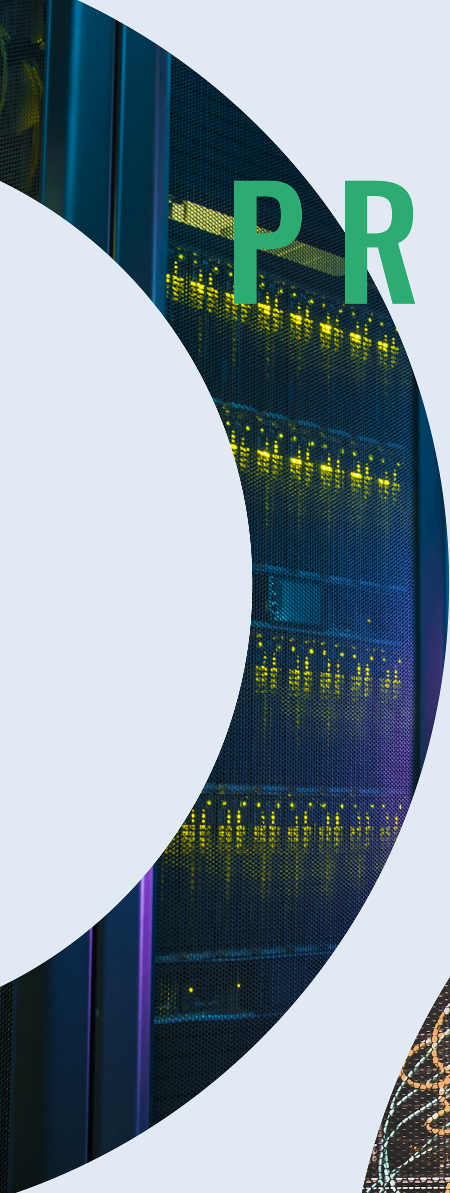

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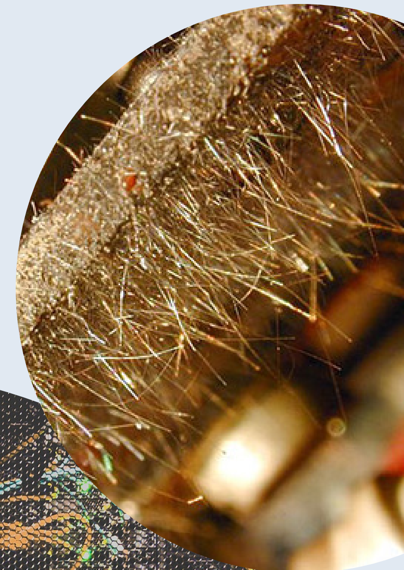

COMMENTARY PAPER

Some data centers are just a whisker away from disaster

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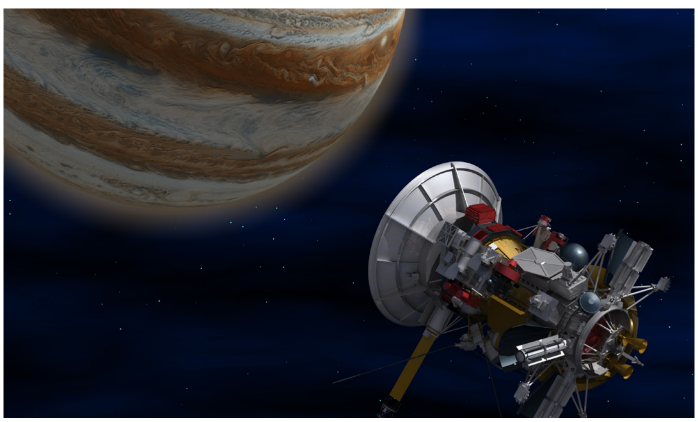
Some data centers are just a whisker away from disaster

Background

Jay Brusse used to work as a senior component engineer at Perot Systems Government Services at the National Aeronautical and Space Administration (NASA) Goddard Space Flight Center. In his article titled "Zinc whiskers: Hidden cause of equipment failures", Brusse explains the problems they encountered. *"During a one-month period, a NASA data center experienced at least 18 catastrophic power supply failures in newly installed mass memory storage devices. The ensuing failure investigation detertemined that the causes were electrical short circuits. But what had prompted such repeated short circuits in modern, typically reliable systems? The investigation concluded that for many years small metallic filaments, practically invisible to the unaided eye, had been growing from the underside of the raised floor tiles and floor support structures. Maintenance activity to install the new equipment dislodged many of these conductive filaments, which were then distributed throughout the data center by the forced-air cooling systems. Many of these particles were drawn into the equipment power supplies, where they bridged exposed conductors, causing electrical failures. Only then did the data center managers become acquainted with the phenomenon scientists call zinc whiskers."*



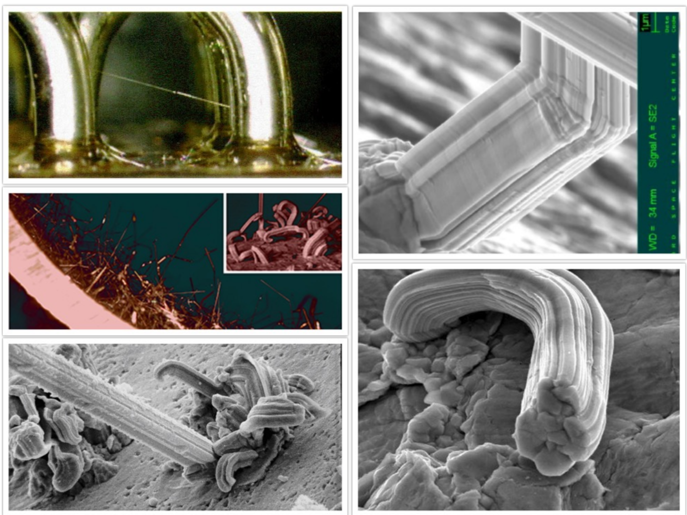
Brusse's article was published in 2004, about 56 years after Bell Labs discovered this phenomenon by which a whisker on a zinc-plated bracket caused increased losses in quartz filters used in a telephone transmission system. In February 2022, NASA's Academy of Program/Project & Engineering Leadership (APPEL) Knowledge Services team published an article titled, "Spotlight on lessons learned: Electrical short circuits due to tin whiskers". The article shared that "NASA's Jet Propulsion Laboratory (JPL) isolated several Cassini electrical shorts to the Cassini Plasma Spectrometer (CAPS) analytical instrument and requested a NASA Engineering and Safety Center (NESC) investigation. The NESC investigation determined the presence of tin whiskers — on tin-plated metal cans of transformer components on a circuit card within the CAPS instrument — was most likely the cause of the electrical shorts." Cassini was a robotic spacecraft that orbited Saturn prior to its decommissioning in 2017.

The article went on to say that "Knowledge of tin whiskers and methods to mitigate them have been known for decades, and policies are in place to address the issue. Even with these actions, the condition continues to occur within NASA systems. The NASA technical community and commercial space enterprises need to have continued awareness that tin whiskers still cause failures on existing spacecraft and may be found on new systems."

Almost 75 years after metal whiskers were discovered, some of the most sophisticated electronic assemblies are still suffering from intermittent electrical short circuits. Another troubling aspect is that metal coatings are used in medical devices such as infusion pumps, defibrillators and pacemakers.

What are metal whiskers?

Metal whiskers are tiny hair-like formations that resemble crystals and have been found to grow on the surface of electroplated steel. Electroplating (often referred to as electrodeposition) is the process of plating (coating) one metal onto another. This process is commonly employed for decorative purposes or to prevent corrosion of a metal. These formations grow outward straight, kinked or odd-shaped.



While cadmium, tin and zinc coatings are susceptible to the development of whiskers, they have also been observed on gold, silver, lead and other metals.

As it relates to data centers, both tin and zinc whiskers have been the culprits of what were once considered mysterious malfunctions. Steel with electroplated zinc has been widely used on a variety of products present in data centers and other computer controlled environments. Zinc whiskers have been found growing on printed circuit board (PCB) components, computer hardware, cabinets and racks, as well as on raised floor panels, pedestals and rails. While some consider zinc whiskers to be a more common problem in older data centers, they aren't exclusively found there.

Hewlett Packard zinc whisker contamination paper:

"The effects of this contaminate could turn out to be the single most failure-causing anomaly of electronic and computer equipment in our data centers. These data centers located deep inside our banks, stock exchanges, government facilities and hundreds of other businesses, are all susceptible to this unique and possibly catastrophic contaminant."

What causes whisker growth?

According to DataSpan, a technology solutions provider, "Electroplating causes significant molecular stress. Zinc overlay is an excellent barrier for preventing corrosion, but the passivation puts the zinc under consistent compression and stress. To relieve the pressure, the zinc may expand outwards, which forms microscopic filaments on the outer surface. Without the protective coating, metal would be susceptible to the moisture from the room climate and cooling systems. But while the zinc prevents one problem (corrosion), its presence in a data center can result in others. The filaments grow over time, resulting in whiskers you can just barely observe with the naked eye."

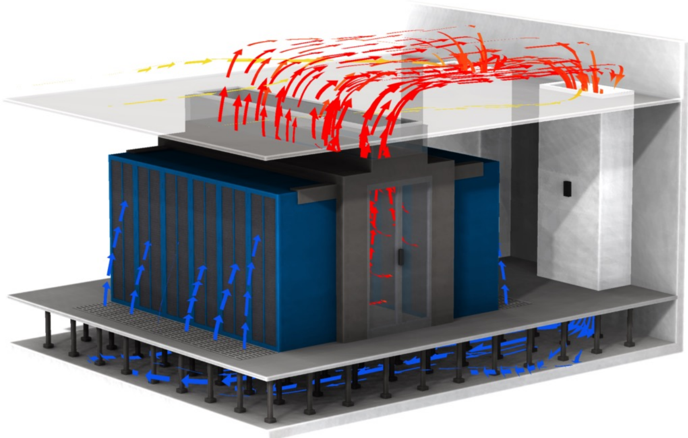
Zinc whiskers are typically two microns in diameter (human hair is approximately 70 microns $\pm$ 20 microns) and their growth rate is unpredictable. Months or even years may pass without any growth at all, followed by growth rates as high as one mm per year. Whiskers can reach lengths up to one cm (0.4 inches). Currently, we do not have techniques that can accelerate the process of zinc whisker development. Perhaps in the future we will be able to predict if, when and to what extent a zinc-coated surface will develop whiskers.

Likewise, tin whisker formation is believed to be encouraged by compressive mechanical stresses caused by electroplating, diffusion of different metals and thermally induced stress, among other factors. Given the wide range of factors that may produce material stress, it is exceedingly difficult to identify or isolate individual factors. Tin whiskers are similar in diameter and length to zinc whiskers.

Why are whiskers still being discussed today?

While new data centers are being constructed all around the world, there are far more computer installations with zinc electroplated floor structures that are 10 to 30 years old. In such facilities, whiskers have had time to grow to lengths capable of bridging exposed PCB conductors. It is important to reiterate that we do not have conclusive data that demonstrates exact growth rates. Whiskers could form in new data centers and impact equipment once detached. Whiskers will grow regardless of humidity, temperature or any other factor. Their existence/growth is primarily dependent on the molecular makeup of the metal.

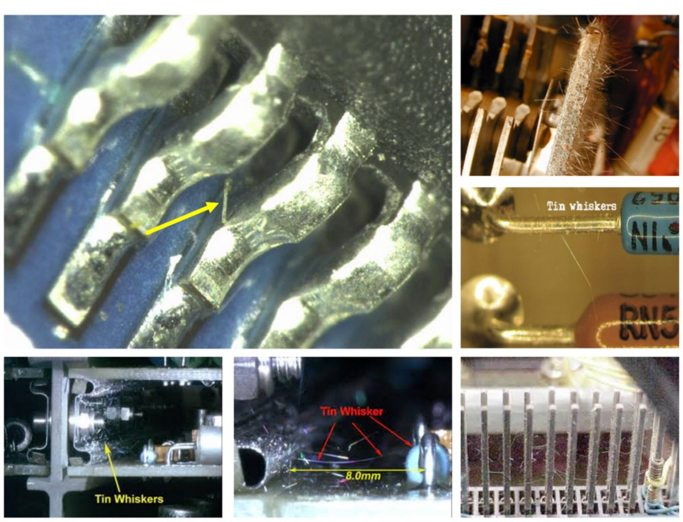
Whiskers start to wreak havoc on sensitive electronic equipment once they break off from the metal coating. Factors that contribute to detachment include air pressure, moving cables, removal or shifting of floor tiles, decommissioning of older racks, adding or removing computer hardware, repositioning or reconfiguring the equipment and even preventive maintenance activities. Once the whiskers break off, they migrate throughout the room as a result of forced air circulation.



The data center diagram illustrates common airflow design that introduces cold air through the raised floor — into the bottom and front of the equipment racks — and exhausts hot air into a controlled space in the back. When floor tiles are removed to address cabling or perform a repair, the airflow can change just enough to cause whisker detachment. This is besides the fact that the floor tile itself may have whiskers that could break off once lifted.

When to suspect tin and zinc whisker related failures

- Equipment failures occur within weeks of repair or maintenance activities that required removal of raised floor tiles. Power supply modules, circuit boards and input/output (I/O) connections are all susceptible.
- Newer equipment is encountering more failures than older assemblies. As a result of continuous miniaturization of circuit boards, electronic components are more densely packed with tighter spacing between conductors so it is easier for whiskers to cause electrical shorts.



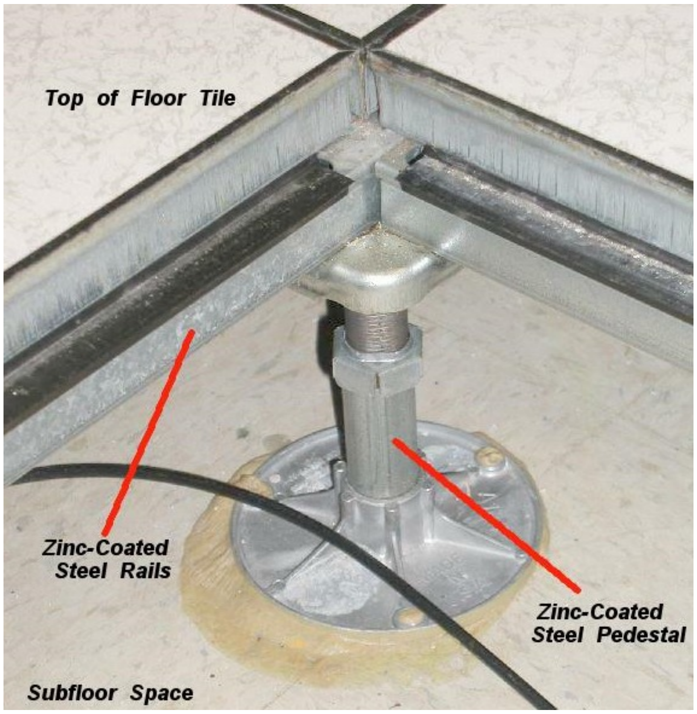
- Equipment failures are noted on assemblies that are located adjajcent to floor vents.
- Data center operators do not thoroughly investigate intermittent system failures unless permanent hardware failures are observed regularly or substantial system downtime occurs. When equipment is repaired by a manufacturer or service vendor because of an existing warranty or service contract, often this means that problem investigation stops as soon as the vendor performs the repair or supplies replacement equipment.

Eaton Corporation 2017 thought leadership whitepaper:

"The telecommunications/high tech industry is experiencing resurgence in zinc whisker failures. This is due to the rooms and microelectronics that are commonly found in today's data-centers and sophisticated electronics. These tiny whiskers create havoc when they find their way into these microelectronics. The problems they create are micro-sized short circuits, voltage variances, or system resets. Effectively creating chaos in expensive and critical electronic equipment or creating un-scheduled down time. The other problem is because of their size the short circuit process often vaporizes them. It essentially leaves no evidence behind except for equipment resets or failure."

High profile documented failures

- The Millstone nuclear power plant located in Waterford, CT, shut down without incident when control circuitry monitoring a steam pressure line experienced a short circuit. The electrical short caused the control circuitry to malfunction and signal an unsafe drop in pressure in the reactor's steam system. In reality, there was no drop in steam pressure. The cause was attributed to tin whiskers. Thereafter, power plant safety implemented a procedure to inspect for these whiskers at every refueling outage or 18 months.
- The U.S. Air Force documented malfunctions in radar equipment on F-15 fighter jets. The malfunctions were a result of tin whiskers that had detached and migrated into powered circuitry. Whisker conductance between electrical leads caused intermittent performance problems for the radars. The malfunctions would suddenly disappear when vibration from the aircraft caused the whiskers to shift their position.



- The Colorado Department of State suffered data center computer malfunctions that crippled its ability to deliver services to its constituents. The failures were deemed a result of zinc whiskers that contaminated the data center.
- The U.S. Navy discovered whiskers in tin-lined enclosures housing Phoenix air-to-air missile target detection systems. At the time, the Phoenix missile was the United States' only long-range air-to-air missile, and certain fighter jets could carry and simultaneously fire up to six missiles towards different targets.

Identifying and remediating tin and zinc whiskers

At times, determining whether zinc or tin whiskers exist can be done visually if the whiskers are long enough to be observed by the naked eye. It is easier to inspect with a digital microscope that enables optical magnification of surface growth, or by collecting field samples that are then analyzed via scanning electron microscopy (SEM). There is another sampling method that requires Ghost wipes to collect particulate from a defined area. The samples are sent to a lab with a request to test for the presence of tin or zinc metal. For this type of sample, the lab will not publish results showing pictures of whiskers, but rather advise what concentration of metal exists is in each sample.

Once an expert identifies the existence of whiskers, thoroughly planning the remediation is just as important as the remediation itself. During the planning phase, minimizing activities within the data center is recommended. As long as the whiskers are not disturbed, the likelihood of detachment is low. As it relates to the actual remediation, one size may not fit all. Replacement of swappable floor tiles may be an economical way to address the tiles, although the raised floor rails, pedestals, equipment cabinets, racks, struts and cable management systems may require a different remediation technique.

About EFI Global

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Get in touch with an expert

Harold Ornstein, PE, CFEI – senior principal mechanical engineer
Dr. Ornstein has more than 55 years of mechanical engineering experience with a focus in root cause failure analysis, accident reconstruction and loss prevention. After completing formal training, Dr. Ornstein has gained extensive experience working on projects related to warnings, labels, instructions and product liability litigation. Dr. Ornstein is a member of several committees and holds an EPA Universal License for Freon handling. For more information, contact **harold.ornstein@efiglobal.com**.

Timothy Korinek, PE, CFEI – senior metallurgist, materials and mechanical engineer
As a multidisciplined forensic engineer with over a decade of materials, metallurgical, and mechanical engineering experience, Timothy provides clients with valuable information to make informed decisions. His extensive background in failure analysis includes projects serving major insurance companies, adjusters, attorneys, defense contractors, manufacturers, and municipalities. For more information, contact **tim.korinek@efiglobal.com**.

Perry V. Young, P.E., C.F.E.I., C.V.F.I. – senior mechanical engineer
Perry Young has more than 13 years of experience utilizing the scientific method to investigate in the failure analysis of equipment and components, cause of fires and explosions, reconstruction of vehicle accidents involving light, heavy, and motorsports vehicles, industrial accidents, and assessment of scope of damage and cost of repairs of mechanical equipment. Additionally, Mr. Young has over 24 years of experience in aerospace and non-aerospace industrial experience. For more information, contact **perry.young@efiglobal.com**.

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