Metal Whiskering:
Tin, Zinc, and Cadmium

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http://nepp.nasa.gov/whisker/
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History --- first years

- 1946: H.Cobb notes that air capacitors used in military equipment had repeated failed because cadmium plating grew whiskers that shorted the plates. This happened about 1942 -- 1943.
- 1952: Since Cd resulted in shorting, Sn and Zn were used instead. But then K.G.Compton, A.Mendizza, and S.M.Arnold (Bell Labs) reported shorting caused by whiskers from these coatings too.
- 1956: review paper by S.M.Arnold, documenting that many materials, but especially Sn, Zn, and Cd, grow whiskers that can cause shorting.

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History --- fast forward!

- Hundreds of cases of substantial damages caused by shorting from whiskers from coatings of Sn, Zn, or Cd are now known.
- "Tin Whiskers: A History of Documented Electrical System Failures", H. Leidecker, J. Brusse, April 2006 (GSFC “whisker” web site).
- Sn, Zn, and Cd coatings are still being used.
- There is a strong switch to PURE Tin in progress: this has already increased the rate of shorting.

Typical Examples: Spring 2006

- A persistent failure in a NAVY weapon system was confirmed as caused by zinc whiskers.
- Cadmium whiskers observed in the kind of electrical switch being planned for flight to HST, and in a test feedthru.
- Zinc whiskers shorted out about 75% of the computer equipment in a particular work center in the summer of 2005: the root cause was only identified in Feb 2006.
- The Shuttle Transportation System has whiskers: some 100 to 300 million whiskers were in OV-105's boxes.
- Reactions: Denial, Anger, Bargaining, Depression, and finally, Acceptance --- these are the "The five stages of whisker grief".

"The Five Stages of Metal Whisker Grief"

By Henning Leidecker

Adapted from Elisabeth Kubler-Ross in her book "On Death and Dying", Macmillan Publishing Company, 1969

Denial

"Metal whiskers?!? We ain't got no stinkin' whiskers! I don't even think metal whiskers exist! I KNOW we don't have any!"

Anger

"You say we got whiskers, I rip your $%# @ lungs out! Who put them there --- I'll murderize him! I'll tear him into pieces so small, they'll fit under one of those *^ &$# % whiskers!"

Bargaining

"We have metal whiskers? But they are so small. And you have only seen a few of them. How could a few small things possibly be a problem to our power supplies and equipment? These few whiskers should be easy to clean up."

Depression

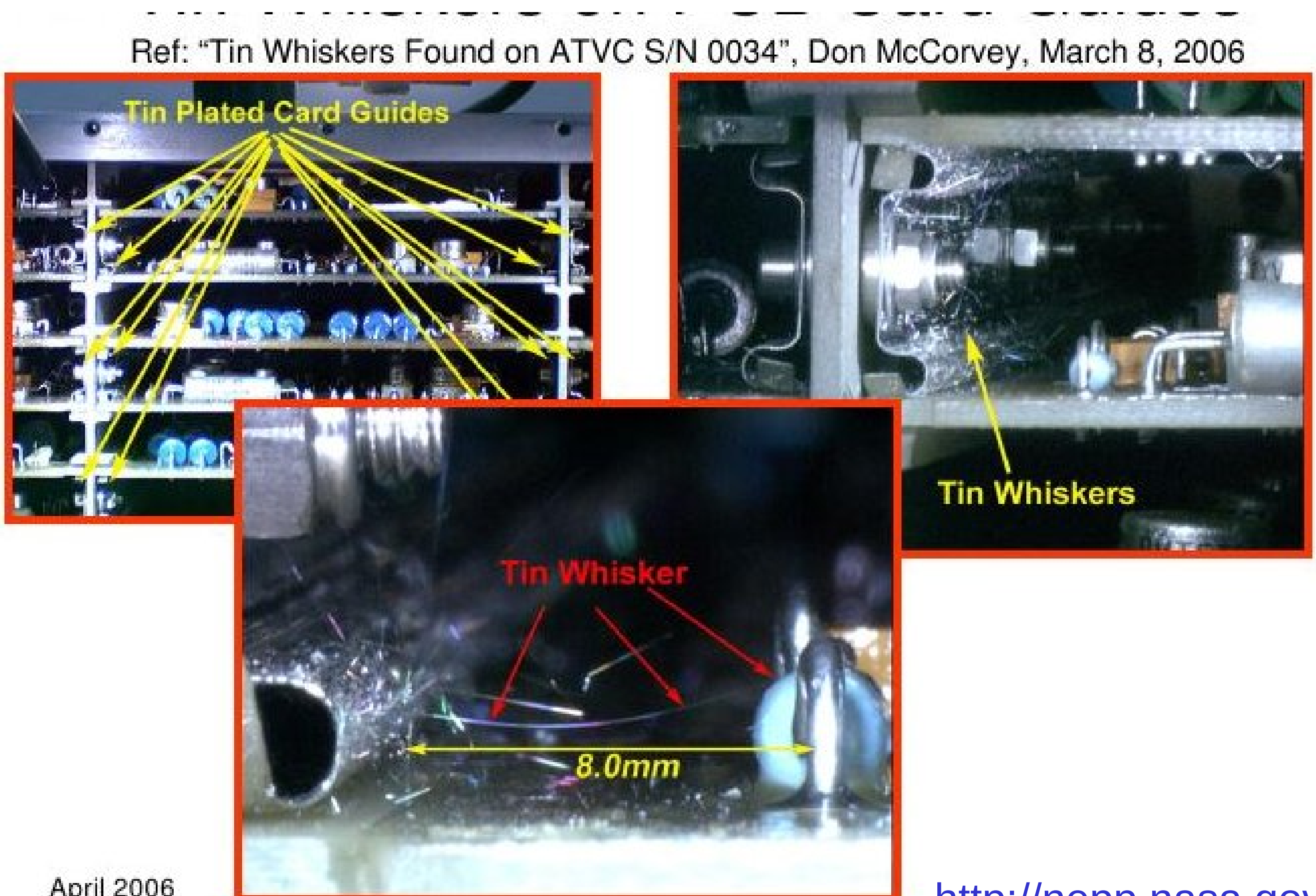
"Dang. Doomed. Close the shop --- we are out of business. Of all the miserable bit joints in all the world, metal whiskers had to come into mine... I'm retiring from here... Going to open a 'Squat & Gobble' on the Keys. "

Acceptance

"Metal whiskers. How about that? Who knew? Well, clean what you can. Put in the particle filters, and schedule periodic checks of what the debris collectors find. Ensure that all the warrantees and service plans are up to date. On with life."

March 2006

- The **Manned Space Program** (KSC, JSC, MSFC) noted a **tin-whisker infestation** had been found in **critical electronics boxes in OV-105**: Endeavor (made in 1988--89, some ten years after the others and after OSHA had made disposal of leaded plating solutions more expensive).



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Whisker Infestation on Shuttle

- OV-105 constructed in 1987 – 89, roughly a decade after OV-100 – 104. OSHA regulations newly made disposal of lead-containing plating solutions more expensive.
- Honeywell (Clearwater, FL) proposed using pure tin platings on the Be-Copper card guides (which needed no coating at all!)
- NASA accepted this proposal: "We know this opens the potential for tin whiskers, but these are only theoretical."
- ATVC box S/N 34 showed incorrect output on 15 Dec 2005. Box opened 1 Mar 2006: tin whisker infestation found.
- July 2005: anomaly noted as consistent with whisker-induced shorting of transistor Q1.

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Why Are Sn, Zn, Cd Still Used?

- Not all Sn (or Zn or Cd) surfaces whisker! Rough estimate: 3% to 30% do whisker.
- Not all metal whiskers cause shorts --- environment (geometry and electrical potentials matter). Rough estimate: 3% to 30% do short.
- Not all whisker-induced shorts are traced to whiskers. (They are very hard to see.) Rough estimate: 0% to 10% are correctly traced.
- Not all identified whisker adventures are reported. Rough estimate: 0% to 3% are reported, once identified.
- Hence, we expect between 0.00% and 0.03% of shorting problems caused by these coatings to be reported, while some 0.1% to 10% of these coatings are actually causing shorts. With such a few public cases, many say “What, me worry?”
- Whiskering stops when 0.5% (or more) lead (Pb) is added to Sn coatings: the shorting rate is then zero: this has been the case for the Hi-Rel community. But the lead is going away, and so the shorting rate may jump to 10% from zero. **==> SWATCH GROUP <==**

Whiskering is a Random Process

- The density of whiskering is Poisson-distributed: there is one parameter, the average number of whiskers per area. All else follows from that.
- The length of whiskers is log-normal distributed. There are two parameters: the median length and the standard deviation of “log(length)”. This standard deviation is 1.0⌖0.1 in the cases examined so far.
- The thickness distribution, and its correlation with length, are not yet known, but are important for the distribution of electrical resistance:
  R = L / (□ thickness^{2} /4).
- Latency and “steady state” growth rate and terminal growth rate: unknown distributions.

Whisker's Melting Current --- Pt. 1

- I_{melt} = [2 sqrt(Lz) T_0 / R_0] * arccos(T_0/T_{melt})
- *where Lz = 2.45×10^{-8} $(V/K)^2$ is the Lorenz number, T_{melt} is the melting temperature, T_0 is ambient, and R_0 is the resistance at ambient.*
- T_{melt}(Sn) = 505.1 K for tin ==> I_{melt}(Sn) = 87.5 mV / R_0
- T_{melt}(Cd) = 594.2 K for cadmium ==> I_{melt}(Cd) = 97.1 mV / R_0
- T_{melt}(Zn) = 692.7 K for zinc ==> I_{melt}(Zn) = 104.4 mV / R_0
- *The melting voltage is then*
- $V_{melt} = R_0 * I_{melt}$ = 88 mV(Sn), = 97 mV(Cd), = 104 mV(Zn)
- *It is possible to have breakdown at as low as a few dozen millivolts. But if breakdown for a particular specimen happens at more than V_melt, then one must quickly drop the applied voltage to less than (roughly) 80% of V_{melt} before the whisker has a chance to melt.*

Whisker's Melting Current --- Pt. 2

- Whiskers are coated with an electrically insulating oxide.
- This is often substantially thicker at the tip, than along the sides.
- The whisker can be in direct mechanical contact with another conductor; however, the oxide layer prevents electrical contact until the potential exceeds “dielectric breakdown”.
- Independent groups have confirmed breakdown ranges from ~ 0.2V to ~ 15V.

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Arcing

- Gaps shorter than a few tenths of a millimeter can support a sustained arc at potential differences of 12 to 14 volts, and currents of 0.1 to 0.3 amperes. (See “Electrical Contacts” by Paul G. Slade, part three.)
- As the gap increases, the EMF needed to sustain the arc increases, as does the current. For 5 mm, some 75 volts at more than 30 amperes is needed.