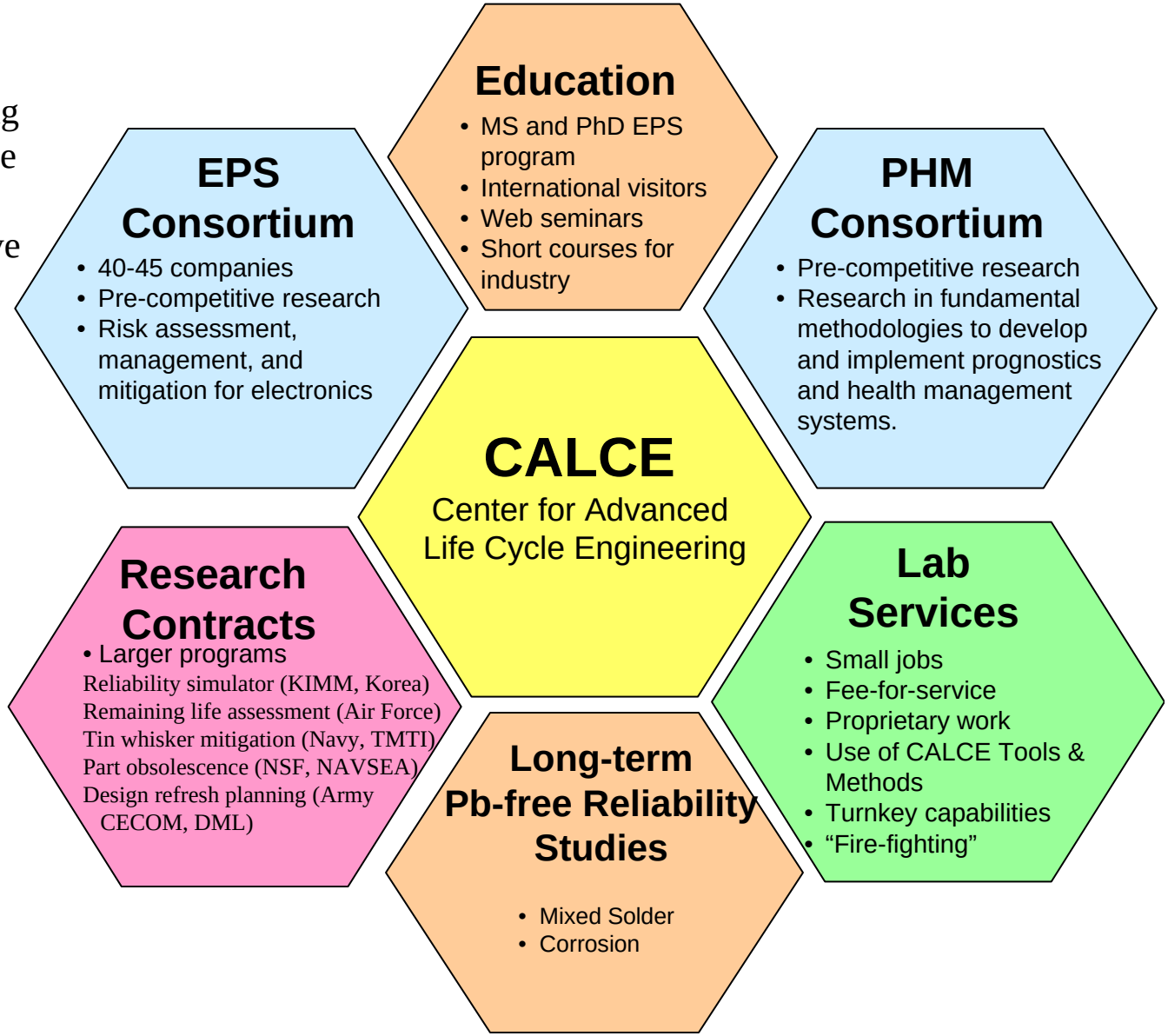
Center for Advanced Life Cycle Engineering (founded 1987) is dedicated to providing a knowledge and resource base to support the development and sustainment of competitive electronic components, products and systems. Focus areas:

- Physics of Failure
- Design of Reliability
- Accelerated Qualification
- Supply-chain Management
- Prognostics
- Obsolescence

Center Organization

16 research faculty
5 technical staff
60+ PhD students
30+ MS students
11 visiting scholars



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- Whirlpool Corp.
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- **Bold: Supermember**

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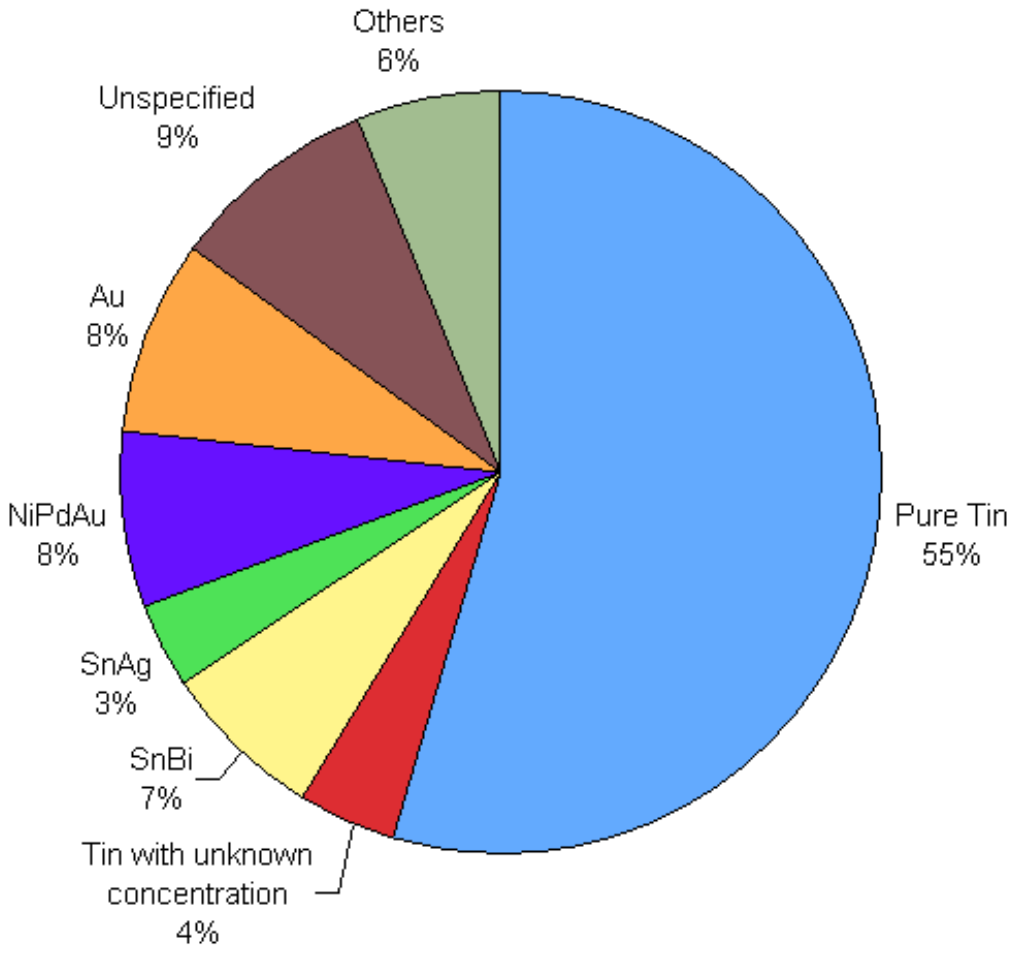
Introduction of Lead-free Tin Finishes

Under pressure to comply with impending government regulations (EU RoHS (effective July 2006), China RoHS (effective March 2007), electronic part manufacturers converted to Pb-free finish that would be compatible with conventional Sn37Pb solder assembly process and the likely Pb-free solder assembly processes. Many new ball grid array parts are only available with lead-free solder balls.



(Based on CALCE survey of 121 suppliers)

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Challenges introduced by Pb-free Electronics

- No exact drop-in replacement for Pb-based materials/components.
  - Tin-Silver-Copper (SAC) alloy dominates the market
  - Exact alloy composition still being tweaked.
- Issues due to Pb-free induced changes in component finishes, die attach materials, solders joints
  - Higher processing temperatures (pop-corning, board warpage, delamination)
  - Compatibility with Pb-free processing (mixed technology)
  - Solder joint reliability (durability, intermetallic growth)
  - Indirect failure mechanisms (electrochemical migration, tin whiskers)
- Long-term reliability of lead-free electronics not established
- Reparability of lead-free electronics
- Verification of part and material conformance
  - Mixed materials
  - Counterfeit materials

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Issues with Using Pb-free Parts in a Pb-based Assembly

Backward incompatibility (component with lead-free termination soldered with tin-lead solder and a tin-lead temperature profile)

- Pb-free finished terminals containing high concentrations of Bismuth (Bi) >4% may produce poor joints. Current testing results indicate commercially available SnBi finish does not present a reliability issue. However, SnBi on Alloy 42 leadframes shows a marked reduced life as compared to pure tin when assembled with SnPb solder. Note, Alloy 42 lead frames have lower life than copper lead frames.
- Ball grid arrays (BGA) packages with Sn-Ag-Cu solder balls may not be compatible with tin-lead solder, as combination of these materials can result in "cold" joint formation during assembly. Higher reflow temperatures may be needed to avoid this issue but this give rise to other issues.
- Tin Whiskers
- Rework still under investigation
- Reballing and Refinishing still under investigation

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Issues with Converting to Pb-free

- **Forward incompatibility** (component with lead-based terminations soldered with lead-free solder and a lead-free temperature profile)
  - lead-based components may not be able to handle reflow temperatures.
  - lead forms a low temperature alloy in tin-silver-copper (SAC) solders at 179°C and can result in interface separation.
- Tin Whiskers
- Inability to obtain certain lead-free parts.
- Lead-free solders (SAC305 and higher silver content SAC alloys) have lower vibration and mechanical shock durability. Industry is lowering silver content in SAC and adding additional elements. More study is needed.
- Acceleration factors and testing protocols still under investigation. However, temperature cycling reliability is expected to be better.
- Rework still under investigation

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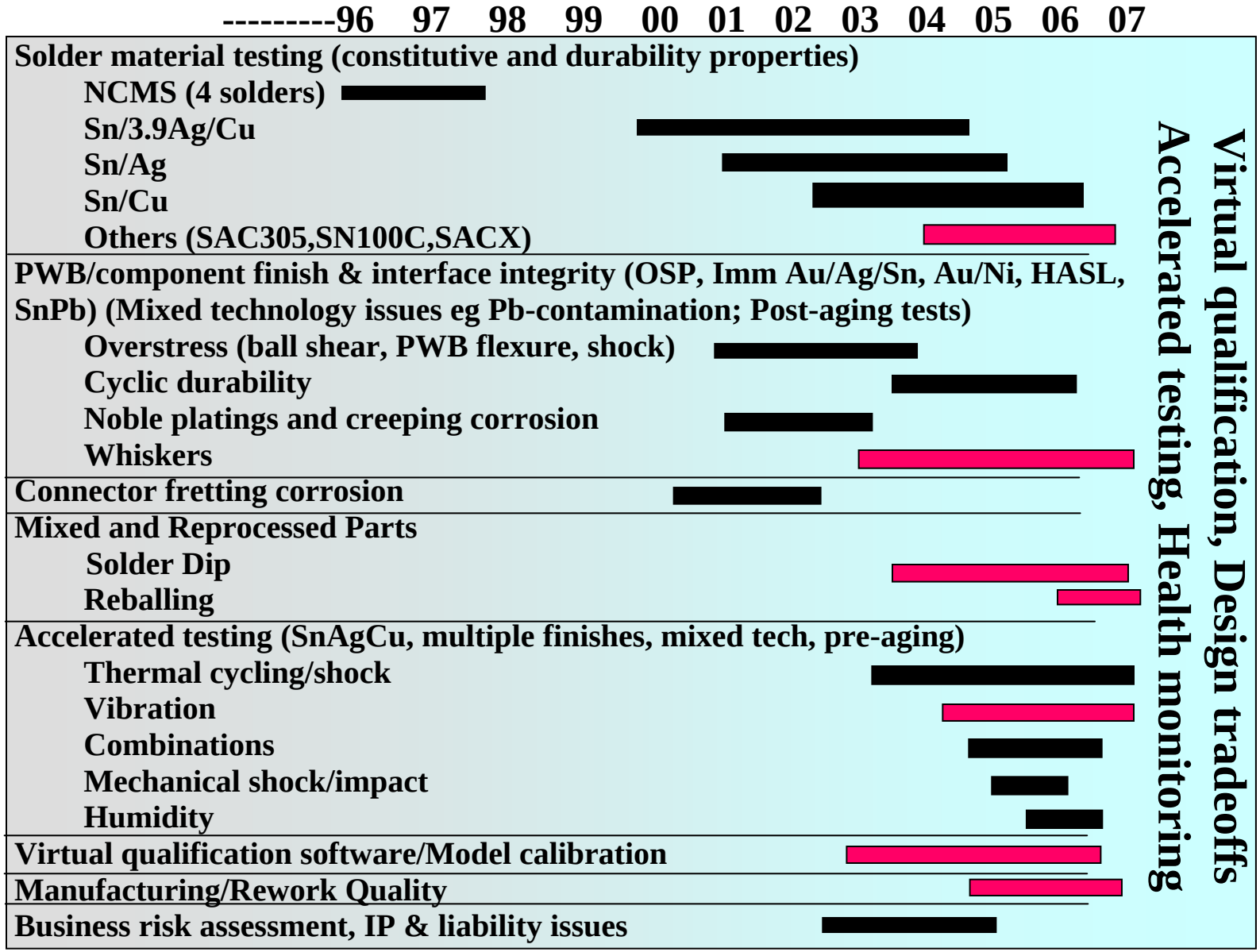
CALCE Lead-free Research



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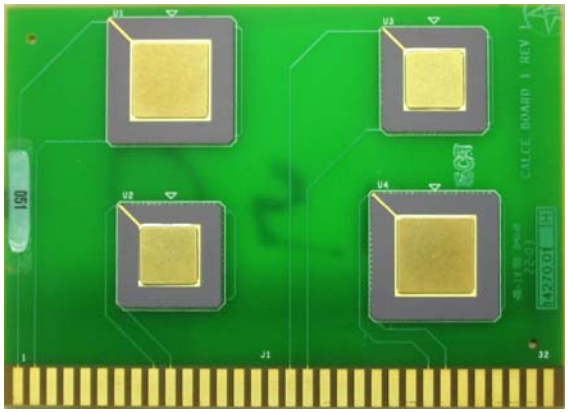
CALCE Pb-free Solder Temperature Cycling Reliability Testing

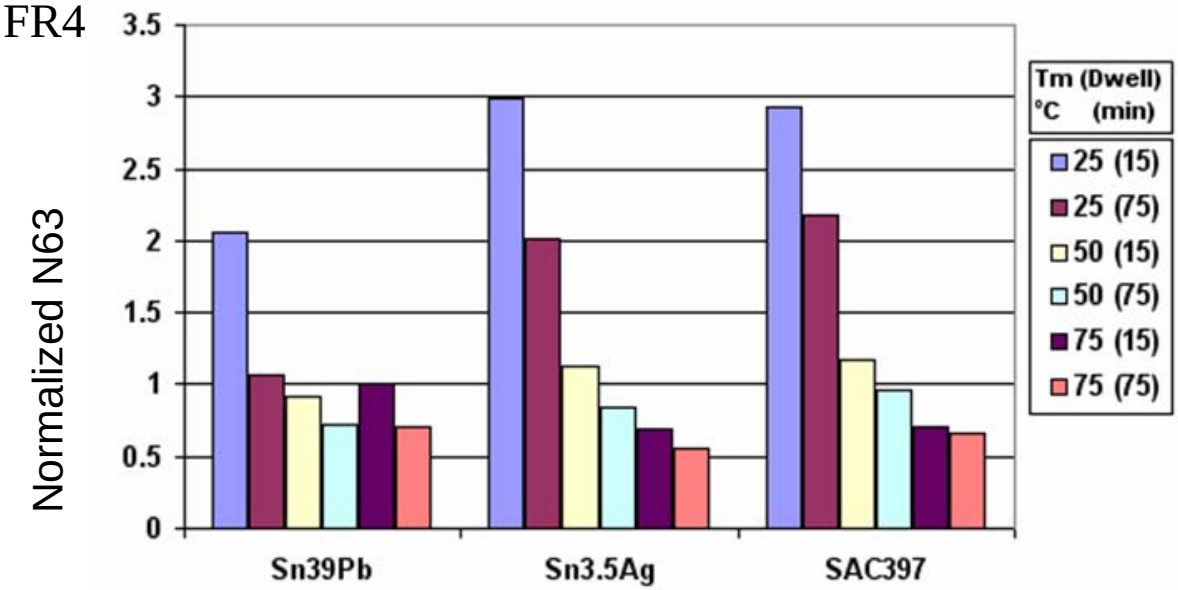


- Temperature cycle range 100 °C
- Mean cycle temperature varied from 25 to 75°C.
- Dwell time varied from 15 to 75 minutes.
- Tested Solder included:
  - SAC397 - Indium SMQ 230 Sn95.4/Ag3.9/Cu0.7
  - Sn3.5Ag - Indium SMQ 230 Sn96.5/Ag3.5
  - Sn39Pb - Indium SMQ 92J Sn63/Pb37

Test Vehicle

- PCB Board: 130 x 93 x 2.5 mm, FR4
- 68-pin LCCC: 24mm × 24mm
- 84-pin LCCC: 30mm × 30mm

Lead-free solders demonstrated longer life of equivalent life under temperature cycle loading



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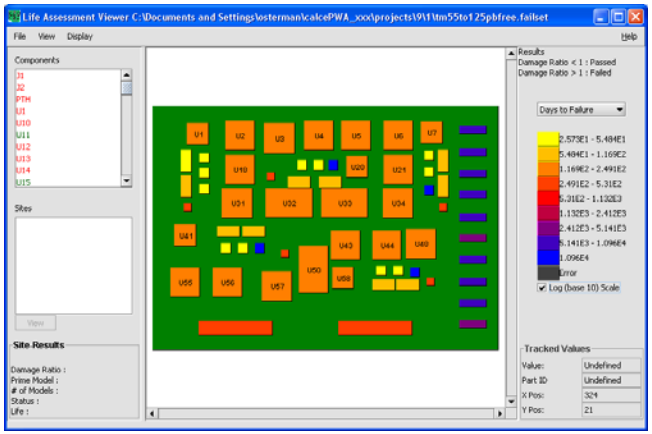
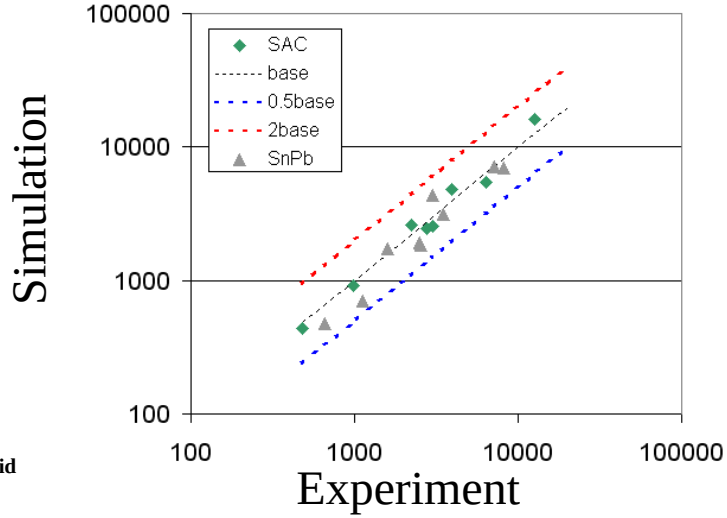
Comparison with CALCE Stain Range Temperature Cycle Fatigue Failure Model

Test Board



Simulation based reliability assessment with calcePWA

2 mm thick board contained PBGA, TSOP, TQFP, CLCC packages. The simulation model is based on testing conducted under the JGPP/JCAA Pb-free Solder Test Program. Test assemblies were subjected to a -55 to 125°C temperature cycle and a -20 to 80°C cycle condition



•JCAA/JG-PP No-Lead Solder Project:-55°C to +125°C Thermal Cycle Testing Final Report, David Hillman and Ross Wilcoxon, March 15, 2006

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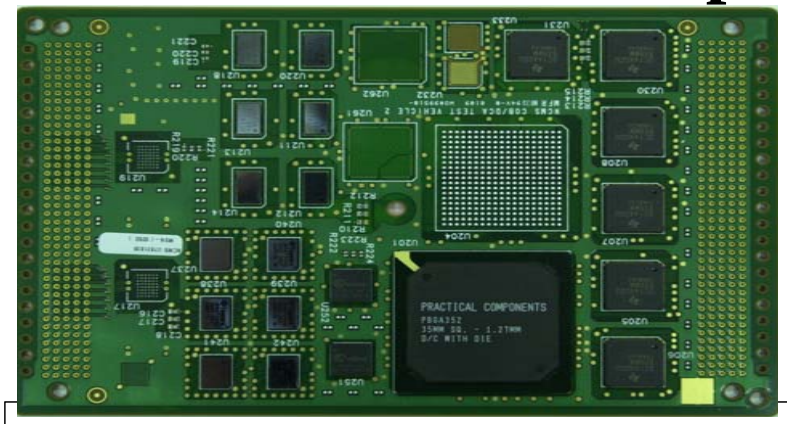
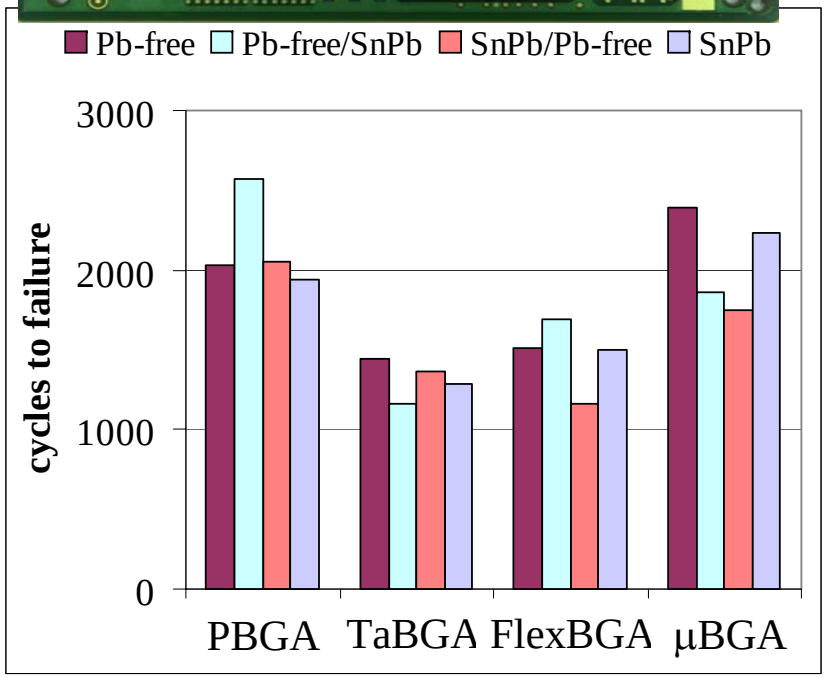
Mixed Solder (Pb-Free BGA/SnPb Paste) Interconnect Temperature Cycling Reliability

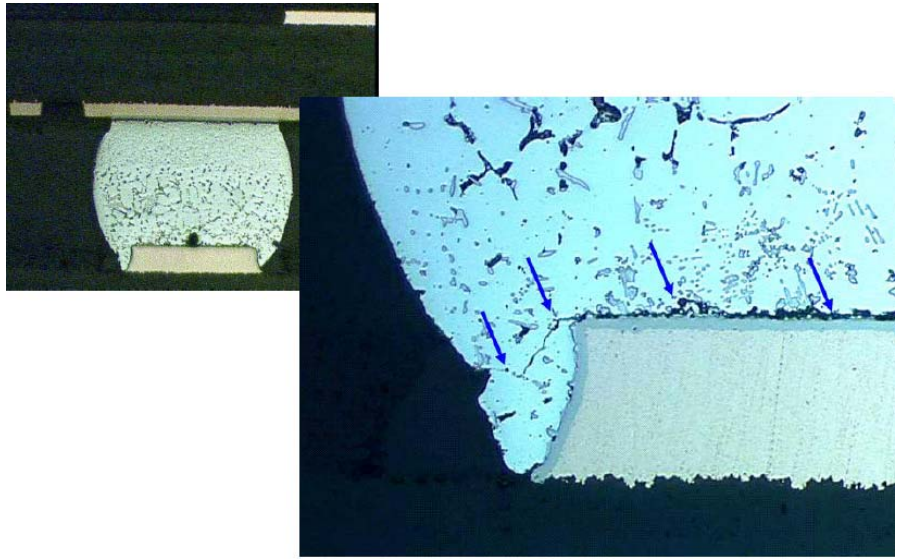




The effect of Pb contamination in mixed technologies

Studies have shown mixing of lead into the final solder ball is important to achieving reliable mixed (lead-free solder ball/tin-lead paste) ball grid array assemblies. If mixing is incomplete, early life failures can occur.

Example of in complete mixing



Hillman, D., Wells, M., and Cho, K., "The Impact of Reflowing a Pb-free Solder Alloy Using A Tin/Lead Solder Alloy Reflow Profile on Solder Joint Reliability" http://www.aciusa.org/lfpdf/lfjournal/CMAP_paper_Rev_A_(2).pdf Last Accessed 1/22/2006

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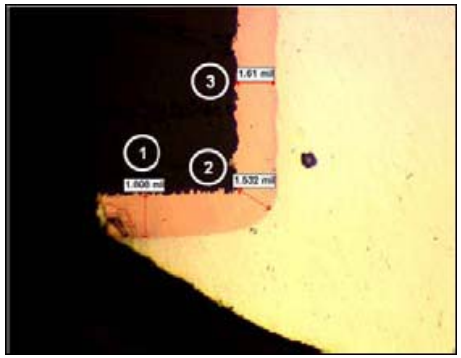
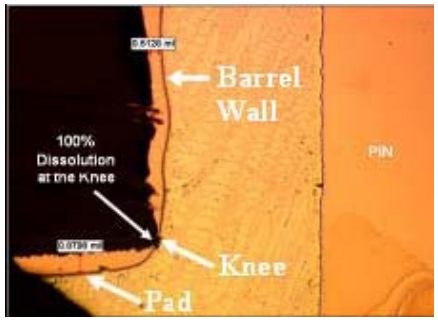
Lead-free Rework

Logistic of repairing electronic systems may be impacted by introduction of lead-free materials.

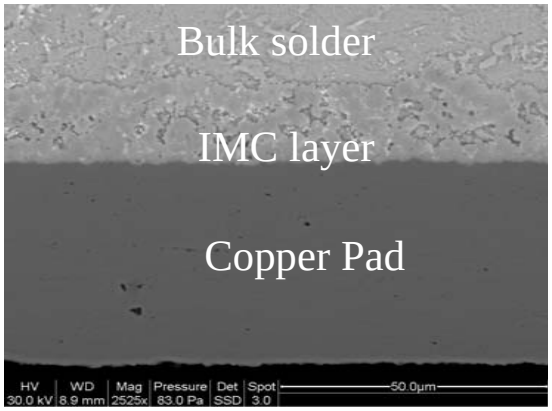


Non-rework PTH

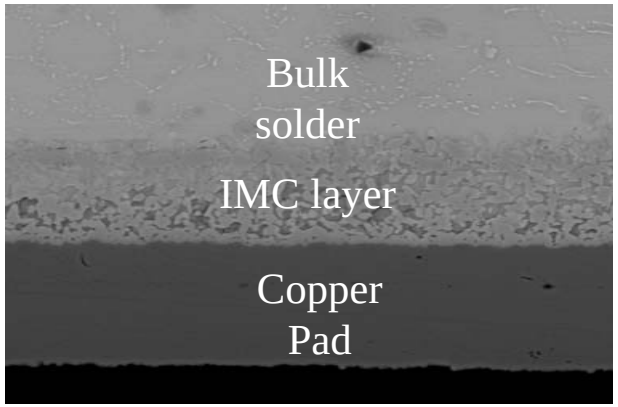


Rework PTH

Images of PTHs taken from C. Hamilton, P. Snugovsky, M. Kelly, A STUDY OF COPPER DISSOLUTION DURING LEAD FREE PTH REWORK USING A THERMALLY MASSIVE TEST VEHICLE, SMT International, Chicago, IL, Sept 24-26, 2006



SnPb Solder Paste



SAC Solder Paste

Solder/pad interface after five BGA part replacements from CALCE study

Rework operations will be limited with SAC solder due to dissolution of copper metalization on the printed wiring board.

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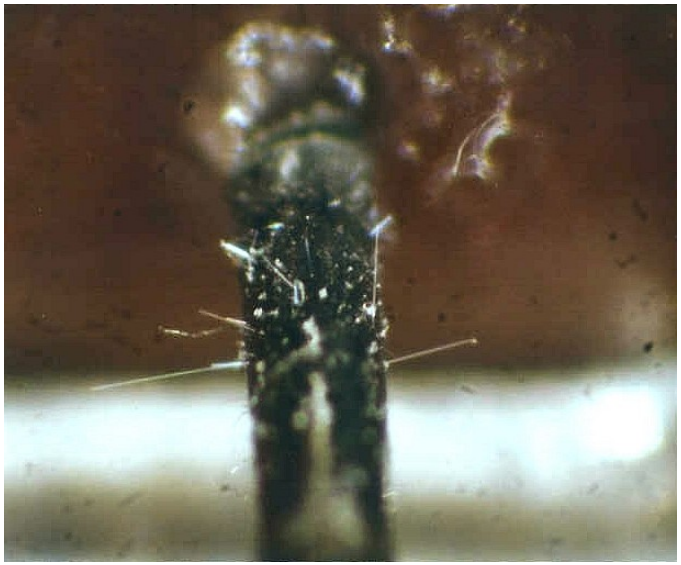
Tin Whiskers Present A Failure Risk

Tin whiskers are columnar or cylindrical filaments of pure tin can grow spontaneously from pure tin and high tin lead-free surface finishes. Whiskers can grow beyond 1 mm creating unintended electrical connections. Whisker can carry up to 10 mA in normal atmospheric conditions but can induce metal vapor arcs in small gap sizes under low pressure and vacuum conditions. There are many documented instances of tin whisker induced fails.



Whiskers above solder dipped region on metal can part which produced failure.

*

Damage from whiskers induced metal vapor arc in relay

* Davy, G., (Northrop Grumman Electronic Systems), "Relay Failure Caused by Tin Whiskers," http://nepp.nasa.gov/whisker/reference/tech_papers/davy2002-relay-failure-caused-by-tin-whiskers.pdf, June 10, 2004.

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Tin Whisker Related Standards

- JESD22A121, Measuring Whisker Growth on Tin and Tin Alloy Surface Finishes, JEDEC, May 2005.
- JEDEC Standard No. 201, Environmental Acceptance Requirements for Tin Whisker Susceptibility of Tin and Tin Alloy Surface Finishes, March 2006
- JP002, Current Tin Whiskers Theory and Mitigation Practices Guideline, JEDEC/IPC Joint Publication, March 2006
- GEIA-STD-0005-2, 'Standard for Mitigating the Risks of Tin in High-Reliability Electronic Systems', June 2006
- IEC 60068-2-82 Ed. 1.0, Environmental Testing- Part 2-82: Test-Test Tx: Whisker test methods for electronic and electric components, 2007

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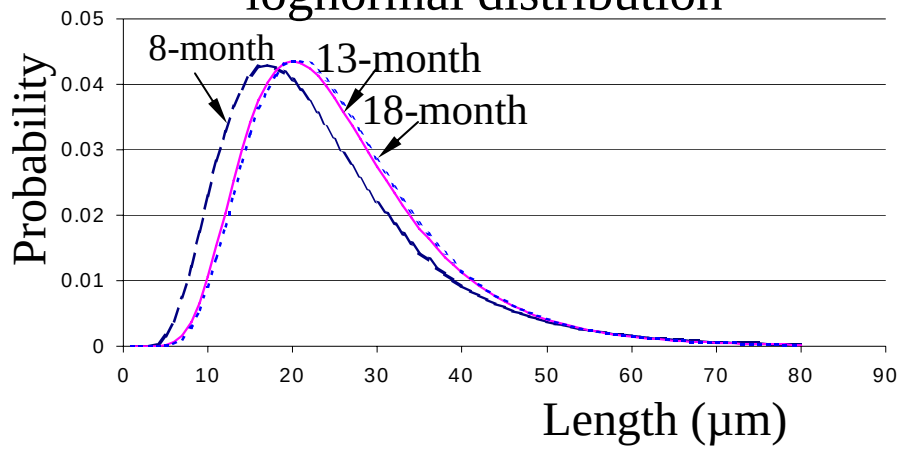
Tin Whisker Risk

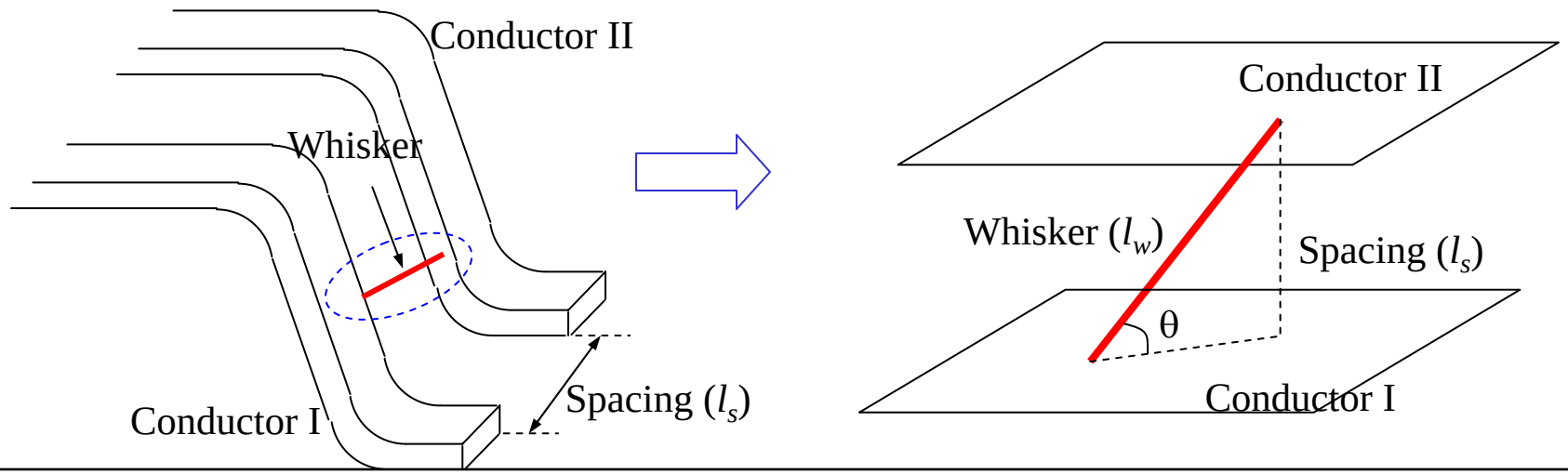
Tin whiskers present a unique challenge. No accepted accelerated test method exists. Multiple factors can influence initiation and growth:

- Intermetallic formation
- Surface oxidation/corrosion
- Temperature expansion mismatch

Whisker length appears to follow a lognormal distribution



Failure risk due to unintended electrical contact between isolated conductors



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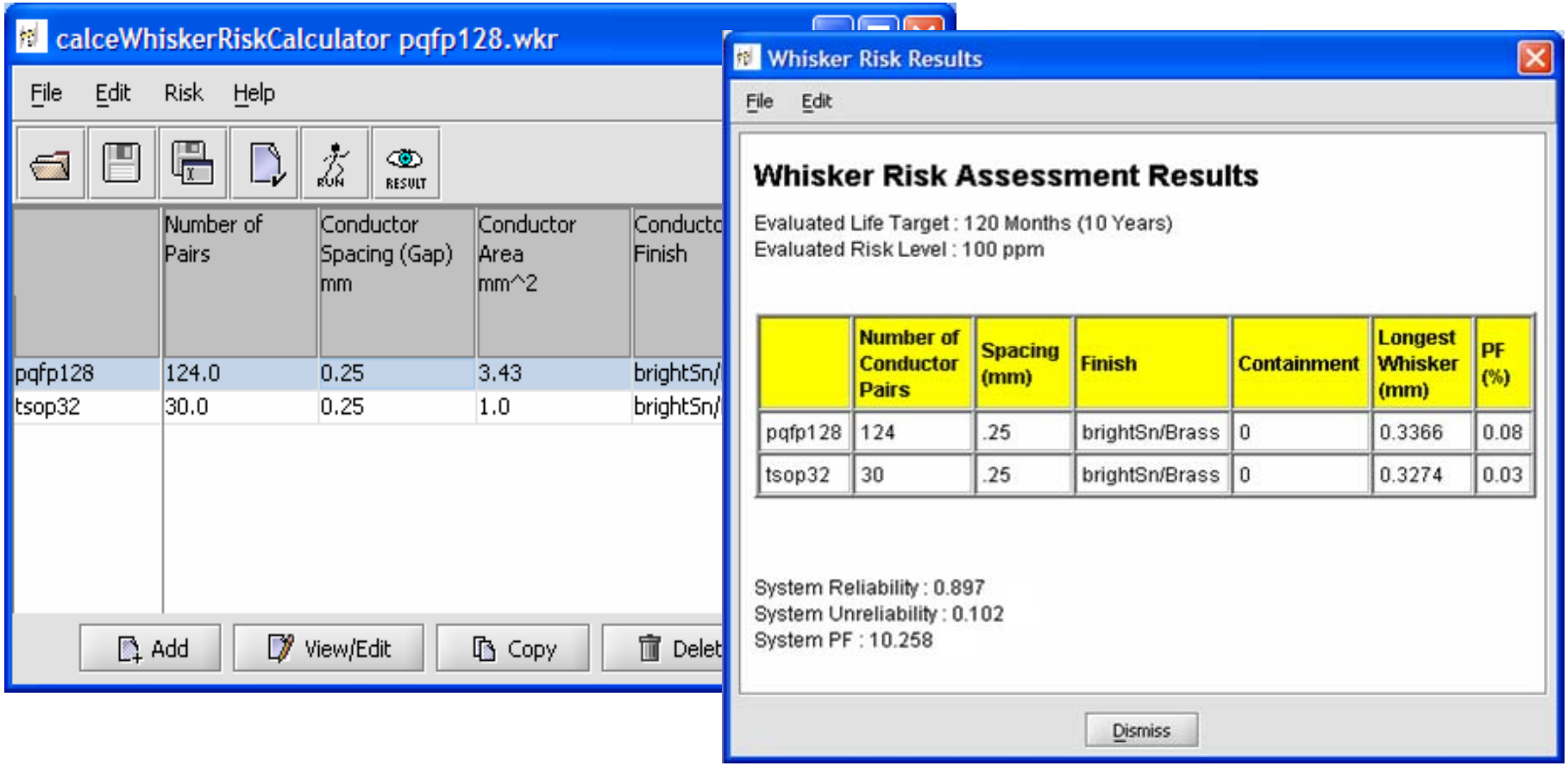
CALCE Tin Whisker Risk Assessment Software

A software package that calculates the probability of tin whisker failure for circuit card assemblies and products. Based on long-term test data.



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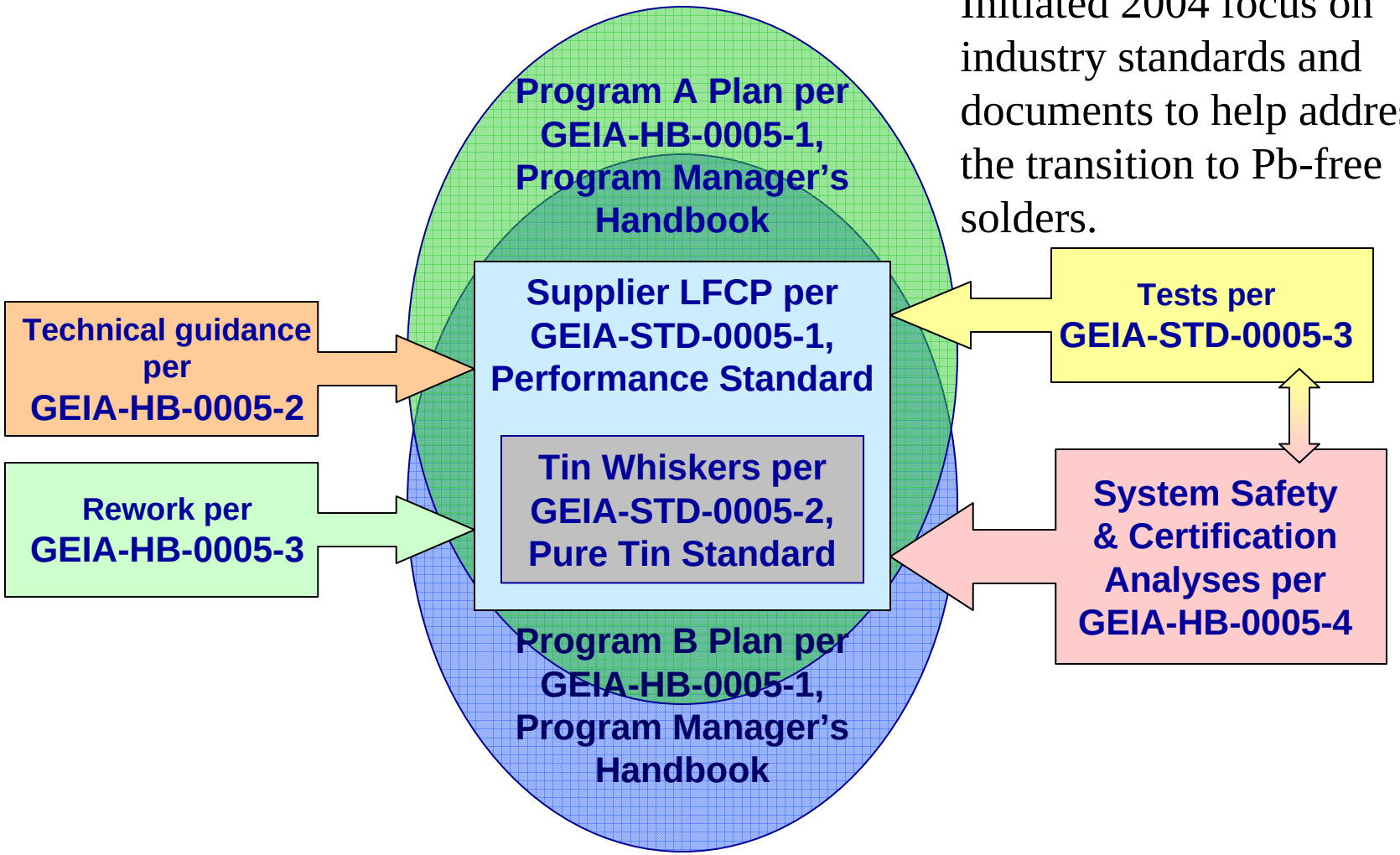
AIA-AMC-GEIA Lead Free Electronics in Aerospace Project (LEAP)

Initiated 2004 focus on industry standards and documents to help address the transition to Pb-free solders.



Contact: Lloyd Condra (lloyd.w.condra@boeing.com)

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Summary

- Companies with products that are exempt or not in scope of the RoHS restrictions are being impacted by the global transition to Pb-free and RoHS compliant electronics.
- The ability to obtain lead-based parts is a challenge to manufacturers attempting to maintain lead-based assemblies.
  - Reprocessing is an option but needs further qualification.
    - Ball attachment of reballed parts can be robust regardless of ball removal and attachment method.
    - Dipped terminals show uneven solder coverage which could impact storage and reliability.
  - Rework/repair also need further assessment.
    - Copper dissolution with tin-silver-copper solder may limit number of rework operations
    - High reflow temperatures may create issues on complex multi-layer assemblies.
  - Opportunity for infiltration of Counterfeit Parts
- Under temperature cycling exposure, pure lead-free (SAC) solder will generally be as good or better than SnPb.
- Under vibration and shock loading, lead-free (SAC) solder is not expected to be as good as SnPb.
- Impact of aging on lead-free (SAC) assemblies is not completely understood.
- Tin whisker formation presents a real reliability risk.
- LEAP initiated GEIA Standards available and being developed to assist programs dealing with lead-free electronics.

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