Robotic Solder Dip – A Key Technique for Mitigating Reliability Risk Posed by Tin Whiskers

DoD Diminishing Manufacturing Sources
and Material Shortages (DMSMS) Workshop
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Best Manufacturing Practices Center of Excellence

- Department of the Navy Manufacturing Technology Program
  - A National Center of Excellence
  - Approximately 45 People Augmented by More Than 150 Subject Matter Experts

- Heritage
  - Transition from Development to Production Templates (1985)
  - Industry Facility On-site Surveys (1985-Present)
  - Practical Engineering Guides for Managing Risk (1985-Present)
  - Support Military Acquisition Activities (1985-Present)
  - Program Manager's WorkStation (1993-Present)
  - Integrated Digital Environment Using Web Technologies (1996-Present)
  - Winner - Innovations in American Government Award (1998)
  - Winner - Vice President's Hammer Award (2000)

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The Problem

- DoD Acquisition Programs are Increasingly Dependent on Commercial Electronic Parts and Assemblies - COTS
- The Commercial World is Going Lead-Free
- Lead-Free Products and Processes Pose a Host of Risks to Reliability — the Most Insidious is the Susceptibility to Growth of Tin Whiskers
- The Problem is Only Going to Get Worse
- High Reliability Systems Most Vulnerable
- Mitigation Techniques are Urgently Needed
- Robotic Solder Dip Provides One Technique for Many Package Types

Missiles And Related Weapons Particularly Vulnerable

- Unique Vulnerability Factors
  - Components Not in Continuous Operation
  - Long Term Unobserved Dormant Storage
  - Diurnal Thermal Cycling
  - Transportation/Launch Vibe/Shock
  - Non Redundant Circuits/HW

- Other Factors
  - Generally No LRU
  - Generally No BIT to CCA Level
  - High Unit Cost (e.g., Trident, THAAD, SM-3, Nuclear Weapons)
  - Many Lives at Stake

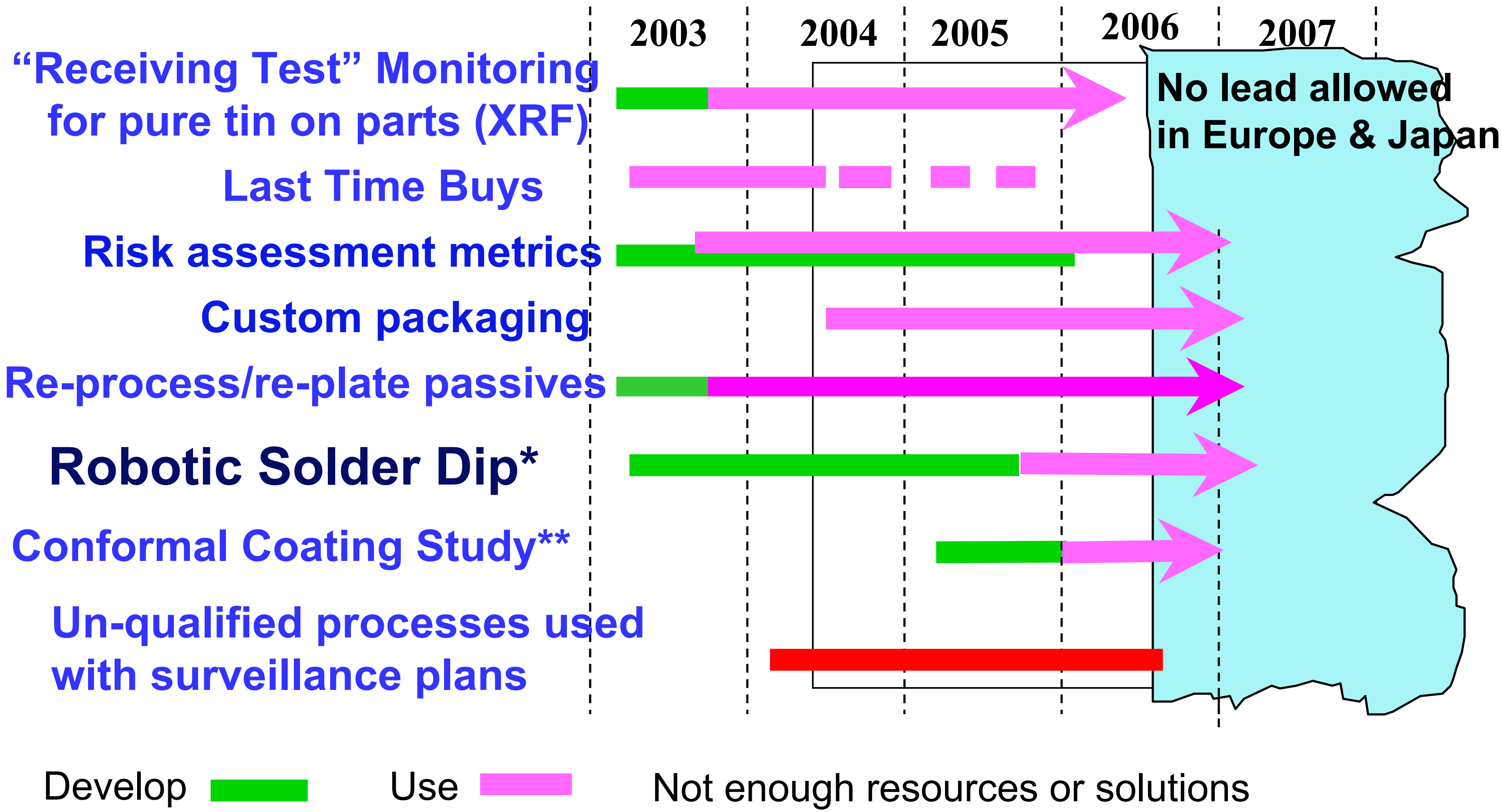
Airworthiness Advisory AA-05-01, Lead-Free Solder

- Issued 9 May 2005 by the Aeronautical Systems Center (AFMC), Wright-Patterson AFB
- Purpose: "…provides information on the trend within the electronics manufacturing community toward the use of lead (Pb)-free solder. To date, no lead-free solders are known to have met the reliability requirements imposed upon military electronics…"
- Scope: "…applies to all USAF aircraft, manned and unmanned, including those operated by the Air National Guard and the USAF Reserve. It also applies to Fielding/ Deployment, Operational Support Activities, Upgrades, and Temporary/Permanent Modifications."
- Guidance/Recommendations: "Until such time that a suitable, reliable, lead-free solder replacement is identified, all program managers should ensure their electronic equipment suppliers continue to provide items which meet all performance, compatibility, and reliability requirements. Failure to do so could adversely affect the reliability of weapons systems…"

Complicating Factors

- Reliability is the Issue, but No Quantifiable Means of Prediction (e.g., Cannot Predict MTTF/MTBF)
- COTS Assemblies (e.g., IMUs)
  - Little Control Over Design/Manufacturing Processes
- Risk Assessment Methodology Still Being Developed and Proven
  - Five Standard Whisker Mitigation Levels
  - Risk Assessment Algorithm
- Most Proposed Partial Mitigation Techniques Still Unproven/Unqualified (e.g., Matte Tin, Manual Hot Solder Dip, Annealing, Nickel Underplate, Conformal Coatings)

Timeline For Tin Whisker Risk Mitigation Tool Development And Implementation

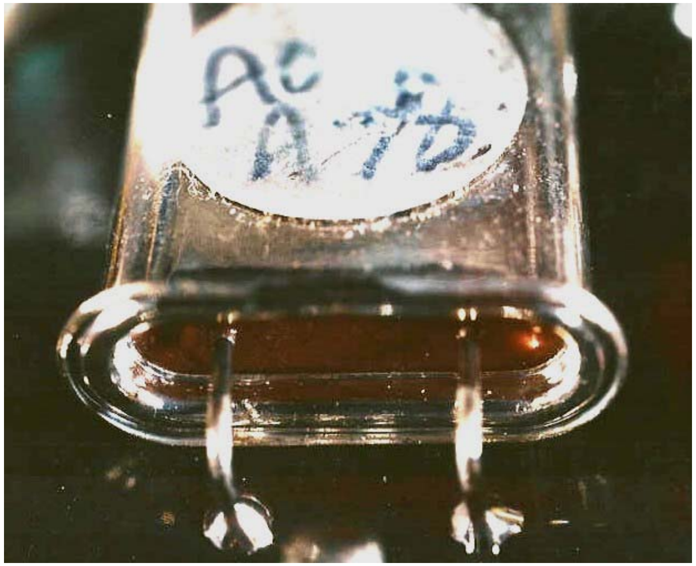


* ONR ManTech Funded

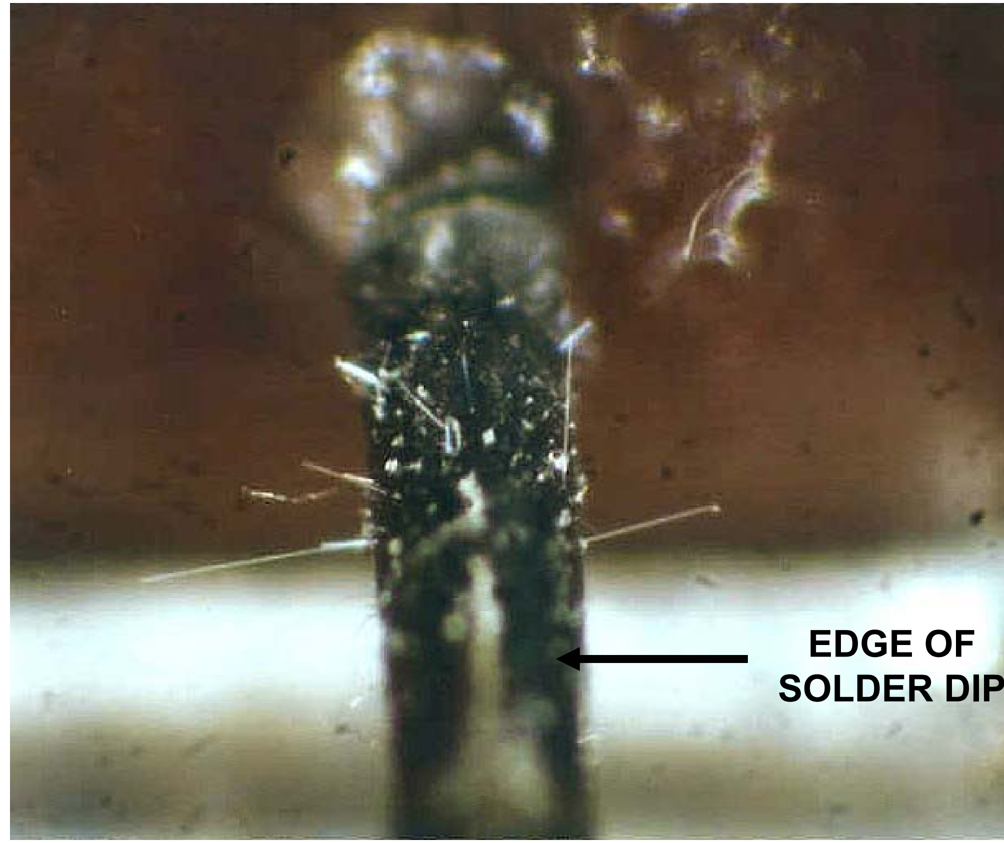
** MDA Funded

Bill Rollins, RMS, 9/05

Tin Whisker Crystal Solder Dip Failure



- Through Hole Crystal
- Lead Diameter 18 mils
- Bright Tin Finish Leads and Case
- Manually 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 Website
http://nepp.nasa.gov/whisker/

The Solder Dip Technical Challenge

- Smaller Circuit Geometries
  - Partial Coverage
  - Solder Bridging
- Plastic Packages
  - Thermal Effects

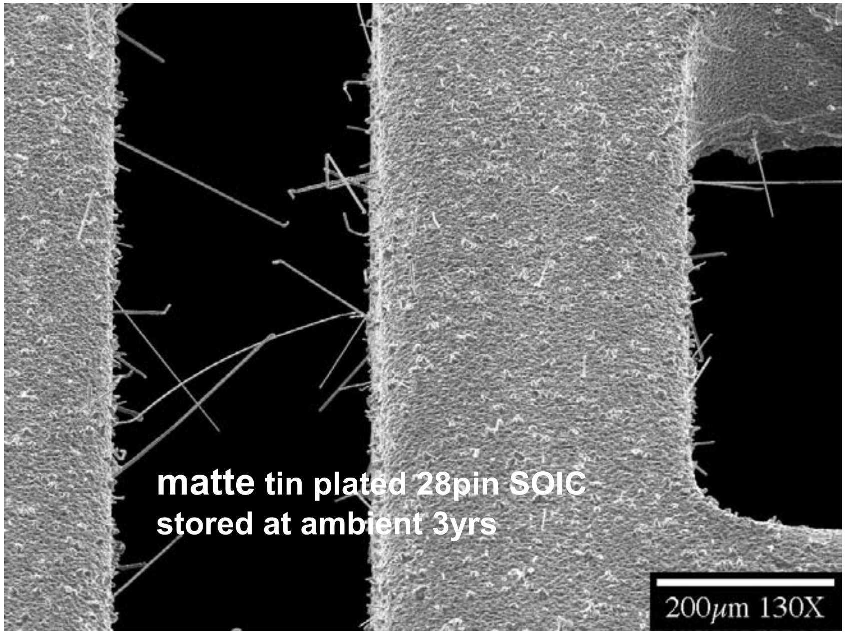
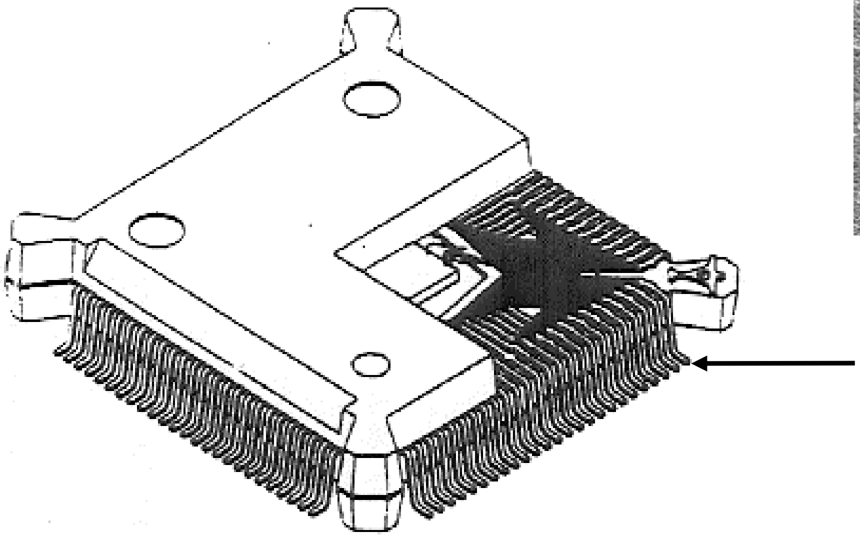


Photo Courtesy Peter Bush, SUNY



Typical PQFP Lead Spacing
9 mil (229 micron)

Typical Quad Flat Pack

One Partial Solution

- Navy ManTech TMTI* Robotic Solder Dip Project Funded by the Office of Naval Research Has Qualified a Process for Use with Many Package Types
- This Presentation Provides an Overview of the Project and Its Results

* Transformational Manufacturing Technology Initiative

TMTI Participants

- Sponsoring Program Offices: Aegis Ballistic Missile Defense (MDA); NAVSEA Program Executive Office for Integrated Warfare Systems (PEO IWS)
- Management: NAVY BMPCOE, Raytheon Tucson, CALCE (University of Maryland)
- Part Selection: Raytheon Tucson, Raytheon Tewksbury, Raytheon Sudbury, CALCE UMD, Corfin Industries, NAVY BMPCOE
- Test and Analysis: Raytheon Tewksbury (Lead), Corfin Industries, CALCE UMD
- Guideline Document: BMPCOE, Raytheon, CALCE

STANDARD Missile-3 (SM-3)

TMTI Project Plan

- Team Participants Mutually Developed Detailed Project Plan
- Team Developed List of Candidate Component Packaging Designs to be Subjected to Solder Replating Process (Favored Missile Use)
- Applicable Participants Ordered Parts
  - 23 Individual Part Numbers (Fit the Overall Budget)
- Conducted Part Functional Tests, plus Acoustic Microscopy
  - Checked for Delaminations (Pre-existing Damage)
  - Control Samples Were Retained at Each Stage of the Test
- Performed Solder Pot Dip Process on Parts
  - Pre-dip Bakeout to J-STD-033A for MSL 5, for <u>All</u> Parts
  - All Dip Processes Robotically Controlled
  - Edge of Component Was Depressed into Flowing Molten Solder at 245 degrees C for 3 Seconds
    - All Pure Tin Was Removed and Replaced with SnPb

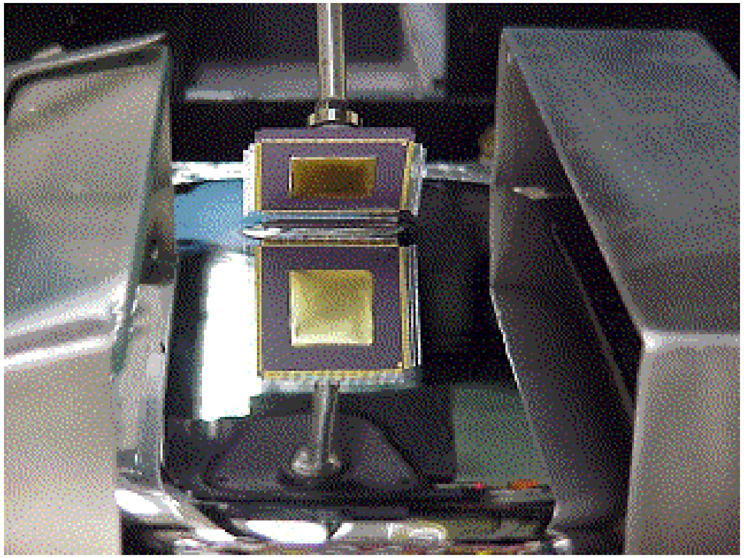
TMTI Project Plan (Cont'd)

- Conducted Post-Dip Functional Tests & Acoustic Microscopy
  - Checked for Functional Failures from Fractures and Delaminations (Damage Caused by Solder Dip)
- Conducted Environmental Life Test
  - Test Designed to Expose the Thermal Shock Failure Modes Normally Associated with the Solder Dip:
    - Immediate Failures: Fractured Wire Bonds
    - Delayed Corrosion Failures from Delaminations
  - Thermal Cycling: 150 cycles, -55C to 125C
  - Temperature-Humidity: 85°C / 85% Relative Humidity, 500 hrs
  - Only Solder Dip Failure Modes Were Relevant to This Test

TMTI Project Plan (Cont'd)

- Conducted Final Functional Tests and Acoustic Microscopy
  - Checked for Failures and Delaminations Exposed by the Environmental Life Test
- Conducted Destructive Physical Analysis of Parts
- Analyzed Results: Were the Observed Failures Caused by the Solder Dip, or Were They From Pre-existing Damage or Damage Induced by Handling or Testing?
  - Only Failures Caused by the Solder Dip Were Relevant
- Producing a Guideline Document for Employing the Process
- BMPCOE and Raytheon to Communicate and Help Implement Guidelines in Acquisition Programs; Initiated a Commercialization Process to Create a Niche Supply Chain for Defense Industry

Robotic Solder Dip Process



Keys for Success:

- Precise Control Over Process Temperature Profile
  - Pre-heat, Solder & Cool Down Temperatures & Dwell
  - N_2 Soldering Environment
    - Eliminated Bridging, Icicles and Dross Buildup on Solder
  - Dynamic Solder Wave
    - Aids in Dross Elimination
    - Facilitates Dipping of Unique Lead Forms and Packages
    - Control of Insertion and Removal Speed & Angle
      - Viscosity and Surface Tension Effects on Adjacent Leads
      - Control of Solder Runoff
      - Control of Solder Wicking onto Lead

TMTI Robotic Solder Dip Project Results

- Root Cause Failure Analysis Indicates that Most of the Microcircuit Failures in this Test Were Due to Small Pre-existing Delaminations Over the Die
  - Substantial Delamination Observed in those Cases After the Life Test, Whether Solder Dip was Performed or Not
  - Extra Tests Performed to Verify This
  - Rule for Solder Dip or Use in Harsh Environment: Always Use Parts that Have No Delaminations Detectable by Acoustic Microscopy

- 22 of 23 Package Styles Tested approved for Robotic Solder Dip
  - Only one package (100 pin plastic Thin Quad Flat Pack) had failures that could not be verified as being independent of the solder dip
    - Not enough information in this test to make that determination

- Note: Not All Available Package Styles Could be Included in this Test, and Those that Were Chosen Had a Reasonable Chance of Success Based on Knowledge from CALCE (UMD)
  - Those Package Styles Chosen Are Widely Used

TMTI Robotic Solder Dip Project Benefits

- TMTI Robotic Solder Dip Project has Qualified a Commercial Process to Completely Replace Pure Tin with Tin-Lead without Damaging the Microcircuits
  - Will be Usable for at Least 80% of Microcircuit Package Styles
  - Will Allow Use of Many Microcircuits made Obsolete (for Users Requiring High Reliability) by being Only Available in Pure Tin
  - Will Allow Many Programs to Avoid Redesigns and Production Interruptions
  - SM-3 will Employ Near Term for a Fairchild IC Going to Pure Tin
  - Guideline Document Soon Available; GEIA Plans to Develop into an Industry Standard
- Some Component Package Styles Do Not Qualify
  - Additional Mitigation Techniques Still Needed
  - Conformal Coatings Offer Most Promise; New, Tougher Ones Need to be Developed

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/

- TMTI Project

  https://www.twg.bmpcoe.org/

- **Article in April 05 DMSMS COE Newsletter - Tin Whiskers: A New DMSMS Issue**

BACKUP

MDA-Sponsored Conformal Coating Study

Just Getting Started – Goals:

- Compile What is Known and What is Unknown about the Ability of Conformal Coating to Contain Tin Whiskers
- Recommend those Coating Materials and Process Parameters Most Likely to Provide Best Risk Mitigation
- Recommend Surveillance Plans and Tests for MDA Systems that Require a Conformal Coating to Mitigate Tin Whisker Risk
  - Would Allow Risk Assessments to be Made Throughout the System's Service Life
- Identify Mission Assurance Risks Associated with Current Lack of Knowledge on Conformal Coating Use for Tin Whisker Mitigation
- Compile Study Data into a Guideline and Widely Distribute

GIDEP Issued by Nuclear Regulatory Commission (NRC)

GIDEP Agency Action Notice AAN-U-05-093 13 Sept 05

- NRC INFORMATION NOTICE 2005-25: INADVERTENT REACTOR TRIP AND PARTIAL SAFETY INJECTION ACTUATION DUE TO TIN WHISKER
- 17 April, 2005 – Millstone Nuclear Generating Station experienced an unexpected safety injection actuation and reactor trip caused by a fault on a solid state protection system (SSPS) circuit card
- Caused "…safety train actuation and reactor trip"
- A single tin whisker created a bridge (short circuit) between a diode and the output trace on a circuit card
- The incident "…demonstrates that a single tin whisker can cause a protective feature to actuate. It is reasonable to assume that the same phenomenon could also prevent a protective system actuation."

List Of 23 Part Types Employed In Robotic Solder Dip Project And The Test Flow Applied To Each

Part Number	Package Type	Functionality	Manufacturer	Test Flow	Electrical anomalies from solder dip
MMBT2222ALT1	SOT 23	Bipolar transistor	ON Semi	MSL Plastic	None
IDT72041 5SOI	SOIC-28	CMOS ASYNCHRONOUS FIFO	INTEGRATED DEV. TECH. INC	MSL Plastic	None
ADG608TRU	TSSOP 16	Analog	Analog Devices	MSL Plastic	None
IDT72V11081	PLASTIC, TQFP-32	3.3 VOLT CMOS SYNCFIFO	INTEGRATED DEV. TECH. INC	MSL Plastic	None
EPM256SRC208-7	208 pinpower quad flat pack	Eraseable PLD	Altera	MSL Plastic	None
EPM7128TI100-10	100 pin plastic thin plastic quad pack	Eraseable PLD	Altera	MSL Plastic	Possible
DAC8412FPC	PLASTIC, LCC-28	QUAD DAC	ADC	MSL Plastic	None
IDT7201LA12J	PLASTIC, LCC-32	AsyncFIFO, 5.0V	IDT	MSL Plastic	None
54ACT00LMQB	54ACT00LMQB	CERAMIC, LCC-20	QUAD 2-INPUT NAND GATE	Hermetic	None
DS26LS32MJ	16 lead ceramic dip	Quad diff. line rec.	NSC	Hermetic	None
LT1058MJ/883B	CERDIP-14	QUAD OP AMP	Linear Tech.	Hermetic	Possible
AM26LS31DC	CERAMIC, DIP-16	Quad Differential Line Driver	TI	Hermetic	None
SN75ALS195J	16 lead ceramic dip	Quad differential line receiver	TI	Hermetic	None
OP490AY	CERDIP-14	QUAD OP AMP	ADC	Hermetic	None
OP284ES	8-lead SOIC	Amplifier, Operational	Analog Devices	NON-MSL Plastic	None
1N4148W-7	SOD-123	Diodes and discrete	Diodes Inc.	NON-MSL Plastic	None
74HC00N	PDIP 14	Logic	Fairchild	NON-MSL Plastic	None
74HC540N	PDIP 20	Logic	Fairchild	NON-MSL Plastic	None
74AC14SC	SOP	Logic	Fairchild	NON-MSL Plastic	None
2N3906	TO-92	Small signal transistor	On Semi	NON-MSL Plastic	Possible
EPM7256AQC208	208 pin plastic quad flat pack	eraseable PLD	Altera	NON-MSL Plastic	None
SI4967DY	SO	Transistor	Siliconix	NON-MSL Plastic	None
FQFP47P06	TO-220 (3-lead)	MosFET	Fairchild	NON-MSL Plastic	None