1.0 Introduction

This document has been compiled to provide the reader with background information on metallic whisker growth, in particular zinc whisker growth. The objectives of the study were to establish:

- What zinc whiskers are and their sources
- What effects they have
- How they are identified
- Whether there are any associated 'control limits'
- What remediation methods exist

2.0 Zinc Whiskers

Formation and Characteristics

Zinc whiskers are a phenomenon that can occur on bare metal surfaces. Metal surfaces are coated with zinc in a galvanisation process to help protect them from corrosion. While several techniques are used, such as hot-dip or spraying, whisker growth appears to be limited to electroplated samples. The whiskers are zinc crystals formed by the degradation (corrosion) of the galvanised metal surface.

Several industry studies have shown that whisker growth is dependent on internal stresses during the plating process. The crystalline structure within the metal will attempt to relieve the internal stress by enlarging the structure through the growth of crystals. The growth path is outward and the material is literally pushed out of the surface of the metal.

Not all electroplated surfaces exhibit whisker growth and not all develop the problem at the same rate. There is no clear evidence that environmental factors will exacerbate whisker growth.

These crystalline growths (whiskers) are typically 2 microns in diameter and over time (many years) can grow to be several millimetres in length, up to 10mm although typically <1mm. Under proper lighting, they can be visible to the naked eye on surfaces. The whisker formation process consists of an unpredictable incubation period, typically lasting months or even years without any growth at all, followed by a period of growth at rates as high as 1mm per year. Some zinc coated surfaces may never grow whiskers. Unfortunately, accelerated techniques do not currently exist to predict if, when, and to what extent a zinc-coated surface will produce whiskers.

Zinc is one of several metals known to produce whiskers, others include:

Antimony
Cadmium
Gold
Indium
Tin

Sources

Zinc whisker growth has been documented on a wide range of zinc-coated materials including

electrical components (electromagnetic relays)
mechanical hardware (nuts, bolts, washers, equipment racks, housings and rails)
zinc-plated underside of raised-access floor tiles (typically found in computer data centres)
raised-access support structures (pedestals and stringers)

Other reported sources include building components such as steel studs, suspended ceiling hangers and grid systems, electrical conduit. Equipment cabinet frames and server frames. Therefore whisker growth can occur on surfaces within the hardware or can be carried to the hardware from outside sources.

Whisker growth on access floor tiles is of particular concern as these have a large surface area and are often disturbed during normal activity on a computer room. Growth is most likely to occur on wood-core access panels and flat-bottomed concrete core panels. Access floor tiles have been used in high-technology facilities since the 1960's, unfortunately it is apparent that some, if not all access floor system manufacturers did not give adequate forethought to the electro-chemical instabilities of the metal stock utilised to produce their products. In essence, many facilities are out-fitted with construction materials that are incompatible with the environmental properties of the facility.

3.0 Effects of Zinc Whiskers: System Failures

While whiskers remain attached to their source ie floor panel, pedestal etc they are basically benign, however when the whiskers are disturbed and dislodged they become airborne and circulate freely throughout the environment. Disturbance is likely to be caused by routine maintenance activities in a data centre, including lifting, sliding and reinstalling of access floor tiles and the pulling of electrical cable in the subfloor space.

For efficient cooling the forced air-system typically pressurises the subfloor space with chilled air. Perforated floor tiles and air vents provide channels through which the cool

air, including the zinc whiskers, can pass into the above floor space. Ultimately many whiskers can pass into the electronic hardware through vents and fans on the equipment. Once inside the equipment zinc whiskers, which are electrically conductive structures, can cause various electrical failures, ranging from intermittent to permanent short circuits. Whisker debris can also become a physical impediment to moving parts or obscure optical surfaces and sensors within some equipment (such as disk or tape drives)
The first identification of zinc whiskers, and its associated system failures, occurred in the 1940's. Renewed interest has arisen triggered by the apparent increase in reported failures. Several factors appear to contribute to the apparent increase:

Continuous miniaturization of electronic components – technological advances have led to more densely packed circuitry and tighter spacing between conductors, therefore smaller conductive particles can now cause shorts.

Reduction in circuit voltages and currents – newer systems operate at lower levels and therefore energy from these components may not be sufficient to melt a zinc whisker, resulting in increased risk for permanent shorts.

Age of existing floor structures – many facilities now have flooring that has been in place for in excess of 10years thus whiskers are of a length capable of bridging exposed conductor spacings.

Increased maintenance and up-grade activity in raised-floor facilities – any activity that involves moving flooring can dislodge whiskers, in today's high-tech environments it is more commonplace for computing facilities to undergo regular maintenance activity, ie adding, removing hardware, repositioning and reconfiguring equipment etc.

During a one-month period, a NASA data centre experienced at least 18 catastrophic power supply failures in newly installed mass memory storage devices. The ensuing failure investigation determined that the causes of failure were electrical short circuits' These had been caused by small metallic filaments growing on the underside of raised floor tiles and support structures that had been dislodged during maintenance and distributed throughout the data centre by forced air cooling systems.

Health Effects

During this research exercise there was very little information found regarding potential health hazards associated with zinc whiskers. One article stated that investigation of the NASA data centre raised concerns about potential health hazards from zinc whisker exposure. Several sources discuss the toxicity of zinc in other forms, particularly zinc oxide in the form of granules, powder, fumes and dust. In these forms, zinc seems generally benign when inhaled or swallowed, except in very high concentrations. Inhalation of zinc fumes can have more serious effects. Various informal reports suggest no health implications from exposure, however these lack cited references from medical or occupational-health professionals. Other research suggests that the shape of airborne fibres can be an important factor regarding the potential pathologic effects on the lung, specifically a length-to-width ratio of 100 to 1 or greater. Zinc whiskers commonly exceed this ratio. Consideration of similar materials and hazards based exclusively on the form (crystalline needle) dictates that caution be urged, ie fibreglass, gypsum and asbestos, it is the shape of these materials that presents a risk to workers.

As health effects are yet to be fully investigated the hazardous potential for any airborne contaminant should be acknowledged and addressed. Failure to initiate a remedy to a contamination problem contributes to the potential for future litigation over system failure and health related injuries.

4.0 Identification of Zinc Whiskers

The identification of zinc whiskers is generally verified through a visual inspection and laboratory tests. There are three strong indicators that are commonly used to show a potential for zinc growing on access tiles:

- Manufactured type/date
- Type of backing on the access floor tile
- Shiny particles

These methods are only indicators of potential zinc growth, however it is impossible to confirm zinc growth from these simple tests as there are too many variables that could mislead even a trained eye. Zinc confirmation only comes from laboratory testing.

During this research it was concluded that the general consensus for confirming zinc whisker growth was as follows:

- Removing tiles from several locations within the facility

Carefully wrapping and packaging the tile for shipment to the laboratory

Appointing the laboratory to test for confirmation of zinc whiskers, such tests can range from the cheaper chemical analysis through to analysis using scanning electron microscopy (SEM), costs quoted for tests were circa $400.

Receipt of a report from the laboratory confirming the outcome.

Thus the most common method for confirming zinc whisker contamination is to utilise SEM to review field samples. Samples can be collected not only from floor panels and understructure components but also from the surface of specific components, such as a failed power supply.

A less expensive, but somewhat less useful testing method is wipe sampling of surfaces. The wipe is sealed in a plastic bag and sent for analysis costs quoted for this analysis are typically $20 per sample. However, this will only provide a result for the concentration of zinc in the sample, it will not determine the presence of individual whiskers. Therefore positive wipe-tests are not conclusive.

If whiskers have migrated it is necessary to determine the extent of contamination. ‘Sampling needs to be undertaken by competent personnel who understand the importance of avoiding spreading zinc to equipment during the sampling process. Ideal candidates for this activity are professionals who have dealt with asbestos abatement and are certified in the prevention of airborne and particle contaminant migration’

5.0 Zinc Whiskers Remediation

Both short and long-term corrective actions can be considered for solutions to zinc whisker problems. Short term actions include replacing affected components with ones that have a protective insulating compound that coats most of the exposed electronic circuitry, minimising activities that require significant handling of floor tiles.

Long term solutions include, but are not limited to:

Carefully planned and controlled removal of all affected or suspicious tiles and support structures while protecting equipment and personnel.

Thorough cleaning of the data centre environment, using H-type vacuums to remove as much whisker debris as possible.

Installation of replacement floor structures that are not prone to zinc whisker formation, including all-aluminium or steel structures with conductive epoxy powder coatings or paints instead of zinc for corrosion protection.

All literature reviewed during the study was in agreement that simply washing whisker infested materials is not an effective long-term remedy as whiskers can grow back. Cleaning and coating whisker prone surfaces may be a solution however whiskers could possibly grow through some conformal coatings, depending on their properties and thicknesses. Long-term testing is required to validate such remediation approaches.

Factors to be addressed to determine which method is most suitable:

Extent of contamination and overall condition of the tiles and structural system
Size of the area to be treated or replaced, location in the facility
Cost – both short term and long term costs must be considered along with future maintenance requirements, if any.
Time- what is the operational demand placed upon the equipment within the facility, is there a zero tolerance for shut-down?
Management commitment to minimise any potential for equipment failure and health risks to workers.

Airborne zinc will be maximised during the remediation procedure. 'Technicians involved in the removal of contamination in clean room and other high technology environments should utilise asbestos abatement personal protection protocols as necessary to prevent aspiration of zinc whiskers and other contaminants. Containment of the working area is necessary to prevent cross-contamination of the facility and to protect non-abatement workers who may be in the facility during the cleaning of any facility with zinc whisker contamination' Partitioning, zone pressurisation and the use of high-efficiency, high volume air filtration units are often employed.

Any remediation project needs careful planning with proper regard to contaminant isolation and conditioned air distribution to minimise the possibility of impacting hardware reliability. The following outlines the *ideal* general procedure for panel replacement:

1 – power down and remove from the environment any equipment that can be removed. ideally the whole room is shut down
2 – power down as many air conditioning units as possible for the remaining load
3 – protect remaining equipment with plastic barrier tents. Create safe envelopes for equipment by sealing plastic sheeting between the ceiling and the floor. Underfloor barriers will also need to be implemented if airflow is still present.

4 – remove affected panels by carefully lifting and placing in a plastic bag, fold and seal the bag and remove from the room.
5 – clean the underfloor plenum, flooring understructure and underfloor infrastructure using HEPA vacuums and wet-wiping.
6 – clean the underside of unmovable panels (under equipment that cannot be moved)
7 – install replacement panel
8 – repeat 4-7 throughout remainder of affected area
9 – clean the entire room and its contents
10 – carefully remove barriers and re-install equipment

Works tend to be carried in live environments and that is also fine.

During the course of this study there were no findings regarding reference to any associated control limits or standard procedures for verifying remediation works such as visual inspection and air or surface testing.

The only reference to cleanliness identified was microscopic particles found per cubic metre of air, ISO 14644 establishes various classifications for cleanliness.

Believe it or not, there is a standard for data Centre cleanliness. The ISO 14644 series of standards (14644-1 to 14644-8) are a series of documents that establish various classifications for cleanliness as well as methods for testing compliance, test methods, design/constructions/startup considerations, and others. This ISO standard differs from another standard developed by the U.S. government called FS209E.

The yardstick for measuring cleanliness is the amount of microscopic particles found per cubic meter of air. These particles range in size from 5μm (micrometer: a millionth of a meter) in diameter down to 0.1μm in diameter. Obviously, the larger the amount of large particles in an environment, the visibly dirtier the environment is. On the other hand, a small amount of very small particles means an extremely clean environment.
The ISO 14644-1 standard sets up ISO classes from 1 through 9; ISO Class 1, for example, allows only 10 0.1μm particles and two 0.2μm per cubic meter of air. Class 1 is the ultimate in cleanliness, a tremendously stringent standard that only highly controlled environments, such as clean rooms in microprocessor fabs, can achieve.
Most data centres need to be kept clean so they meet ISO Class 8 or 9 standards. Class 8 allows 3.52 million 0.5μm particles per cubic meter, while Class 9 ramps up the 0.5μm

particle size allowance by a factor of 10, up to 35.2 million particles per cubic meter of air.