Presented to:

Parts Standardization Management Committee

Current Topics in Parts, Materials, and Processes for Military Applications

DISTRIBUTION STATEMENT A. Approved for public release: distribution unlimited. Review completed by the AMRDEC Public Affairs Office (PR 0833).

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

June 2014

Presented by:

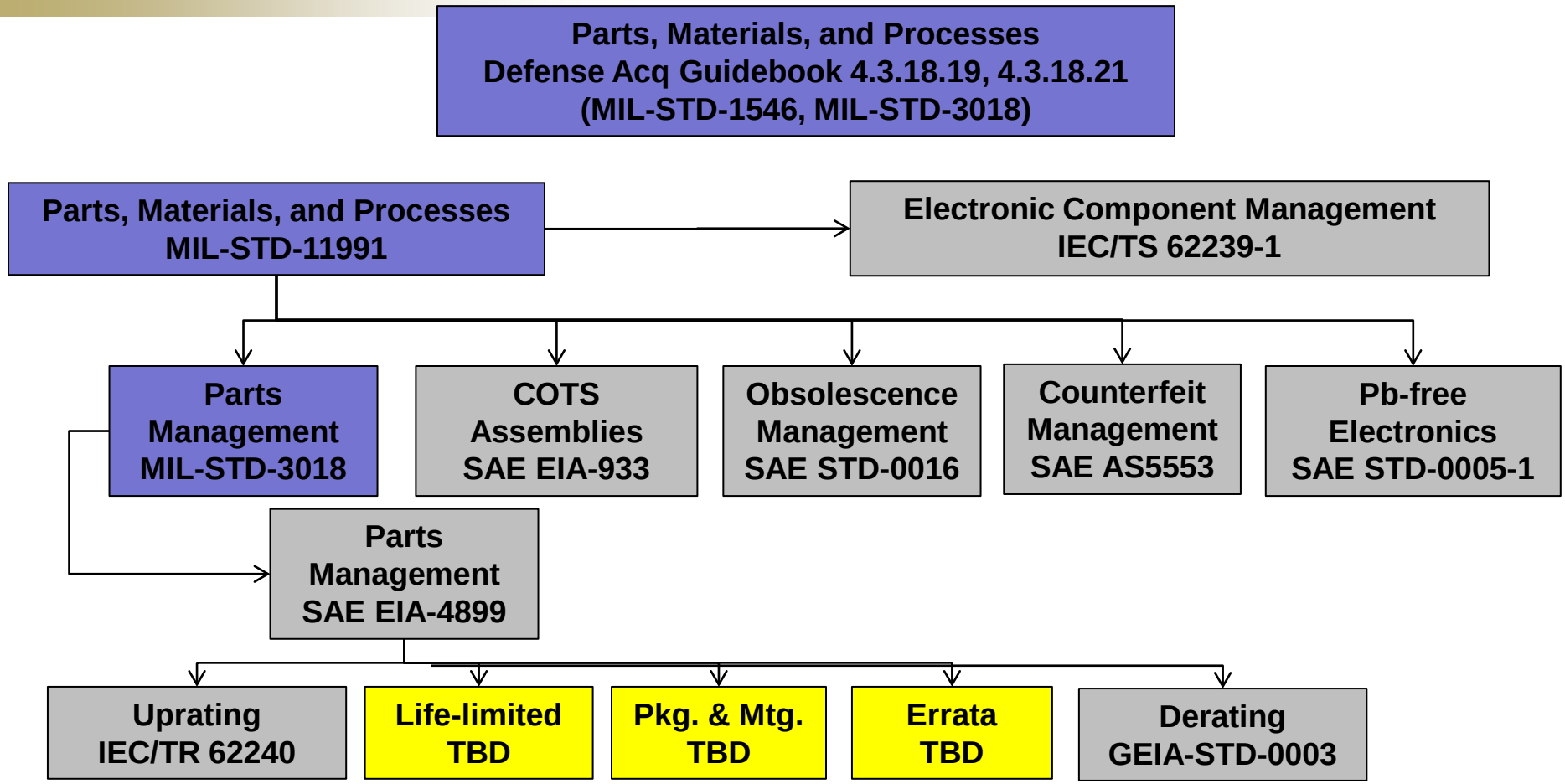
U.S. Army Aviation and Missile Research, Development, and Engineering Center

Reference herein to any specific commercial, private or public products, process, or service by trade name, trademark, manufacturer, or otherwise, does not constitute or imply its endorsement, recommendation, or favoring by the United States Government.

Parts, Materials, and Processes Management

- EIA-STD-4899B going to ballot soon
  - Reduced "shalls" by about half from 4899A: improved communication of requirements
  - Management process focus of structure
    1. Component Application
    2. Component Selection
    3. Component Life Cycle Management
  - Includes verification matrix
- MIL-STD-11991 approved for reinstatement (von Braun legacy)
  - General Standard for Parts, Materials, and Processes
  - References MIL-STD-3018
  - Leverage existing approaches in Aero & Defense Supply Chain
    - ✓ Missile Defense Agency Mission Assurance Plan
    - ✓ Boeing Commercial D6-55583
- SAE G-24 Committee started to manage Pb-free Electronics standards
  - GEIA-STD-0005-1, etc.
- IPC starting project to develop J-STD-001 military "addendum"
- SAE and IEC working on coordination to not duplicate work

Parts, Materials, and Processes Management



PM&P Policy Gap

- DAG provides reasonable best practices framework
  - Preferable to have more exposure, such as DTM or DoDI
- DoD parts useage profile inadequate
  - DoD needs greater insight into parts used across programs to improve:
    - Obsolescence/availability management
    - Quality and Reliability assurance
    - Standardization
    - Cost control
  - Must address all parts used
  - Defense Supply Chain needs insight into parts use across programs to be responsive suppliers

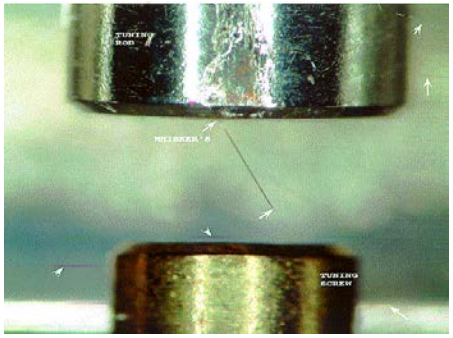
DoD policy needs to require that all programs submit parts/COTS lists to DLA for consolidation and sharing (not identifiable to design agent or program)

Lead-free Electronics Impact Topics

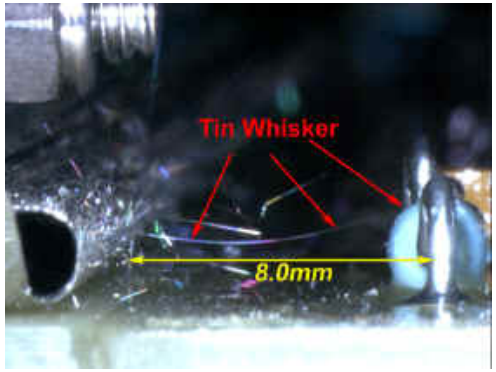
- Lead-free (Pb-free) Electronics Risks
  - Tin Whisker electrical short circuits
  - Solder joint reliability
- Lead-free impact on design practices
- Lead-free impact on qualification test practices
- Lead-free Electronics Risk Management

Pb-Free Solder Joint

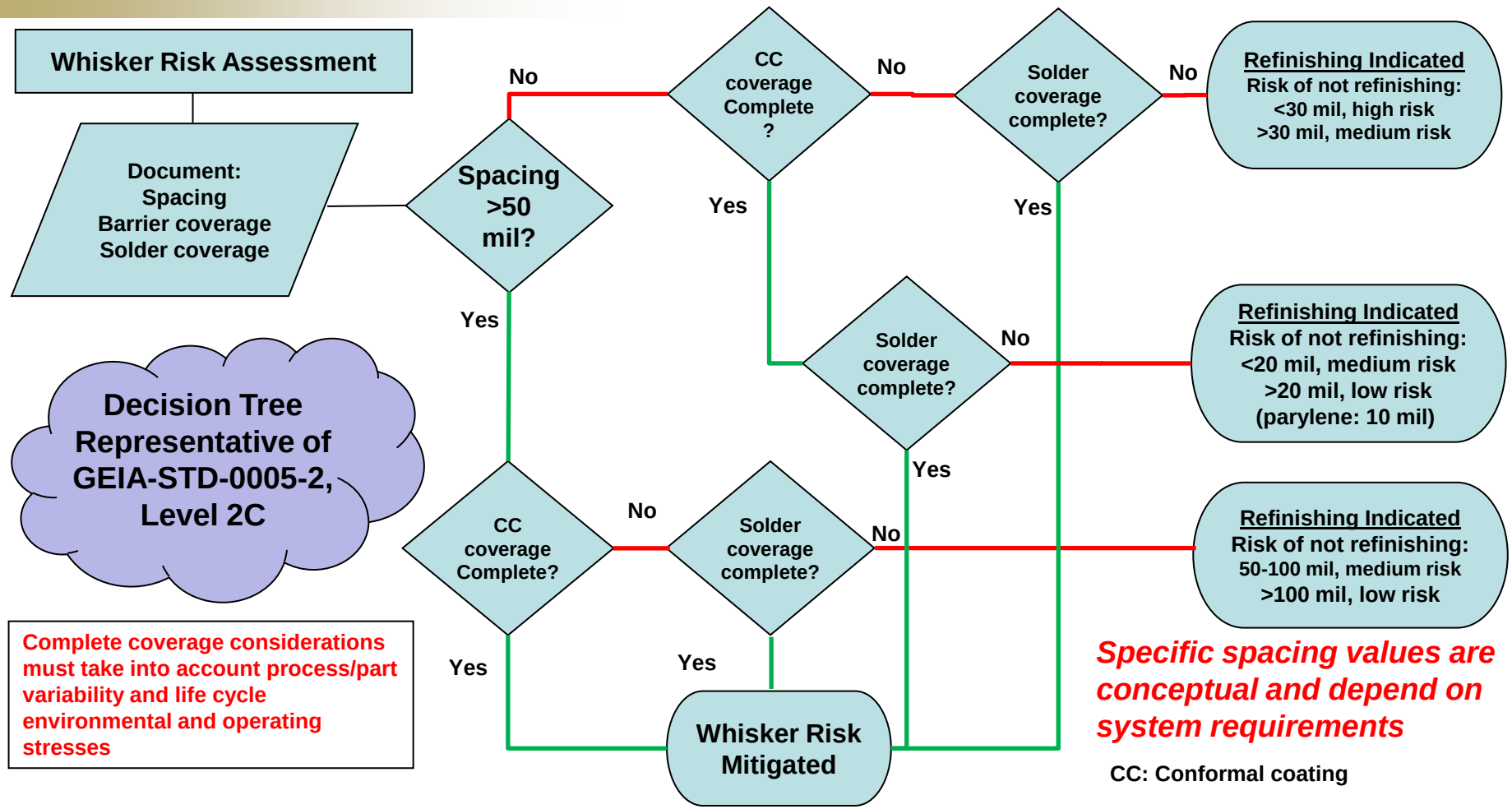
Tin Whisker Risk Management



- Tin whiskers cause system failures
  - Many failures from hardware built during period with limited pure tin use (see nepp.nasa.gov/whisker)
  - Risk is dramatically higher for hardware built today due to much greater prevalence of pure tin
  - Whiskers can grow a long time after delivery, >10 years documented
- Tin whisker risk management critical to assure system integrity and reliability
  - Design considerations: spacing, conformal coating and solder coverage, circuit impact of shorts
  - Supply chain management: requirements flow-down, receiving inspection
- Cannot Qualify pure tin finishes without specific risk mitigation design and process
  - Lack of sufficient knowledge of whisker growth mechanism to predict the extent of growth through analysis or test



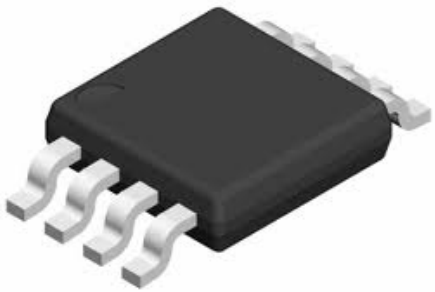
Tin Whisker Risk Management



- **Raytheon Tin Whisker Risk Assessment Algorithm provides insight**
  - **Helps identify applications that require most scrutiny and trade-offs**
  - **Annealing risk mitigation effect estimate may be too large**
  - Available at https://www.reliabilityanalysislab.com/

Tin Whisker Risk Mitigation
Conformal Coating

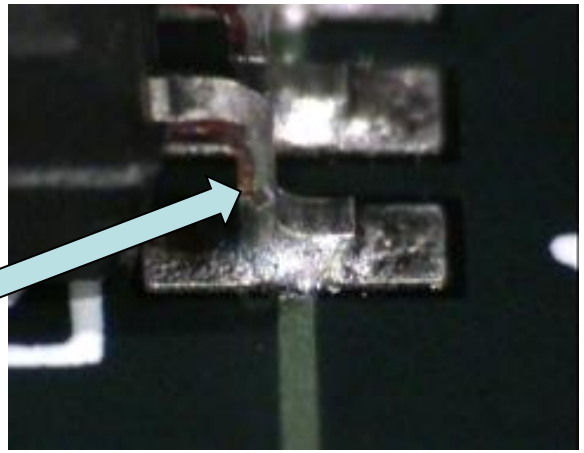
- Conformal coating coverage verification
  - GEIA-STD-0005-2 revision A provides some clarification
  - Process must assure complete coverage of pure tin surfaces
    - IPC-CC-830 does not yet provide completely sufficient requirements for tin whisker risk mitigation
    - Lead shoulders/backsides difficult to coat, unless using parylene
  - Materials/process must provide protection for life of equipment
    - Humidity and temperature cycling primary degrading environments, so reliability verification must include exposure to these requirements representative of the application
- Conformal coating materials and process
  - Cleanliness critical
  - Parylene has proven field durability, truly conformal
  - Urethane generally durable
  - Acrylic has inconsistent field performance
  - Some promising new materials
    - not proven yet for both whisker resistance and durability



Tin Whisker Risk Mitigation
Solder Coverage

- Solder coverage depends on multiple factors
  - Curvilinear length
  - Solder paste (Pb-free often wets less than SnPb)
  - Reflow profile
  - Paste volume, pad size
  - Finish residues

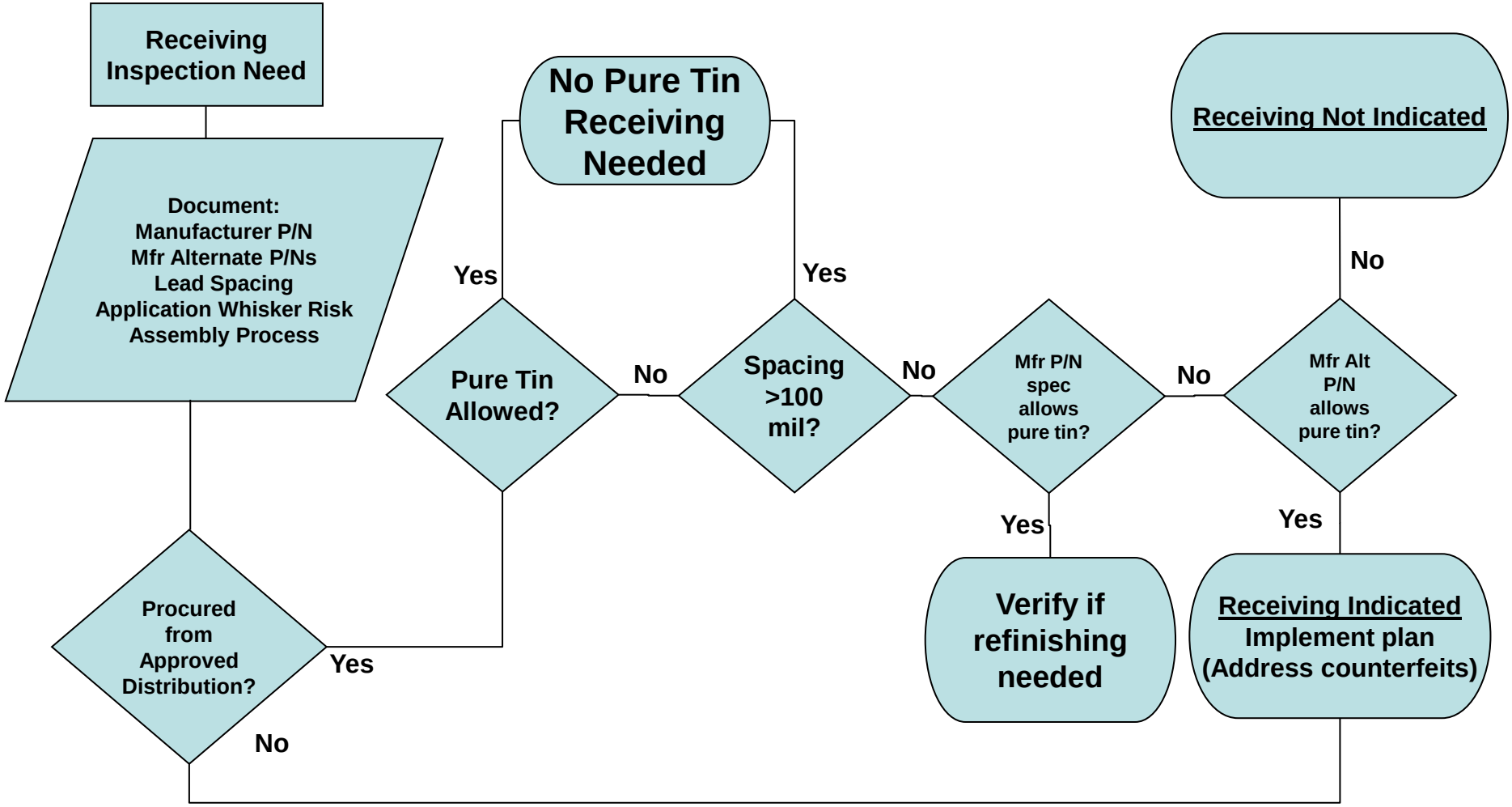
Height of solder coverage



- Coverage process capability needs to be verified for each assembly to address factors that affect coverage
- Raytheon report, Tom Hester, "Tin Whisker Self Mitigation in Surface Mount Components Attached with Leaded (Pb containing) Solder Alloys," European Symposium on Reliability of Electron Devices, Failure Physics and Analysis 2011, provides approach for assessing coverage parameters

Photo from Navy Benchmarking and Best Practices Portal
http://portal.navyb2pcoe.org/kb/phase3/index.php/Lead_Free_Manufacturing:_Inspection

Tin Whisker Risk Management
Notional Inspection Decision Tree

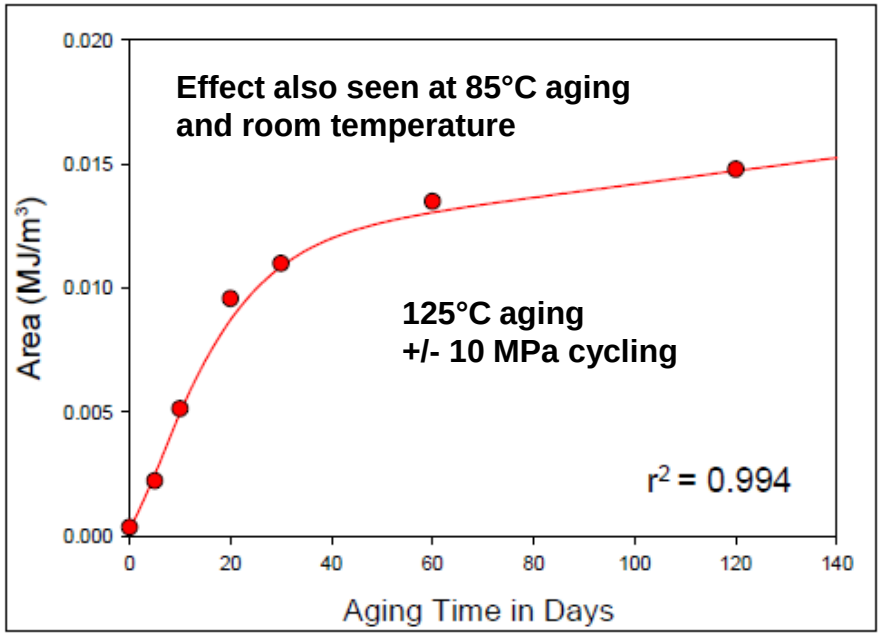


Approved Distribution: Approved by part manufacturer

Lead-free Solder Joint Reliability

- Lead-free solder materials can have significantly different physical properties compared to SnPb solder
  - Melting/freezing points, aging, modulus, creep
    - Need further model refinement
    - New alloys continually introduced
      - Indicative of performance trade-offs for Pb-free solders
  - Structural rules of thumb for SnPb do not apply
  - Application thermo-mechanical stress must be thoroughly understood
    - High and low cycle fatigue, shock, aging
    - Finite element analysis necessary to characterize stress/strain
- Electronics package miniaturization requires increased emphasis on understanding structural properties of solder
  - Even staying with SnPb solder requires increased understanding of application stress-strain
  - Critical to follow part manufacturer's application recommendations
    - Best starting point for pad sizes, vias, etc.
- Finish material effects: Intermetallic compounds, Solderability, Corrosion

Lead-free Solder Behavior Compared to SnPb Solder



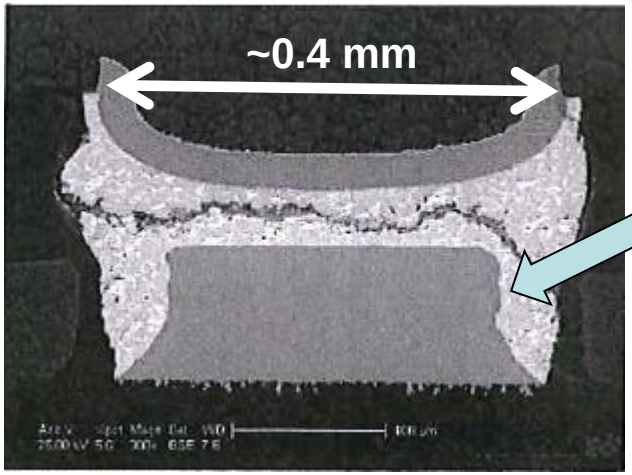
Mustafa, M. et al., Characterization of Hysteresis Loop Evolution in Aged Lead Free Solders, Proceedings of the ASME Pacific Rim Technical Conf & Expo on Packaging, (InterPACK2011), July 2011

Material property differences AND continued joint miniaturization necessitate greater understanding of application stresses for Lead-free solder joints

- Significant creep and strength changes with aging (seen at room temperature and accelerated effect at higher temperatures), much greater than SnPb solder
- Modulus generally higher, particularly for Sn-Ag-Cu (SAC) alloys
- Creep for SAC can be lower than SnPb, but appears to become greater after aging
- Generally, SAC fatigue life greater at low strain ranges, but less at high strain ranges (consistent with aging effect)
- Small changes in alloy composition can have large effects on process requirements (e.g., reflow temp) and durability, generally accompanied by trade-offs between low cycle fatigue life and shock life

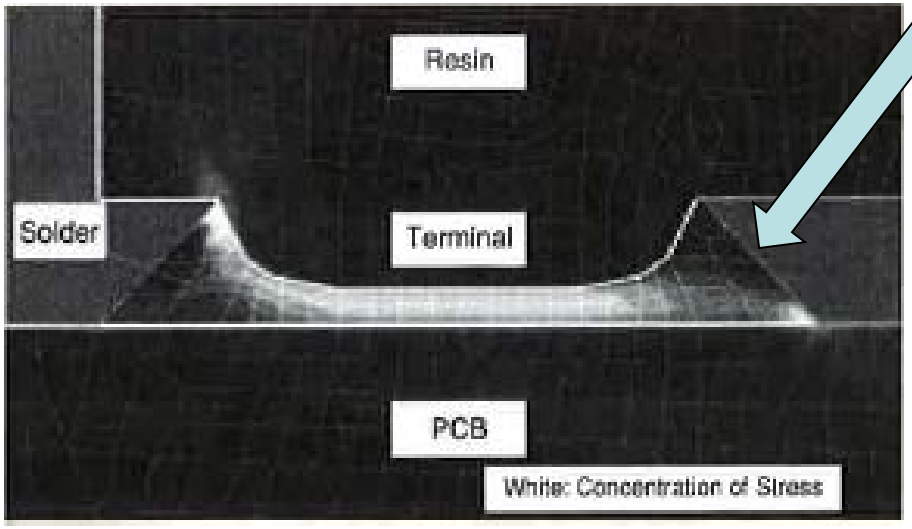
Part Manufacturer Recommendations

Bump chip carrier SnPb solder joint failed with less than half life demonstrated by part manufacturer



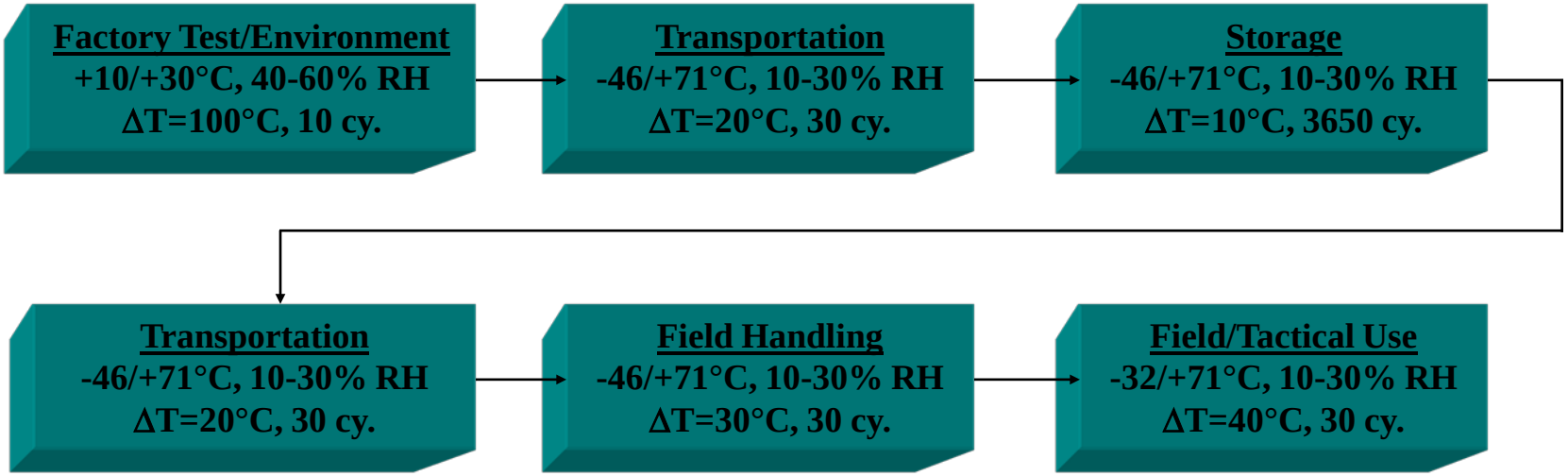
Pad appears over-etched. Joint does not form shape representative of design baseline provided by part manufacturer

Manufacturer recommended joint has larger fillet supported by larger effective pad



Sensitivity of solder joint life to solder joint volume and shape likely greater for Lead-free solders than for SnPb solder in many applications

Qualification Methodology
Life Cycle Environments



- **Determine all environments to be experienced**
- **Understand degradation mechanisms for item**
- **Determine appropriate assembly level for verifying all requirements**
  - ✓ **Example: System level testing cannot likely address solder joint durability and tin whisker risk due to considerations for test acceleration factors and competing failure mechanisms**

System Environmental Testing
MIL-STD-810G

MIL-STD-810G includes no standard temperature cycling test method

Temperature cycling represents major damage mechanism for electronics

The typical system qualification test includes about 20 temperature cycles within the storage temperature limits on a limited sample. This criteria represents a low confidence of solder joints meeting:

~5 years of non-operating diurnal cycling (Coffin-Manson m=2)

~150 operation duty cycles

Most system qualification plans need to better address temperature cycling effects, particularly on electronics

- **Can be assessed by qualification at lower assembly levels**
- **Humidity effects are also generally not sufficiently addressed in most system qualification regimens**
- **Consistent with MIL-STD-810 Life Cycle Environmental Profile concept**

System Qualification Test Approach
Notional Improvement

All hardware sees these environments, so all qualification items should be exposed; significant synergistic effects of these environments with other Qual environments

Humidity

Generally, should be longer than typically used now to reflect most life cycles

Temperature Shock AND cycling

Need to add more temperature cycles to most Qualification plans

Cold Temperature
- Storage
- Operating
- Vibration
- Acceleration
- Shock
- Altitude

Ambient
- Operating
- Vibration
- Shock
- Sand & Dust
- Rain
- Altitude
- Salt Fog
- Exp. Atmosphere

High Temperature
- Storage
- Operating
- Vibration
- Acceleration
- Shock
- Altitude

Adjustments needed in Qualification approach to address current electronics technology with SnPb solder and in future with Pb-free solder

Lower Assembly Qualification Methodology

Aging
Bake at high temp
(may address with longer temp cycle hot dwell)

↓

Humidity
85°C/85%RH

↓

Temperature Cycling
ΔT, <20°C/min, 15 minute dwell

↓

Vibration
Consider system effect at the solder joint level

↓

Mechanical Shock
Handling, application (pyro, launch, etc.)

Applying Life Cycle Considerations to Pb-free Solder Notional Test Sequence

Aging effects must be considered for Pb-free solder due to evidence that materials properties change by several orders of magnitude over time

Temperature range, average temperature, cycling frequency, and dwell time are known to influence solder life (Credible acceleration factors must be applied), IPC-9701 provides guidance

Consider repeated sequences to better represent life cycle profile and evaluate synergistic effects

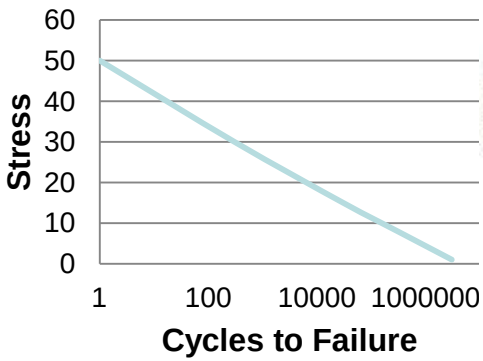
CAUTION: Knowledge level at this time does not allow definition of qualification requirements for Pb-free solder with appropriate confidence for most military applications, particularly those considered safety and performance critical

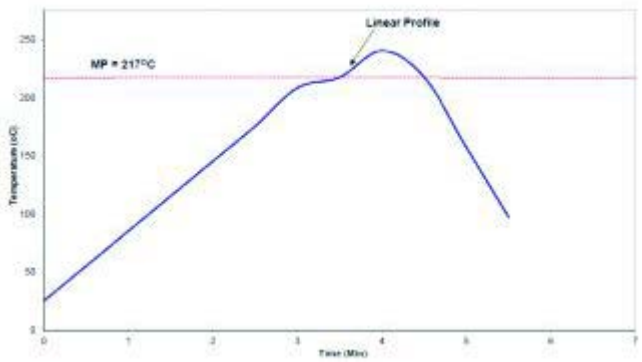
Lead-free Risk Management

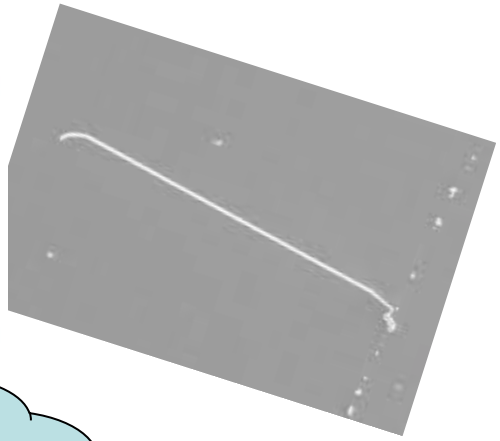
- Contractually require Lead-free Control Plans (LFCP) with requirements that assure compliance for all assembly levels
  - Most efficient to require accordance with GEIA-STD-0005-1
  - Must determine appropriate Tin Whisker risk mitigation level
    - GEIA-STD-0005-2 defines levels and best practices
    - For mission critical equipment, level 2C or 3 applies
      - Level 2C and 3 are only ones that require process to assure not getting pure tin when it is not allowed
      - Possible to tailor 2C to efficiently address classes of components for acceptable mitigation approaches
- Parts Management Plan (PMP), MIL-STD-3018, provides convenient data item (DI-SDMP-81748) vehicle for LFCP
  - Can also address counterfeit parts (SAE AS5553) in PMP
  - *MIL-STD-3018 specifically excludes COTS: MIL-STD-11991 to address COTS gap*
- Commercial off-the-Shelf (COTS) Management critical
  - Continued increase in COTS items in military equipment
  - COTS management must be contractual requirement to effectively address risks (Lead-free, and others)
  - EIA-933 provides framework for COTS management

Pb-free Knowledge Gaps

- **Pb-free Electronics Risk Management Council maintains gap listing**
  - **Tin whisker growth prediction**
  - **Pb-free solder fatigue life**
  - **Pb-free solder design rules for high reliability applications**
  - **Printed Board pad cratering resistant materials/design**
  - **Pb-free assembly process rules for high reliability**
- **Projects with defined tasks and funding requirements identified**







Funding vehicle sought to provide public domain data

IPC Organization
Military Pb-free Focus

Pb-free Electronics Risk Management PERM is now in IPC (Association Connecting Electronics Industries)

PERM Task Teams

- Research Coordination & Guidance
- Pb-free Controls and Processes
- Communications
- Global Advocacy
- Training

Industry, Government, and Academia Participation is Needed!

PERM → Knowledge → SAE INTERNATIONAL

- IPC Members
  - IPC Board of Directors
    - PERM Council
    - EMS Mgt Council
    - PCB Mgt Council
    - Critical Components Council
    - EMT Steering Council
    - OEM Council
    - Solder Products Council
    - SMEMA Mgt Council
    - TAEC Council
    - PCB Suppliers Council

Pb-free Standards
High Performance Systems

TechAmerica GEIA Standards now in SAE INTERNATIONAL

- **PERM provides primary technical input to Pb-free Standards**
- **SAE (formerly TechAmerica) Pb-free Standards**
  - GEIA-STD-0005-1, PERFORMANCE STANDARD FOR AEROSPACE AND HIGH PERFORMANCE ELECTRONIC SYSTEMS CONTAINING LEAD-FREE SOLDER
  - GEIA-STD-0005-2, STANDARD FOR MITIGATING THE EFFECTS OF TIN WHISKERS IN AEROSPACE AND HIGH PERFORMANCE ELECTRONIC SYSTEMS
  - GEIA-STD-0005-3, PERFORMANCE TESTING FOR AEROSPACE AND HIGH PERFORMANCE ELECTRONIC INTERCONNECTS CONTAINING PB-FREE SOLDER AND FINISHES
  - GEIA-HDBK-0005-1, PROGRAM MANAGEMENT/SYSTEMS ENGINEERING GUIDELINES FOR MANAGING THETRANSITION TO LEAD-FREE ELECTRONICS
  - GEIA-HDBK-0005-2, TECHNICAL GUIDELINES FOR AEROSPACE AND HIGH PERFORMANCE ELECTRONICSYSTEMS CONTAINING LEAD-FREE SOLDER AND FINISHES
  - GEIA-HB-0005-3, REWORK/REPAIR HANDBOOK TO ADDRESS THE IMPLICATIONS OF LEAD-FREE ELECTRONICS AND MIXED ASSEMBLIES IN AEROSPACE AND HIGH PERFORMANCE ELECTRONIC SYSTEMS
- **IEC versions available: working to split work share between**
- **TechAmerica Systems, Standards & Technology Council (SSTC) now a part of SAE International**
  - **G-24 Pb-free standards committee established**