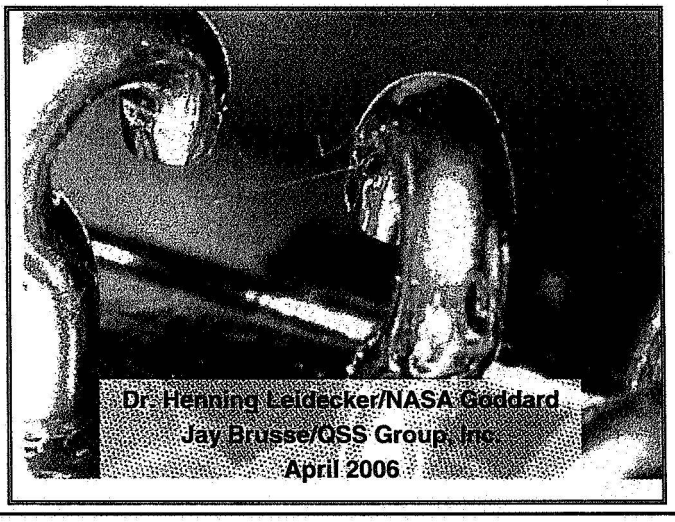
Tin Whiskers:
A History of Documented Electrical System Failures
A Briefing Prepared for the Space Shuttle Program Office



Dr. Henning Leidecker/NASA Goddard
Jay Brusse/QSS Group, Inc.
April 2006

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.

The absence of evidence is NOT evidence of absence

*GIDEP = Government and Industry Data Exchange Program

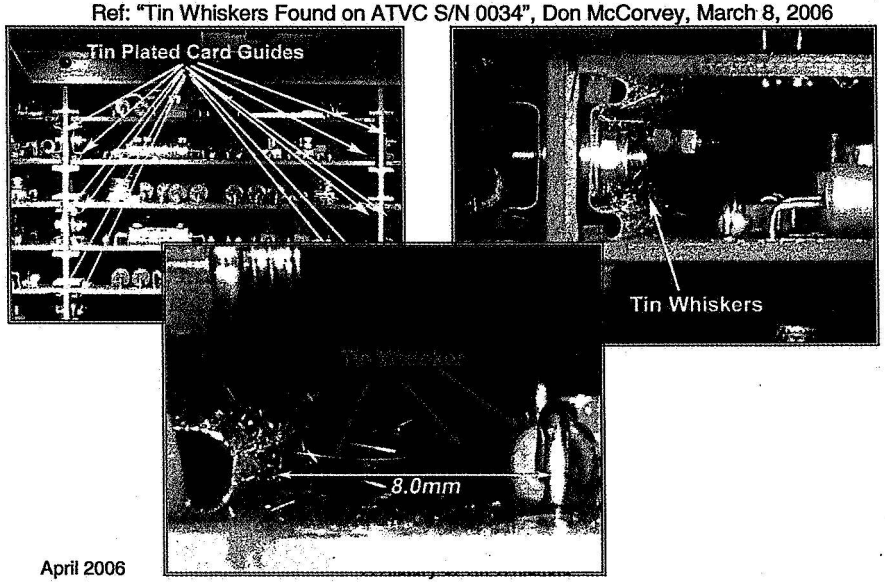
Some Observations Regarding Reporting of Metal Whisker Problems

- 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

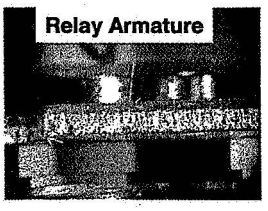
Tin Whiskers on PCB Card Guides

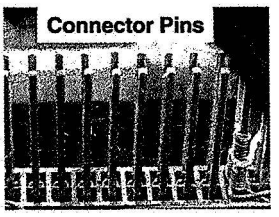
Ref: "Tin Whiskers Found on ATVC S/N 0034", Don McCorvey, March 8, 2006



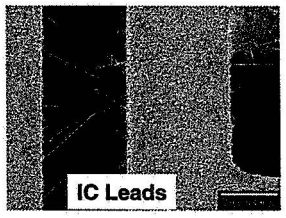
Tin Whiskers on Components

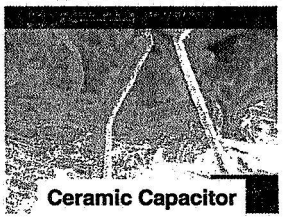
Optical Microscopy

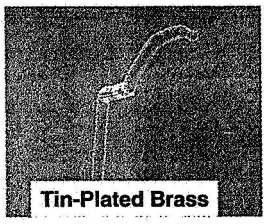




Scanning Electron Microscopy







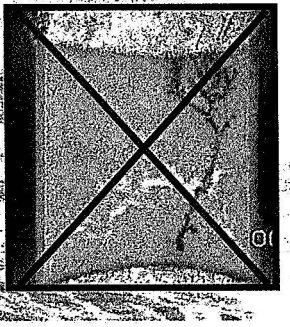
What are Tin (or Zinc or Cadmium) Whiskers?

- "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 < 1mm or less)
- DIAMETER: Range 0.006 to 10 um (Typical ~ 1 um)
- Grow from the Base Not the Tip
- *Growth Mechanism(s): UNKNOWN!*

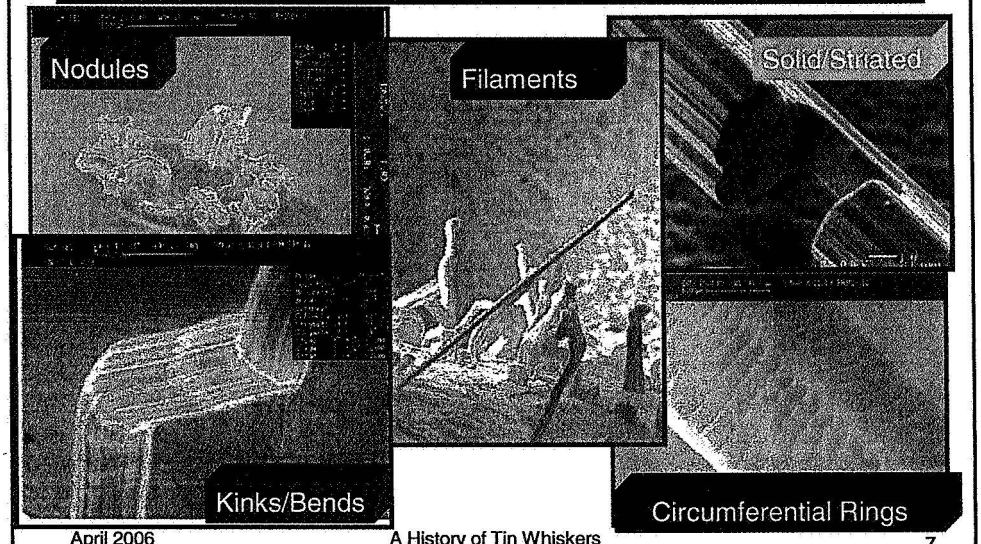
No theories are yet useful for predicting whisker density or length vs. time

Fundamental Research is INCOMPLETE

Whiskers are NOT Dendrites



Metal Whisker Shapes & Features



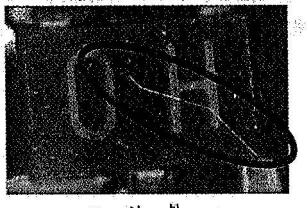
Whisker Failure Modes

Electrical Short Circuits

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

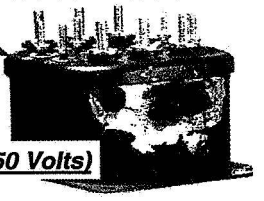
Debris/Contamination

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



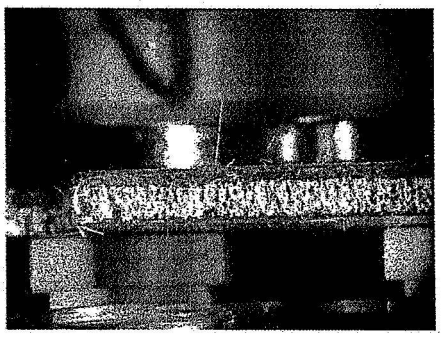
METAL VAPOR ARC

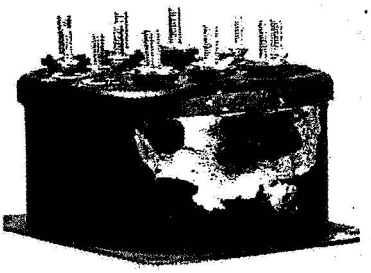
- **Under Some Electrical/Atmospheric Conditions, Whisker Shorts May Vaporize into Conductive PLASMA of Metal Ions**
- **Plasma Forms Arc Capable of Carrying *HUNDREDS OF AMPS! With Resulting CATASTROPHIC DAMAGE***



(V > 50 Volts)

Catastrophic Damage Due to Tin Whisker Induced Metal Vapor Arc *(In Air!!!)*





Is your supplier reliable?
This Electromagnetic Relay Was Purchased To MIL Spec Prohibiting Pure Tin Finish Inside, But IT WAS Pure Tin

G. Davy, "Relay Failure Caused by Tin Whiskers", Northrop Grumman, Technical Article, October 2002
http://nepp.nasa.gov/whisker/reference/tech_papers/davy2002-relay-failure-caused-by-tin-whiskers.pdf

History of Documented Metal Whisker Failures: 1940s thru 1980s

Year**	Application	Industry	Failure Cause	Whiskers on?
1946	Military	Military	Cadmium Whiskers	Capacitor plates
1948	Telecom Equipment	Telecom	Cadmium Whiskers	Channel Filters
1954	Telecom Equipment	Telecom	Zinc Whiskers	Channel Filters
1959	Telecom Equipment	Telecom	Tin Whiskers	-Copper Oxide Rectifier -Potentiometer -Protector Mounting (Mechanical) -Terminal Strip -Relay Mechanical Elements
1959	Telecom Equipment	Telecom	Cadmium Whiskers	Relay Armature Return Spring
1959	Telecom Equipment	Telecom	Cadmium or Zinc Whiskers	-Chassis/Structural Members -Variable Air Capacitor
1959	Telecom Equipment	Telecom	Tin, Zinc or Cadmium Whiskers	Metal Enclosures/Cans
		History from 1959 to 1985 Not Detailed Herein		
1986	F15 Radar	Military	Tin Whiskers	Hybrid Package Lid
1986	Heart Pacemakers	Medical (RECALL)	Tin Whiskers	Crystal Can
1986	Phoenix Missile	Military	Tin Whiskers	Electronics Enclosure
1987	Dresden nuclear Power Station	Power	Metal Whiskers	LPRM Detectors
1987	MIL/Aerospace PWB	MIL/Aerospace	Tin Whiskers	PWB traces
1988	Missile Program "A"	Military	Tin Whiskers	Relays

History of Documented Metal Whisker Failures: 1990s

Year**	Application	Industry	Failure Cause	Whiskers on?
1990	Apnea Monitors	Medical (RECALL)	Zinc Whiskers	Rotary Switch
1990	Duane Arnold Nuclear Power Station	Power	Metal Whiskers	LPRM Detectors
1992	Missile Program "C"	Military	Tin Whiskers	Xsistor Package +Standoff
1993	Govt. Electronics	Govt. Systems	Tin Whiskers	Transistor, Diode, Lug
1995	Telecom Equipment	Telecom	Zinc Whiskers	Framework
1996	Computer Routers	Computers	Zinc Whiskers	Chassis
1996	MIL Aerospace	MIL Aerospace	Tin Whiskers	Relays
1998	Aerospace Electronics	Space	Tin Whiskers	Hybrid Package Lid
1998	Computer Hardware	Computers	Zinc Whiskers	Chassis
1998	DBS-1 (Side 1)	Space	Tin Whiskers	Relays
1998	Dresden nuclear Power Station	Power	Metal Whiskers	LPRM Detectors
1998	GALAXY IV (Side 2)	Space (Complete Loss)	Tin Whiskers	Relays
1998	GALAXY VII (Side 1)	Space	Tin Whiskers	Relays
1998	Military Aerospace	Military Aerospace	Tin Whiskers	Plastic Film Capacitor
1998	PAS-4 (Side 1)	Space	Tin Whiskers	Relays
1999	Eng Computer Center	Architectural	Zinc Whiskers	Floor Tiles
1999	SOLIDARIDAD I (Side 1)	Space	Tin Whiskers	Relays
1999	South Texas Nuclear Plant	Power	Tin Whiskers	Relays
199X	Telecom Equipment	Telecom	Zinc Whiskers	PSU Housing

History of Documented Metal Whisker Failures: 2000s

Year**	Application	Industry	Failure Cause	Whiskers on?
2000	GALAXY VII (Side 2)	Space (Complete Loss)	Tin Whiskers	Relays
2000	Missile Program "D"	Military	Tin Whiskers	Terminals
2000	Power Mgmt Modules	Industrial	Tin Whiskers	Connectors
2000	SOLIDARIDAD I (Side 2)	Space (Complete Loss)	Tin Whiskers	Relays
2001	GALAXY IIIR (Side 1)	Space	Tin Whiskers	Relays
2001	Hi-Rel	Hi-Rel	Tin Whiskers	Ceramic Chip Caps
2001	Nuclear Power Plant	Power	Tin Whiskers	Relays
2001	Space Ground Test Eqpt	Ground Support	Zinc Whiskers	Bus Rail
2002	DirecTV 3 (Side 1)	Space	Tin Whiskers	Relays
2002	Electric Power Plant	Power	Tin Whiskers	Microcircuit Leads
2002	GPS Receiver	Aeronautical	Tin Whiskers	RF Enclosure
2002	MIL Aerospace	MIL Aerospace	Tin Whiskers	Mounting Hardware (nuts)
2002	Military Aircraft	Military	Tin Whiskers	Relays
2002	Nuclear Power Plant	Power	Tin Whiskers	Potentiometer
2003	Commercial Electronics	Telecom	Tin Whiskers	RF Enclosure
2003	Missile Program "E"	Military	Tin Whiskers	Connectors
2003	Missile Program "F"	Military	Tin Whiskers	Relays
2003	Telecom Equipment	Telecom	Tin Whiskers	Ckt Breaker
2004	Military	Military	Tin Whiskers	Waveguide
2005	Communications	Radio (1960s vintage)	Tin Whiskers	Transitor TO Package
2005	Millstone Nuclear Power Plant	Power	Tin Whiskers	Diode (Axial Leads)
2005	OPTUS B1	Space	Tin Whiskers	Relays
2005	Telecom Equipment	Telecom	Tin Whiskers	RF Enclosure
2006	GALAXY IIIR (Side 2)	Space	Tin Whiskers	Relays

** 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

HS601 Spacecraft Bus: Failures "Suspected" from Tin Whiskers

Source: Hughes Press Release 8/11/98
http://www.boeing.com/defense-space/space/bss/hsc_pressreleases/98_08_11_601ok.html

- 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."*

HS601 On-Orbit SCP Failures "Suspected" Due to Tin Whiskers

(Publicly Reported Events Only)

Info Source: http://sat-nd.com/failures/hs601.html

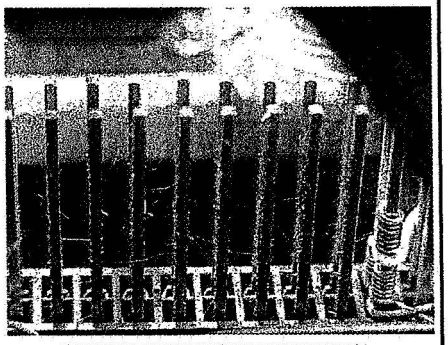
Satellite Name	Launch Date	Date of SUSPECTED Whisker Failure	Time to Failure from Launch Date (YEARS)	Comment	Contracted Life (Years)
GALAXY IV (PanAmSat)	6/24/1993	5/19/1998	4.90	Side 2 Failure. Side 1 failure non-whisker related SATELLITE IS COMPLETE LOSS	12
GALAXY VII (PanAmSat)	10/27/1992	6/13/1998	5.63	Side 1 Failure	12
DBS-1 (DirecTV)	12/17/1993	7/4/1998	4.55	Side 1 Failure	12
08/11/1998 -- 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 both SCPs failing on one in-orbit HS 601 satellite is very low." -- M. Smith, CEO Hughes Electronics*					
PAS-4 (PanAMSat)	8/3/1995	10/1/1998	3.16	Side 1 Failure	15
Solidaridad I (SatMex)	11/19/1993	4/28/1999	5.44	Side 1 Failure	14
Solidaridad I (SatMex)	11/19/1993	8/27/2000	6.77	Side 2 Failure. SATELLITE IS COMPLETE LOSS	14
GALAXY VII (PanAmSat)	10/27/1992	11/22/2000	7.01	Side 2 Failure. SATELLITE IS COMPLETE LOSS	12
GALAXY IIIR (PanAmSat)	12/15/1995	4/21/2001	5.35	Side 1 Failure	8
DirecTV 3 (DirecTV)	6/9/1995	5/4/2002	6.90	Side 1 Failure	12
OPTUS B1	8/13/1992	5/21/2005	12.77	Side 1 Failure	10
GALAXY IIIR (PanAmSat)	12/15/1995	1/15/2006	13.42	Side 2 Failure. SATELLITE IS COMPLETE LOSS	8
		Min	3.16		
		Avg	6.90		
		Max	13.42		
		Std. Dev	3.27		

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/pm/support/dls/dlssb01.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 that cause whiskers will relieve over time, and the frequency and magnitude of new whiskers will decrease accordingly.
- ***We recommend using a nonconductive bristled 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 Brosius
Quality Engineer
AMP Card Edge
Connector Product Team
Feb. 14, 2000



Tin-Plated Connector Pins Displaying Tin Whisker Growths

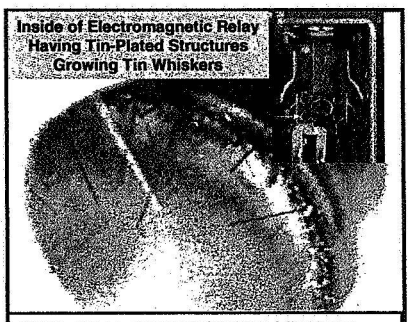
Ex. 2: What have others recommended when encountering whisker infestations?

The Foxboro Company

http://www.nrc.gov/reading-rm/doc-collections/event-status/part21/1999/1999352.html
http://nepp.nasa.gov/whisker/reference/tech_papers/stevens2001-relay-failures-induced-by-tin-whiskers.pdf

- ***The Foxboro Company is recommending that each customer inspect for, and replace, N0152CK & C0147SS relays manufactured by Potter & Brumfield which display manufacturer's date codes between 7707 and 9352, with those replacement relays manufactured by Communications Instruments Inc.***
- ***Inspection for those relays supplied by Potter & Brumfield will require removal of the N-2A0-L2C-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



Inside of Electromagnetic Relay Having Tin-Plated Structures Growing Tin Whiskers

"Three relays were reported to have failed by an overseas electric power company. The customer indicated that energized relays inadvertently closed without the proper control signals. Such condition contributed to a false contact closure condition, which in turn produced unnecessary alarm protection signals initiating a plant shutdown."
- C. Stevens/ Foxboro Company

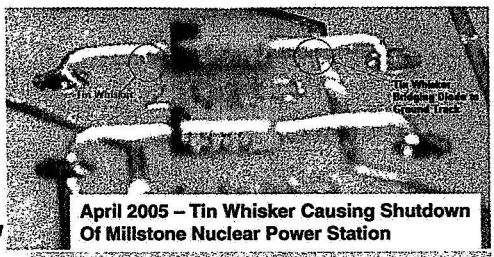
Ex. 3: What have others recommended when encountering whisker infestations?

Westinghouse Electric Company Technical Service Bulletin TB-05-4 (06/08/2005)
http://nepp.nasa.gov/whisker/reference/tech_papers/2005-westinghouse-tb05004.pdf

- Westinghouse recommends that utilities conduct periodic inspections for tin whiskers.
- In order to detect the presence of tin whiskers, the ***inspections 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 affects 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 5 to 6 years, depending on the operating unit's refueling cycle.***

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

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.*



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

Tin-Plated Diode Terminals Displaying Tin Whisker Growths Which Short From Terminal to Exposed Circuit Trace
Photo Credit: Dominion – Millstone Power Station

Ex. 4: What have others recommended when encountering whisker infestations?

Westinghouse Electric Company Technical Service Bulletin TB-02-5 (07/12/2002)
http://nepp.nasa.gov/whisker/reference/tech_papers/2002-westinghouse-tb02005.pdf

- ***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 ¾ inch heat shrink around the outside case or lightly coat the external case of the potentiometer with humi-seal coating.***

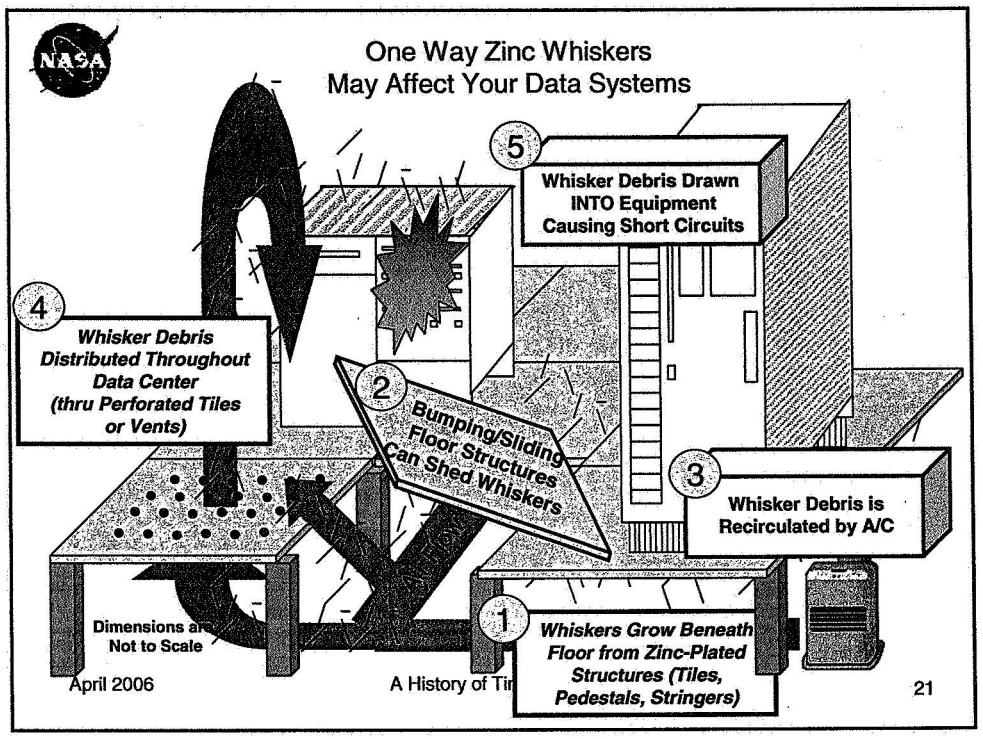
H. A. Sepp, Manager
Regulatory and Licensing Engineering
Westinghouse Electric Company

- 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 shorted 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.

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... SCHEDULE 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 info 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.


One Way Zinc Whiskers
May Affect Your Data Systems
5
Whisker Debris Drawn INTO Equipment Causing Short Circuits
4
Whisker Debris Distributed Throughout Data Center (thru Perforated Tiles or Vents)
2
Bumping/Sliding Floor Structures Can Shed Whiskers
3
Whisker Debris is Recirculated by A/C
1
Whiskers Grow Beneath Floor from Zinc-Plated Structures (Tiles, Pedestals, Stringers)
Dimensions are Not to Scale
April 2006
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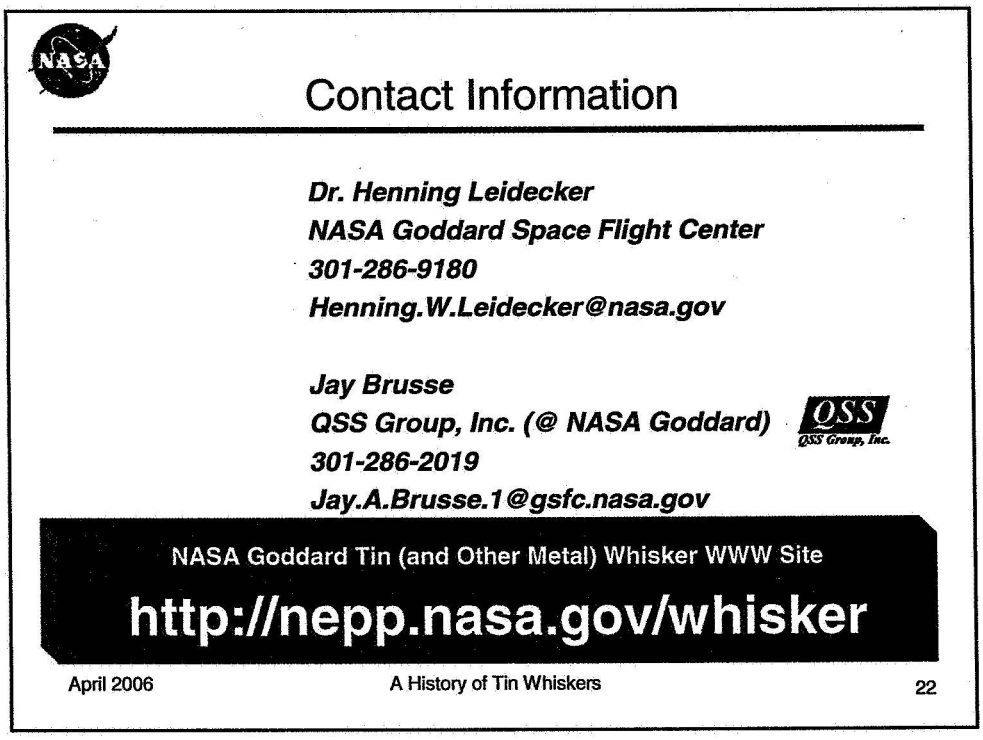
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QSS
QSS Group, Inc.
NASA Goddard Tin (and Other Metal) Whisker WWW Site
http://nepp.nasa.gov/whisker
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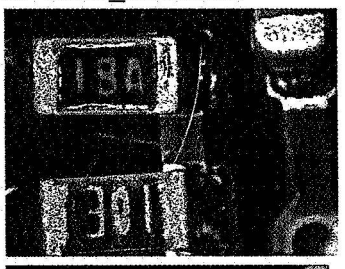
Backup Slides

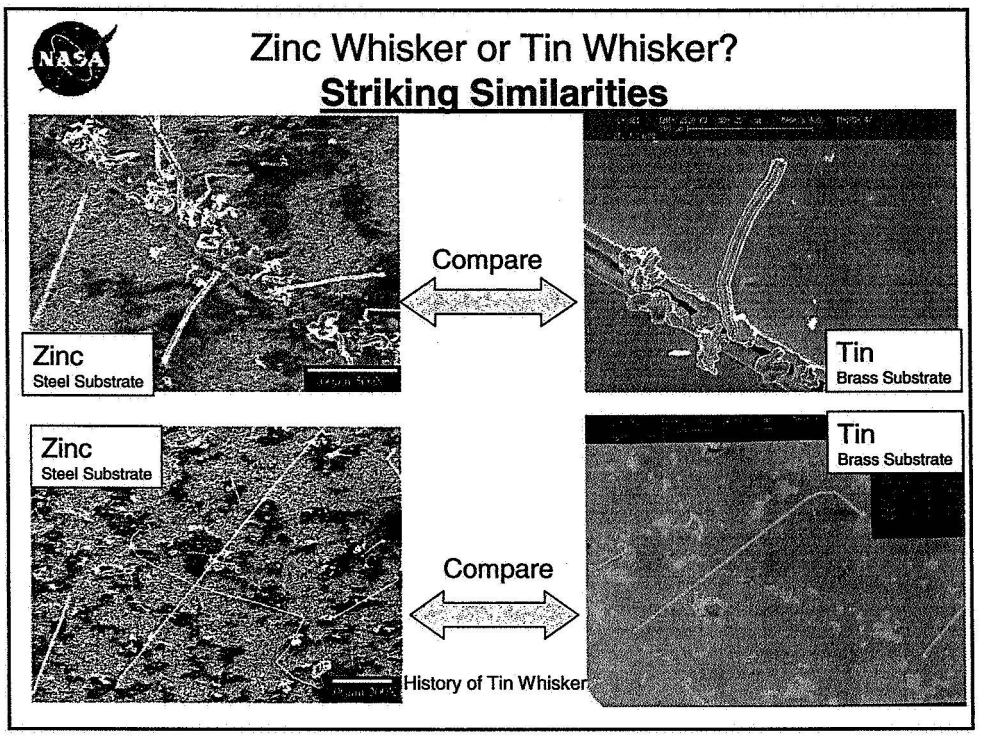
Electrical Failures Due to Tin Whisker Debris

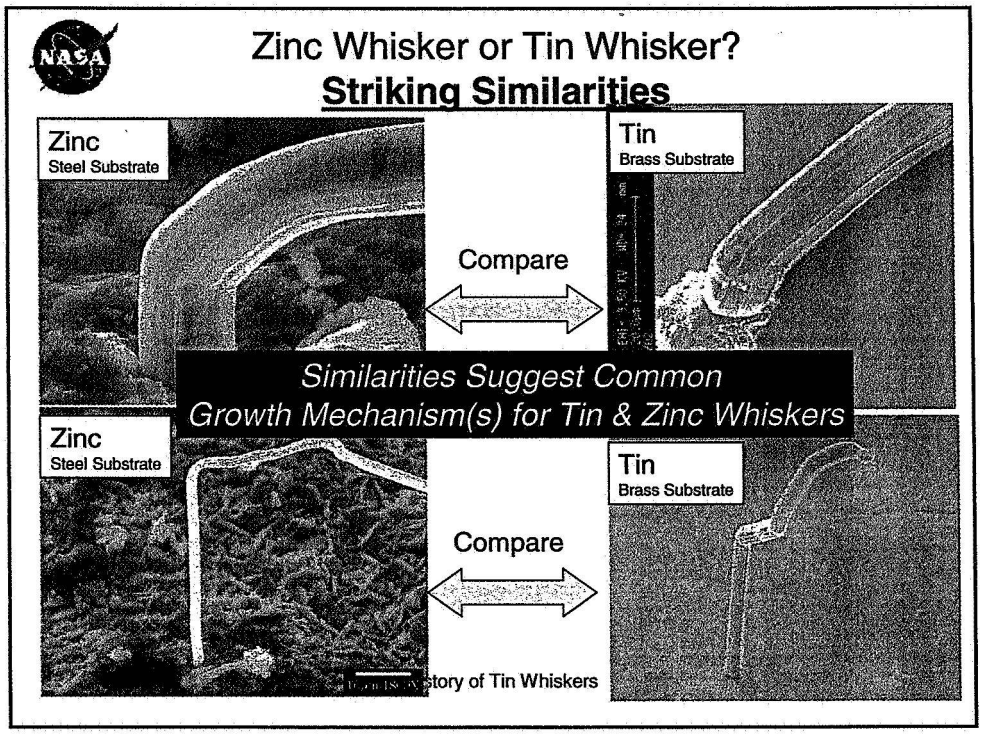
http://nepp.nasa.gov/whisker/anecdote/2003rf_enclosure/

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")

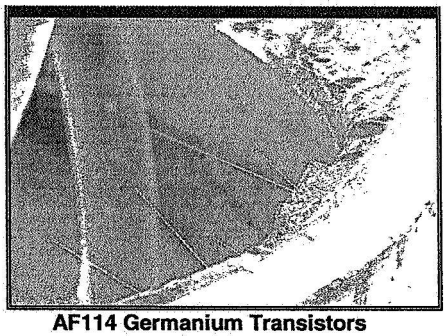



Zinc Whisker or Tin Whisker?
Striking Similarities
Zinc
Steel Substrate
Compare
Tin
Brass Substrate
Zinc
Steel Substrate
Compare
Tin
Brass Substrate
History of Tin Whisker


Zinc Whisker or Tin Whisker?
Striking Similarities
Zinc
Steel Substrate
Tin
Brass Substrate
Compare
Similarities Suggest Common
Growth Mechanism(s) for Tin & Zinc Whiskers
Zinc
Steel Substrate
Tin
Brass Substrate
Compare
tory of Tin Whiskers

Early Examples of Tin Whiskers on Electrical Components

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



AF114 Germanium Transistors
Mfr Date ~1960. Observation Date – 2005

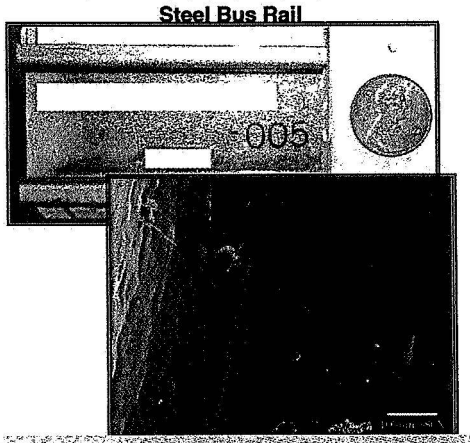
Tin Whiskers grow from tin-plated housing. Some whiskers ~1cm long.

Variable Air Capacitor
Mfr Date ~1959. Observation Date - 2006

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.**

Zinc-Plated Yellow Chromate Steel Bus Rail



Don't assume "color" of the metal finish is a sufficient indicator of whiskering potential.