Tin Whiskers:
A History of Documented
Electrical System Failures
A Briefing Prepared for the Space Shuttle Program Office

Disclaimer:
This history of tin (and other metal) whisker related failures is NOT all-encompassing. These failures represent only those for which we have obtained a public reporting of the event through literature research and other formal communications. We obtained most of this history from refereed literature and failure reporting media (e.g., GIDEP*) that are readily accessible to us.

We have also been briefed about numerous other metal whisker field problems. In many of these cases authorization has not been given for public release.

We are recently discovering other communities (e.g., nuclear power industry, vintage radio collectors and radio HAMS) each with their own means of communicating problems within their community who know of whisker-induced problems. We are including these new communities as we learn of them.

We are confident we have 80% or more of the public literature on metal whiskers. But we still believe this historical summary represents a small fraction of the actual field events caused by metal whiskers.

*GIDEP = Government and Industry Data Exchange Program

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Some Observations Regarding Reporting of Metal Whisker Problems

- In 1940s Western Electric and Bell Labs first taught us of damage caused by tin whisker formation from high tin content surface finishes. Since then, we have observed:
  - 6 decades (and counting) of metallurgical studies trying to understand this phenomenon, and failing to positively prevent whiskering;
  - 6 decades (and counting) of sporadic damage by whiskering;
  - So we conclude: *If you can't live with tin whiskers, then “Don't Use Tin”*

- The ongoing history of failures attributed to metal whiskers is an example of the failure of the educational system to inform students about the risk of metal whiskers to electronic systems
  - Analogy - failure (until recent times) of medical education system to inform doctors to practice good hygiene or else risk infecting patients

"The school of experience is the best teacher... BUT only a fool would choose to learn in the school of experience."
- Ben Franklin

Tin Whiskers on PCB Card Guides

Ref: "Tin Whiskers Found on ATVC S/N 0034", Don McCorvey, March 8, 2006

Tin Plated Card Guides

Tin Whiskers
Tin Whiskers on Components

Optical Microscopy
- Relay Terminals
- Relay Armature
- Connector Pins

Scanning Electron Microscopy
- IC Leads
- Ceramic Capacitor
- Tin-Plated Brass

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What are Tin (or Zinc or Cadmium) Whiskers?

- "Hair-Like" Crystal Structures that May Grow from Surfaces Coated by mostly pure Tin (or Zn or Cd) Finishes
  - LENGTH: Occasionally up to 10 mm or more (Typically < 1 mm or less)
  - DIAMETER: Range 0.006 to 10 um (Typical = 1 um)
- Grow from the Base Not the Tip
- Growth Mechanism(s): UNKNOWN!
- No theories are yet useful for predicting whisker density or length vs. time

Whiskers are NOT Dendrites

Fundamental Research is INCOMPLETE
Metal Whisker Shapes & Features

- Nodules
- Filaments
- Circumferential Rings
- Kinks/Bends

Whisker Failure Modes

**Electrical Short Circuits**
- Permanent (if current < 10's of mA)
- Intermittent (if current > 10's of mA) Whisker Melts

**Debris/Contamination**
- Interfere with Sensitive Optics or MEMS
- Shorts in Areas REMOTE From Whisker Origins
  (Zinc Whiskers on raised flooring are a PRIME Example)

**METAL VAPOR ARC**
- Under Some Electrical/Atmospheric Conditions, Whisker Shorts May Vaporize into Conductive PLASMA of Metal Ions
- Plasma Forms Arc Capable of Carrying HUNDREDS OF AMPS! With Resulting CATASTROPHIC DAMAGE
  ($V > 50$ Volts)
Catastrophic Damage Due to Tin Whisker Induced Metal Vapor Arc (In Air!!!)

G. Davy, "Relay Failure Caused by Tin Whiskers", Northrop Grumman, Technical Article, October 2002
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History of Documented Metal Whisker Failures: 1940s thru 1980s

<table>
<thead>
<tr>
<th>Year</th>
<th>Application</th>
<th>Industry</th>
<th>Failure Cause</th>
<th>Whiskers on?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1946</td>
<td>Military</td>
<td>Military</td>
<td>Cadmium Whiskers</td>
<td>Capacitor plates</td>
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<tr>
<td>1948</td>
<td>Telecom Equipment</td>
<td>Telecom</td>
<td>Cadmium Whiskers</td>
<td>Channel Filters</td>
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<td>1954</td>
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<td>Zinc Whiskers</td>
<td>Channel Filters</td>
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<td>1959</td>
<td>Telecom Equipment</td>
<td>Telecom</td>
<td>Tin Whiskers</td>
<td>Copper Oxide Rectifier, Potentiometer, Protector Mounting (Mechanical), Terminal Strip, Relay Mechanical Elements</td>
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</table>

History from 1959 to 1985 Not Detailed Herein

<table>
<thead>
<tr>
<th>Year</th>
<th>Application</th>
<th>Industry</th>
<th>Failure Cause</th>
<th>Whiskers on?</th>
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<tbody>
<tr>
<td>1986</td>
<td>F16 Radar</td>
<td>Military</td>
<td>Tin Whiskers</td>
<td>Hybrid Package Lid</td>
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<td>1986</td>
<td>Heart Pacemakers</td>
<td>Medical (RECALL)</td>
<td>Tin Whiskers</td>
<td>Crystal Can</td>
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<td>1989</td>
<td>Phoenix Missile</td>
<td>Military</td>
<td>Tin Whiskers</td>
<td>Electronics Enclosure</td>
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<td>1987</td>
<td>Dresden nuclear Power Station</td>
<td>Power</td>
<td>Metal Whiskers</td>
<td>LPRM Detectors</td>
</tr>
<tr>
<td>1997</td>
<td>MIL/Aerospace PWB</td>
<td>MIL/Aerospace</td>
<td>Tin Whiskers</td>
<td>PWB traces</td>
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<tr>
<td>1996</td>
<td>Missile Program &quot;A&quot;</td>
<td>Military</td>
<td>Tin Whiskers</td>
<td>Relays</td>
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### History of Documented Metal Whisker Failures: 1990s

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<th>Year</th>
<th>Application</th>
<th>Industry</th>
<th>Failure Cause</th>
<th>Whiskers on?</th>
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<tr>
<td>1990</td>
<td>Apples Monitors</td>
<td>Medical (RECALL)</td>
<td>Zinc Whiskers</td>
<td>Rotary Switch</td>
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<td>1992</td>
<td>Duane Arnold Nuclear Power Station</td>
<td>Power</td>
<td>Metal Whiskers</td>
<td>LPRM Detectors</td>
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<td>1992</td>
<td>Missile Program &quot;C&quot;</td>
<td>Military</td>
<td>Tin Whiskers</td>
<td>Xlator Package + Standoff</td>
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<tr>
<td>1993</td>
<td>Govt. Electronics</td>
<td>Govt. Systems</td>
<td>Tin Whiskers</td>
<td>Terminal, Diode, Leg</td>
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<tr>
<td>1993</td>
<td>Telecom Equipment</td>
<td>Telecom</td>
<td>Zinc Whiskers</td>
<td>Framework</td>
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<td>1994</td>
<td>Computer Routers</td>
<td>Computers</td>
<td>Zinc Whiskers</td>
<td>Chassis</td>
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<td>1995</td>
<td>MIL Aerospace</td>
<td>MIL Aerospace</td>
<td>Tin Whiskers</td>
<td>Relays</td>
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<td>1995</td>
<td>Aerospace Electronics</td>
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<td>Hybrid Package Lid</td>
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<td>1998</td>
<td>Computer Hardware</td>
<td>Computers</td>
<td>Zinc Whiskers</td>
<td>Chassis</td>
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<td>1998</td>
<td>OBS-I (Side 1)</td>
<td>Space</td>
<td>Tin Whiskers</td>
<td>Relays</td>
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<tr>
<td>1998</td>
<td>Dresden Nuclear Power Station</td>
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<td>LPRM Detectors</td>
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<tr>
<td>1998</td>
<td>GALAXY IV (Side 2)</td>
<td>Space (Complete Loss)</td>
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<td>1998</td>
<td>GALAXY VII (Side 1)</td>
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<td>Tin Whiskers</td>
<td>Relays</td>
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<td>Military Aerospace</td>
<td>Military Aerospace</td>
<td>Tin Whiskers</td>
<td>Plastic Film Capacitor</td>
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<td>1999</td>
<td>FAS-II (Side 1)</td>
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<td>Tin Whiskers</td>
<td>Relays</td>
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<td>1999</td>
<td>Eng Computer Center</td>
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<td>Floor Tiles</td>
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<td>1999</td>
<td>SOLIDARIDAD I (Side 1)</td>
<td>Space</td>
<td>Tin Whiskers</td>
<td>Relays</td>
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<tr>
<td>1999</td>
<td>South Texas Nuclear Plant Power</td>
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<td>Relays</td>
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<td>1999</td>
<td>Telecom Equipment</td>
<td>Telecom</td>
<td>Zinc Whiskers</td>
<td>PSU Housing</td>
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### History of Documented Metal Whisker Failures: 2000s

<table>
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<th>Year</th>
<th>Application</th>
<th>Industry</th>
<th>Failure Cause</th>
<th>Whiskers on?</th>
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<tbody>
<tr>
<td>2000</td>
<td>GALAXY VII (Side 2)</td>
<td>Space (Complete Loss)</td>
<td>Tin Whiskers</td>
<td>Relays</td>
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<tr>
<td>2000</td>
<td>Missile Program &quot;D&quot;</td>
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<td>Tin Whiskers</td>
<td>Terminals</td>
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<td>2005</td>
<td>Power Mast Modules</td>
<td>Industrial</td>
<td>Tin Whiskers</td>
<td>Connectors</td>
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<tr>
<td>2000</td>
<td>SOLIDARIDAD I (Side 2)</td>
<td>Space (Complete Loss)</td>
<td>Tin Whiskers</td>
<td>Relays</td>
</tr>
<tr>
<td>2001</td>
<td>GALAXY BRI (Side 1)</td>
<td>Space</td>
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<td>Relays</td>
</tr>
<tr>
<td>2001</td>
<td>Hi-Rel</td>
<td>Hi-Rel</td>
<td>Tin Whiskers</td>
<td>Ceramic Chip Caps</td>
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<tr>
<td>2001</td>
<td>Nuclear Power Plant</td>
<td>Power</td>
<td>Tin Whiskers</td>
<td>Relays</td>
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<tr>
<td>2001</td>
<td>Space Ground Test Equip</td>
<td>Ground Support</td>
<td>Zinc Whiskers</td>
<td>Bus Rail</td>
</tr>
<tr>
<td>2002</td>
<td>DIRECT 3 (Side 1)</td>
<td>Space</td>
<td>Tin Whiskers</td>
<td>Relays</td>
</tr>
<tr>
<td>2002</td>
<td>Electric Power Plant</td>
<td>Power</td>
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<td>Microcircuit Leads</td>
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<td>2002</td>
<td>GPS Receiver</td>
<td>Aeronautical</td>
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<td>RP Enclosure</td>
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<td>2002</td>
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<td>Mounting Hardware (ends)</td>
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<td>2002</td>
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<td>Military</td>
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<td>2003</td>
<td>Commercial Electronics</td>
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<td>RP Enclosure</td>
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<td>2003</td>
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<td>2003</td>
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<td>Military</td>
<td>Tin Whiskers</td>
<td>Relays</td>
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<td>2003</td>
<td>Telecom Equipment</td>
<td>Telecom</td>
<td>Tin Whiskers</td>
<td>Cat Breaker</td>
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<td>2004</td>
<td>Military</td>
<td>Military</td>
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<td>Waveguide</td>
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<td>Communications</td>
<td>Radio (1990s vintage)</td>
<td>Tin Whiskers</td>
<td>Transistor TO Package</td>
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<td>2005</td>
<td>Mittersona Nuclear Power Plant</td>
<td>Power</td>
<td>Tin Whiskers</td>
<td>Diode (Axial Leads)</td>
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<td>2005</td>
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<td>2006</td>
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<td>Telecom</td>
<td>Tin Whiskers</td>
<td>RP Enclosure</td>
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<td>2006</td>
<td>GALAXY BRI (Side 2)</td>
<td>Space</td>
<td>Tin Whiskers</td>
<td>Relays</td>
</tr>
</tbody>
</table>

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**Numerous Documented Zinc Whisker Events Have Been Excluded From this Chart For Presentation Purposes**
"There is a name for those who suppose that doing the same thing will produce different results. That name is 'Idiot'."

- Albert Einstein

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HS601 Spacecraft Bus:
Failures "Suspected" from Tin Whiskers

- In mid-1998, the Hughes (now Boeing) HS601 satellites known as GALAXY IV, GALAXY VII and DBS-1 experienced on-orbit failures of one side of redundant satellite control processors (SCP)

- In August 1998, Hughes publicly reported the following:
  - "...electrical shorts involving tin-plated relay switches are the most likely cause of the three spacecraft control processor (SCP) failures on in-orbit satellites."
  - "A team of Hughes engineers and outside experts confirmed that all three satellites experienced an electrical short within the SCP, resulting in blown fuses."
  - "The investigators have narrowed down the most probable cause to a tin-plated latching relay that serves as an on/off switch within the SCP. Under certain combined conditions, a tiny, crystalline structure, less than the width of a human hair, can grow and bridge a relay terminal to its case, causing an electrical short."

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HS601 On-Orbit SCP Failures
“Suspected” Due to Tin Whiskers
(Publicly Reported Events Only)

Info Source: http://sat.nd.com/failures/h601.html

<table>
<thead>
<tr>
<th>Satellite Name</th>
<th>Launch Date</th>
<th>Date of SUSPECTED</th>
<th>Time to Failure</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>GALAXY IV</td>
<td>6/24/1997</td>
<td>5/19/1998</td>
<td>4.50</td>
<td>Side 2 Failure, Side 1 Failure non-whisker related</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SATELLITE IS COMPLETE LOSS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12</td>
</tr>
</tbody>
</table>

08/15/1998 — Hughes Issues Press Release About the 3 Previous HS601 Failures from Tin Whiskers

"While our investigation cannot rule out the possibility that another currently operating SCP could fail, the probability of such an event is very low."
— M. Smith, CEO Hughes Electronics

Ex. 1: What have others recommended when encountering whisker infestations?
GE Power Management Service Bulletin for Modular 10 Series Relays (March 2000)
http://www.geindustrial.com/pn/support/docs/dssb01.pdf

- Tin whiskers can occur in pure electroplated tin plating.
- AMP rarely specifies the use of pure tin plating because of the possible whisker growth problem.
- AMP currently specifies (93%-7%) tin-lead alloy whenever possible to retard whisker growth and reduce lead exposure to the environment.
- From our experience the plating stresses in tin cause whiskers to relax over time, and the frequency and magnitude of new whiskers will decrease accordingly.
- We recommend using a nonconductive bristle brush, nylon for example, to agitate and sever the whisker from the contact and use a vacuum or compressed air to remove the whisker from the connector and the relay equipment.
- Although, we believe a one time cleaning to remove the whiskers will be sufficient to solve this problem, an inspection of the connectors six month to one year after the cleaning is recommended.

James Brolius
Quality Engineer
AMP Card Edge
Connector Product Team
Feb. 14, 2000

April 2006
Ex. 2: What have others recommended when encountering whisker infestations?

The Foxboro Company

- The Foxboro Company is recommending that each customer inspect for, and replace, NO152CK & NO147SS relays manufactured by Potter & Brumfield which display manufacturer's date codes between 7707 and 9332, with those replacement relays manufactured by Communications Instruments Inc.

- Inspection for those relays supplied by Potter & Brumfield will require removal of the N-240-LDC-R card from the nest. Visual inspection of the relay package allows easy identification of those relays manufactured by Potter & Brumfield.

- The U.S. Nuclear Regulatory Commission has been informed of this potential defect. The Foxboro Company sincerely regrets any inconvenience this potential defect may cause you and trusts that our actions will completely resolve this matter to your satisfaction.

George Robert Johnson
Director, Corporate Quality Assurance and Product Safety
The Foxboro Company

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Ex. 3: What have others recommended when encountering whisker infestations?


- Westinghouse recommends that utilities conduct periodic inspections for tin whiskers.

- In order to detect the presence of tin whiskers, the inspection should be done with a minimum of 10x magnification and directed light.

- An inspection of a 15% random sample of installed components is recommended to ensure an adequate population is inspected and to minimize the adverse effects of handling and temperature cycling. If any of the randomly selected components have tin whiskers, 100% inspection of the components installed in the system is recommended.

- Upon completion of the inspection, the components should be gently cleaned with a soft bristle, static-free brush and cleaned with either canned air or a static-free vacuum.

- Westinghouse recommends that the inspections be performed periodically at least every 3 to 6 years, depending on the operating unit's refueling cycle.

J. A. Gresham, Manager
Regulatory Compliance and Plant Licensing
Westinghouse Electric Company

April 2005 – Tin Whisker Causing Shutdown Of Millstone Nuclear Power Station

A higher magnification factor will make identifying whisker growth easier. Utilities that have performed inspections... have indicated that both light and the magnification level are critical to observing whiskers since whisker diameters are typically in the range of 1 to 2 microns and are difficult to see under normal conditions.
### Ex. 4: What have others recommended when encountering whisker infestations?


- Inspect the affected installed power supplies to determine if "whiskers" are present on R11 and R13.
- Clean the two potentiometers by using a soft bristle brush to remove any "whiskers" that may be present.
- After cleaning, cover each potentiometer with ½ inch heat shrink around the outside case or lightly coat the external case of the potentiometer with hum-seal coating.

H. A. Sepp, Manager
Regulatory and Licensing Engineering
Westinghouse Electric Company

- 48-Volt power supply trip its output breaker.
- The power supply was replaced and sent to the lab for repair. The power supply operated normally and initially no apparent fault could be found.
- Further investigations noted small metallic "whiskers" on the outside cases of the R11 and R13 variable resistors.
- These variable resistors are coated with tin. The metallic "whiskers" are tin and can spontaneously occur when pure tin is present.
- It is assumed that the "whiskers" were of sufficient length to cause a short between the cases of the two potentiometers.
- When the cases of these two potentiometers are shoted together, the overvoltage setpoint circuit actuates and trips the output breaker. This short circuit vaporizes the small whiskers, thus eliminating the cause of the fault.

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### Ex. 5: What have others recommended when encountering whisker infestations?

Zinc Whisker Infestations in Raised Floor Computer Settings

- Remarks from Zinc Whisker Consultant Regarding Mitigation after Discovering Zinc Whiskers on Raised Flooring:
  - General response is REPLACEMENT of infested floor tiles and careful cleanup of the facility unless you only plan to continue operations in the facility for a short time longer.
  - This activity should be done with air conditioners OFF. Users often say they can't run equipment without air conditioning. "Consultant" smiles and says BINGO... get the equipment offline and fans offline during remediation or suffer the consequences of failures during remediation. You have 2 choices... SCHEDULED OUTAGES vs. UNSCHEDULED OUTAGES. You can control the scheduled ones and plan effectively.
  - "Consultant" has been directly involved in 20 to 30 data center remediation projects during days with major IT systems manufacturer (Company X). Company X would do the project management and hire a cleaning company to do the labor. Claims that when they managed the clean-up project, they only lost a few pieces of equipment after restarting all systems (suspect whiskers inside of cabinets).
  - For their hardware products Company X would NOT RECOMMEND attempting to clean the existing hardware (no disassembly, washing, etc.) as this has potential for MORE harm than good. Instead, clean the data center environment and hope that any whiskers inside will either get blown "out" or get lodged in harmless location.

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NASA Goddard Tin (and Other Metal) Whisker WWW Site
http://nepp.nasa.gov/whisker
Backup Slides

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Electrical Failures Due to Tin Whisker Debris

http://nepp.nasa.gov/whisker/anecdote/2003rf_enclosure/

2003 Anecdote shared by SANMINA-SCI

- We ordered fences and covers for a RF assembly, our customer specified matte tin, and hoped for the best.

- Our customer brought us failed assemblies after working ~ 1 year.

- During FA we found “Whiskers galore! Not from the components, not attached to them, but just laying across everything. The lid is attached over the fences by the customer after receiving the assembly from us. Whiskers fell from the lid all over the place in the enclosure.

- Today I checked 2 year-old lids under the microscope. SCHWARZWALD! (“Black Forest”)

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Zinc Whisker or Tin Whisker?

Striking Similarities

Similarities Suggest Common Growth Mechanism(s) for Tin & Zinc Whiskers
Early Examples of Tin Whiskers on Electrical Components

Tin Whiskers grow INSIDE tin-plated transistor package, causing shorting to internal connections.

Tin Whiskers grow from tin-plated housing. Some whiskers ~1cm long.

AF114 Germanium Transistors
Mfr Date ~1960, Observation Date ~ 2005

Variable Air Capacitor
Mfr Date ~1959, Observation Date ~ 2006

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ZINC Whiskers and Metal Vapor Arcing

- Circa 2001 Metal Vapor Arcing was induced by zinc whiskers on a twin of this bus rail during system level thermal-vac testing at a space contractor facility:
  - Whiskers bridged a 45-mil gap from the bus rail to an aluminum chassis
  - The short ignited a metal vapor arc which lasted 4.7 seconds.
  - Extinction of the arc occurred after interruption of 20-Amp fuse pairs on 11 separate boards within the electronics box.
  - The current was sufficient to melt most of the bus rail, a portion of the aluminum housing under the rail, and some nylon.

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