LIFE EXPECTANCY OF ELECTRONIC EQUIPMENT POST-LOSS

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ABSTRACT

Businesses in virtually every industry utilize electrical and electronic equipment and sometimes those businesses experience catastrophic losses. Following a disaster (smoke, water, tornado/hurricane), if technical reconditioning is an option, there is a need to understand the reasonable expectation for the remaining equipment life. Will electronic assemblies experience higher failure rates and a diminished lifespan? Or will the assemblies benefit from lower failure rates and actually reach their designed life? Perhaps after thoroughly removing pre-existing and loss-related contaminants, equipment will exceed its designed life.

Considering the capital investment, one would assume that operators employ measures to maximize equipment life and minimize unforeseen failures. Is this assumption correct? This paper will not dive into the world of reliability centered or condition-based maintenance, nor preventive or predictive maintenance programs. Regardless of which program is followed, performing some type of maintenance is better than operating equipment until it simply fails. Instead, we will discuss a reasonable expectation for equipment lifespan following a disaster and answer the following questions: What factors contribute to electrical and electronic system degradation? Is there a graphical representation that depicts failure rates over the course of equipment life? What does research show about factors that may cause accelerated failures or prolong system functionality? Finally, does performing technical reconditioning restore the equipment back to a pre-loss condition?

INTRODUCTION

In 1979, German manufacturer, Siemens, formed a venture with Munich Re and Allianz Insurance that specialized in restoring contaminated equipment to a pre-loss condition. Today, the service is perhaps even important when considering equipment recovery options for sophisticated electronic modules. The long history of technical equipment recovery is not commonplace knowledge. Post-loss, while the need and success of decontamination is proven with scientific empirical data, equipment owners still contemplate equipment longevity when deciding whether to restore or replace equipment. To add some clarity to that discussion and decision making process, we need to consider the normal life of a piece of equipment absent any major event to understand a reasonable expectation for equipment lifespan.

LIFE EXPECTANCY BATHTUB CURVE

Dennis Wilkins, a retired Hewlett Packard (HP) Senior Reliability Specialist, noted in a paper titled "The Bathtub Curve and Product Failure Behavior" that reliability specialists often describe the lifetime of a population of products using a graphical representation called the bathtub curve. The bathtub curve consists of three periods: an infant mortality period with a decreasing failure rate, followed by a normal life period (also known as "useful life") with a low, relatively constant failure rate, and concluding with a wear-out period that exhibits an increasing failure rate.

The bathtub curve, displayed in Figure 1.0, does not depict the failure rate of a single item, but describes the relative failure rate of an entire population of products over time. Some individual units will fail relatively early (infant mortality failures), others will last until wear-out, and some will fail during the relatively long period typically called normal life. The curve is typically used as a visual model to illustrate the three key periods of product failure and is not calibrated to depict a graph of the expected behavior for a particular product family. It is rare to have enough short-term and long-term failure information to actually model a population of products with a calibrated bathtub curve.

The actual time periods for these three characteristic failure distributions can vary greatly. Infant mortality does not mean "products that fail within 90 days" or any other defined time period. Infant mortality is the time over which the failure rate of a product is decreasing. It can come from any number of causes but it is the primary reason that a warranty exists on a new piece of equipment. Conversely, wear-out will not always happen long after the expected product life. It is a period when the failure rate is increasing, and while it is often years after installation, it has also been observed in products after just a few months of use. This, of course, is a problem from a warranty standpoint as manufacturers tend to want their warranties to expire before significant wear-out failures occur.

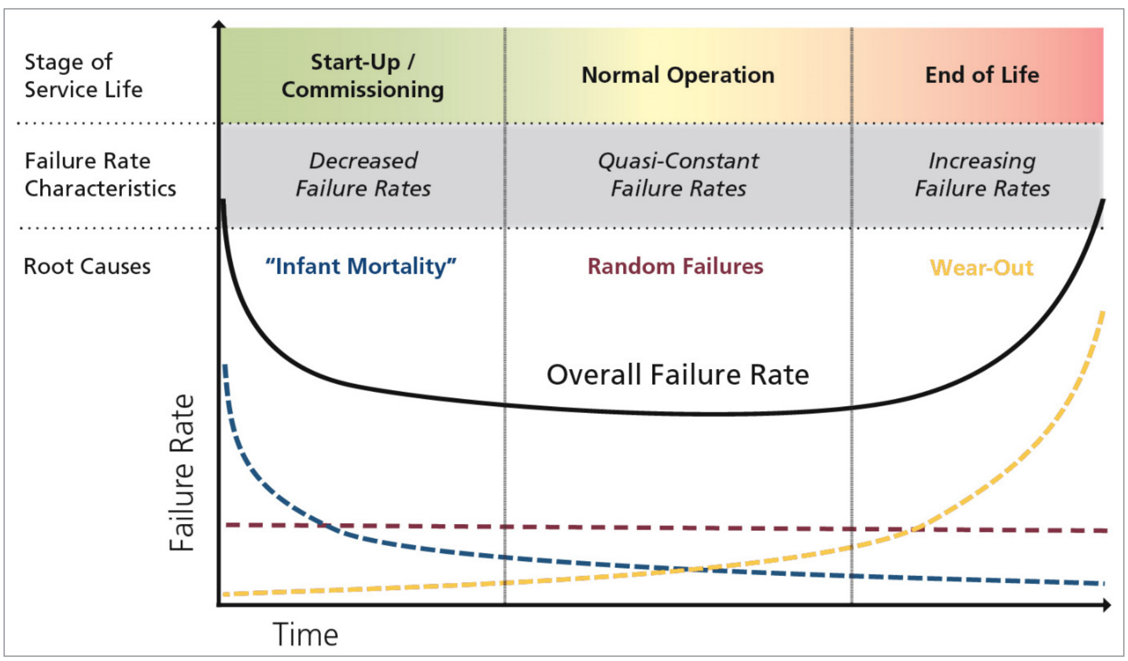

Figure 1.0 – Bathtub curve courtesy of OSI Hardware

Infant Mortality: Higher probability for early failures upon first use and burn-in period.

Random (normal life): Flat or constant failure rate due to arbitrary causes of failure.

Wear-Out: Probability for failure increases due to expiration of design lifetime.

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ELECTRONIC EQUIPMENT FAILURE MODES

As electronic equipment ages, factors such as design, material composition, maintenance, operational wear and the environment contribute to failures. A robust design and quality material composition could be considered a leading favorable indicator of equipment reliability and lifespan. Countless books detail maintenance programs and operators use a range of methods from ad hoc "as time permits" to rigid, planned preventive schedules. Operational wear is a direct result of production requirements. Environmental factors such as temperature, humidity, dust and manufacturing byproducts contribute to degradation and failures, although these factors can often be controlled. One of the most commonly controlled factors is temperature.

EFFECT OF TEMPERATURE ON ELECTRONIC CIRCUITRY

Siemens published a paper titled "Integrated Automotive Circuit Board Design and Verification", where it is noted that temperature changes and the difference in temperature-induced growth of materials triggers structural stress. When a microcontroller starts to run, it initially heats up locally, causing the chip, and all of the microcircuits inside, to expand. The circuit board, however, is not heating up as fast and therefore does not expand at the same rate. This circuit board issue is further complicated by the fact that the chip and board have different rates of temperature-induced growth due to the varying materials that make up each component. The net effect is that the microcontroller solder joints become strained due to this growth difference. As this cycle repeats, cracks can initiate and ultimately propagate through the joint, resulting in a break in the electronic circuit. In many cases, this is the primary failure mechanism of such systems. Thus, to minimize this failure mode, temperature should be kept as constant as possible. In many cases, maintaining a constant temperature may not be a realistic option, such as in an unconditioned manufacturing facility coupled with intermittent use of a system. The repeated temperature swings can be over 100°F.

Siemens' paper goes on to say that the fundamental enemy of electronics is heat; higher temperatures reduce the life expectancy of components, solder joints and circuit boards. Even small temperature reductions can lead to meaningful operational and lifespan component improvements. Therefore, thermal analysis is extremely valuable for evaluating cooling concepts to achieve these improvements. Two main factors drive the thermal performance of an electronic system: the power of the components and the environment around the electronic module.

VTT Technical Research Centre (VTT) researched corrosion and climatic effects in electronics. VTT noted that the majority of reasons for faults in electronic devices are related to heat and humidity. The temperature readings cold/hot, their fluctuation and humidity, affect the physical and chemical properties of materials and components. The scale of these effects determines when a change or absolute level of temperature, or the level of humidity, becomes significant for the properties or reliability of the product.

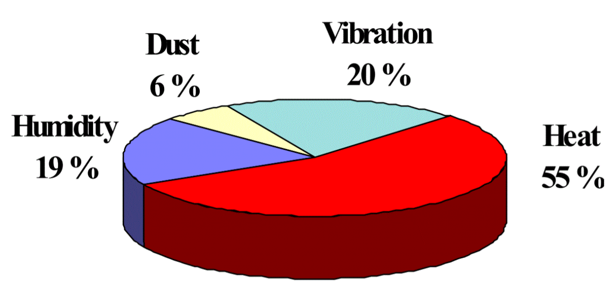

Figure 2.0 – Drivers of electronic failures. High temperature causes over 50 percent of electronic equipment failures according to a study by the US Air Force Avionics Integrity Program (Wright-Patterson technical report ASD-TR-84-5030).

Texas Instruments (TI) published an application report titled "Calculating Useful Lifetimes of Embedded Processors", where TI advises that electro-migration, defined as movement of atoms based on the flow of current through material, is one the dominant wear-out mechanisms in semiconductors. The most important variable with respect to electro-migration is the junction temperature (TJ) of the silicon. Junction temperature is the highest operating temperature of the semiconductor itself in an electronic device.

Assuming a device is operating within the specified design parameters, the critical variable influencing silicon lifetime is the junction temperature of the silicon. Figure 3.0 shows how the onset of electro-migration changes with junction temperature on a TI proprietary silicon node. Note that electro-migration performance may differ per technology but the principle of fail rate vs. temperature will apply: running at temperature extremes for long durations above 105°C (221°F) will shorten the lifetime.

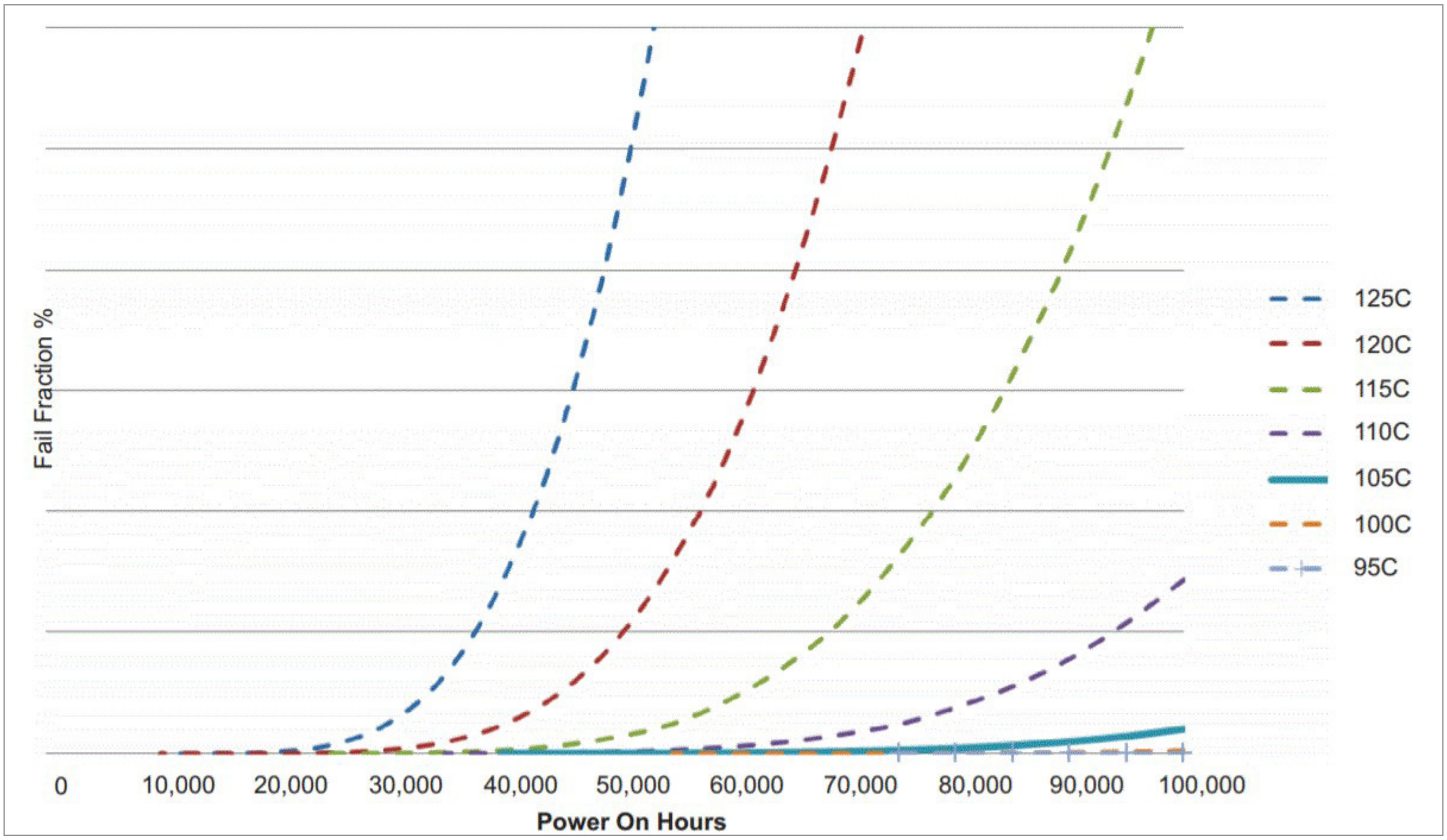

Figure 3.0 – Impact of electro-migration on a TI embedded microprocessor over temperature

It is imperative to control the temperature in the life of a piece of electronic equipment to prolong its useful life. One of the easiest methods of controlling temperature is to keep the equipment heat sinks and filters clean, to maximize the heat transfer away from the electronics and stay within the original design parameters. In reality, the temperature is seldom closely controlled, which shortens the expected life of the equipment.

An often quoted rule of thumb in electronics reliability for capacitors is that every 10°C (18°F) increase, the lifetime approximately halves. For semiconductors, it is a similar change but lifetime is further reduced at higher temperatures.

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EFFECT OF DUST ON ELECTRONIC CIRCUITRY

The Center for Advanced Life Cycle Engineering (CALCE) at the University of Maryland researched the effects of dust on circuit board assemblies. Findings were published in a paper titled "Impact of Dust on Printed Circuit Assemblies Reliability". The paper notes that dust is always present in the air. It is considered as a new factor in describing the operating condition of electronics, besides temperature and relative humidity. The impact of dust on the reliability of electronics is increasing due to a number of factors: driven by the new technology of miniaturization, the trace-to-trace spacing on the printed circuit boards (PCBs), and lead-to-lead spacing on the component that have been reduced greatly over the years. Therefore, PCB assemblies have become more sensitive to dust particles due to closer spacing and tolerances.

At the same time, electronics are no longer only residing in benign environments. For example, a lot of functionalities of telecom equipment have been moved outdoors, and will utilize the free air cooling method, which uses the ambient outdoor air to provide the heat transfer away from the equipment. This has been adopted by data centers to reduce costs and greenhouse gas emissions. These factors have contributed to the growth of research interests in dust.

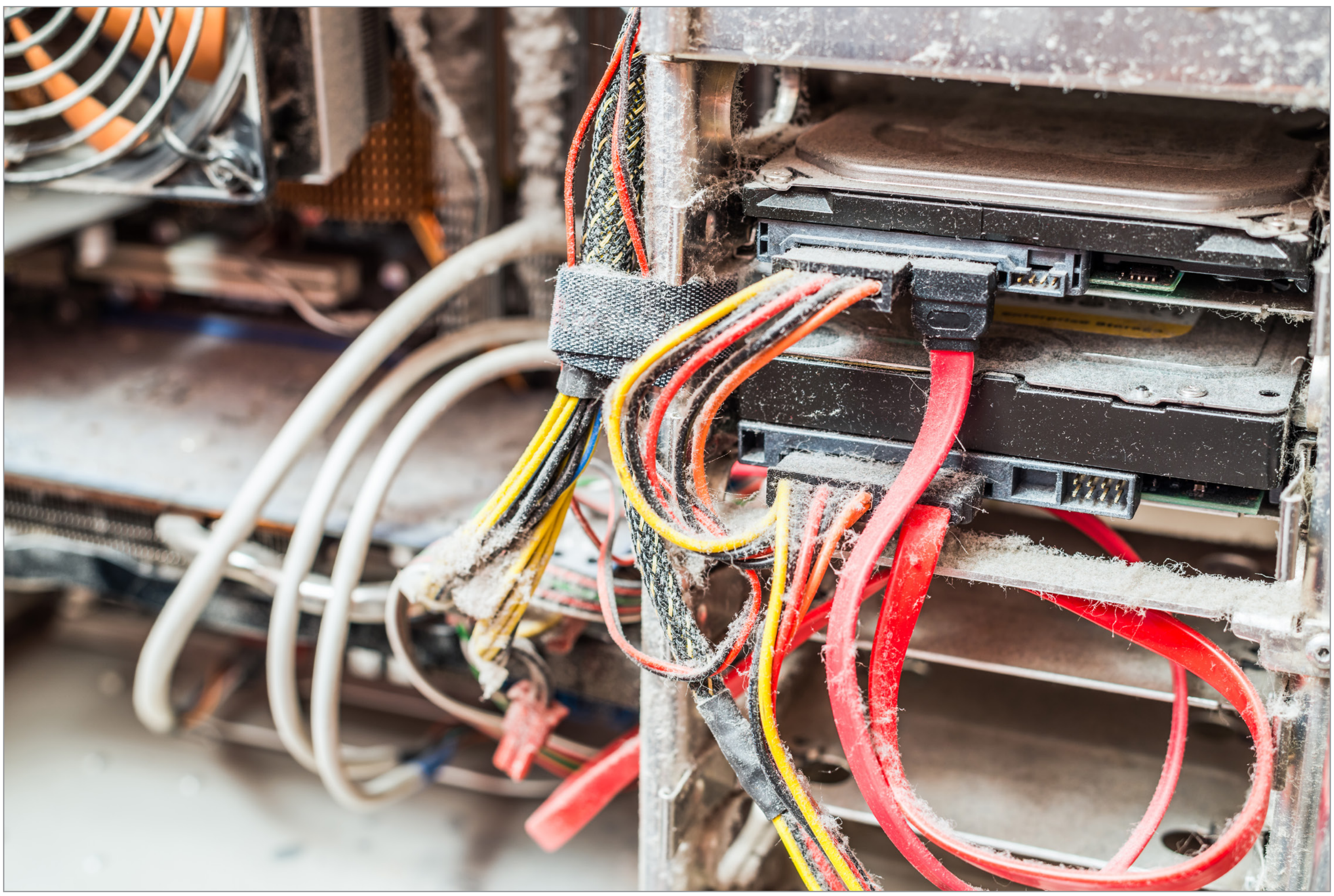

Figure 4.0 – Typical desktop computer dust accumulation after a couple of years in the field

Research organizations such as Bell Labs, Telcordia Technologies, Technical University of Denmark, Royal Institute of Technology in Sweden and IBM, have all published papers on dust focusing on the impact of dust on PCBs and connectors/contacts. Through this research, it is noted that dust may cause electrical leakage and short circuiting. Dust particles can increase friction on contacting surfaces, thus promoting third-body wear and fretting corrosion, which in turn can change the contact resistance. Dust particles act as dielectric materials to induce signal interference in the contaminated signal connectors and lines. Dust accumulation on the heat sink, power connectors, or active devices can act as an insulator and cause overheating.

CALCE then designed a group of temperature-humidity experiments using real-life dust collected from both indoor and outdoor areas. The data showed that the presence of dust had a significant impact on the reliability of printed circuit board assemblies. There was negligible change on control samples at different relative humidity levels, while there were orders of magnitude changes observed in the samples in presence of indoor or outdoor dust.

> Moist or wet dust can act as a conductor and cause electrical short circuits that may immediately compromise electronic components. AREPA recommends maintaining relative humidity in compromised environments between 45 percent and 55 percent.

Therefore, the accumulation of dust is also detrimental to the prolonged life of a piece of equipment. It is recommended that dust controls be put into place in conjunction with periodic dust mitigation to maximize equipment life. Since this, too, is addressed less often than required, dust accumulation on a normally operating piece of equipment is often far above the design parameters, thus, shortening the life of the equipment.

CONTAMINATION FOLLOWING A LOSS EVENT

Fires can spread contaminants from consumed matter. Water can leave behind impurities that were either in the water, or those accumulated on the path from the liquid source to the piece of equipment. For example, in a multi-story building loss where water falls on equipment from the floor above, the water will include contaminants from the floor above, the joist space between floors, debris on top of the ceiling tile and the ceiling tile itself. To complicate matters, tornados and hurricanes circulate both environmental debris and construction dust when a structure is compromised. Regardless of the event, loss-related contaminants settle on top of pre-existing environmental dirt as well as production byproduct. Considering the effects of temperature and dust on electronic circuitry, an added layer of loss-related contaminants can exacerbate operational integrity and shorten life expectancy even further. The good news is that if the contamination, whether it is from the loss event or the accumulation of years of operation, is removed, the deleterious effects are also removed. This can be accomplished through professional decontamination.

Professional decontamination techniques mirror those employed when circuit boards are first fabricated. Cleanliness is measured analytically by harvesting samples and processing them in a lab via ion chromatography. The results are compared to thresholds established by the electronics industry. The IPC industry consortium publishes the standards for testing results specifically so we can know a PCB is clean for use.

EFFECTS OF CONTAMINATION FOLLOWING A LOSS EVENT

While there are numerous studies on the effects of temperature and dust on electronic circuitry, the impending impact of loss-related contaminants is perhaps even more important to quantify, as operators power on contaminated equipment following a disaster in an effort to satisfy production needs or in an attempt to assess the condition of the equipment. It is important to consider the following seven issues that can arise from contamination.

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1. Staining – Smoke that emanates from a fire causes soot and at times oily deposits to settle on a surface. Depending on the composition/corrosiveness of the contaminant, the surface may stain. Staining could be subtle, as in the case when it is light and even, or blatant when heavy and aggressively etching the surface leading to pitting.

2. Odor – Another manifestation of contamination is odor, such as that which radiates from smoked equipment, or a stale scent from water exposure. Other effects are less obvious, although are well documented by AREPA and other industry professionals, including comprehensive studies performed by US Office of Nuclear Regulatory Research.

3. Mechanical binding – A less obvious effect of contamination is mechanical binding, in which soot particles can act like grains of sand, and thick oily residue can act as a glue to bind delicate mechanical components.

4. Obscuration – Obscuration is another name for blockage, which primarily affects optical connections in which light signals, such as those used in fiber optics, are blocked by contaminants, thereby deteriorating or preventing transmission of the signal.

5. Increased Resistance – Increased contact resistance occurs when soot blocks the flow of electricity by insulating or tarnishing electrical contacts in connectors, switches, and other devices.

6. Short circuiting – Depending on materials consumed in a fire, some soot will have conductive properties and will cause a short circuit when it bridges two conductors.

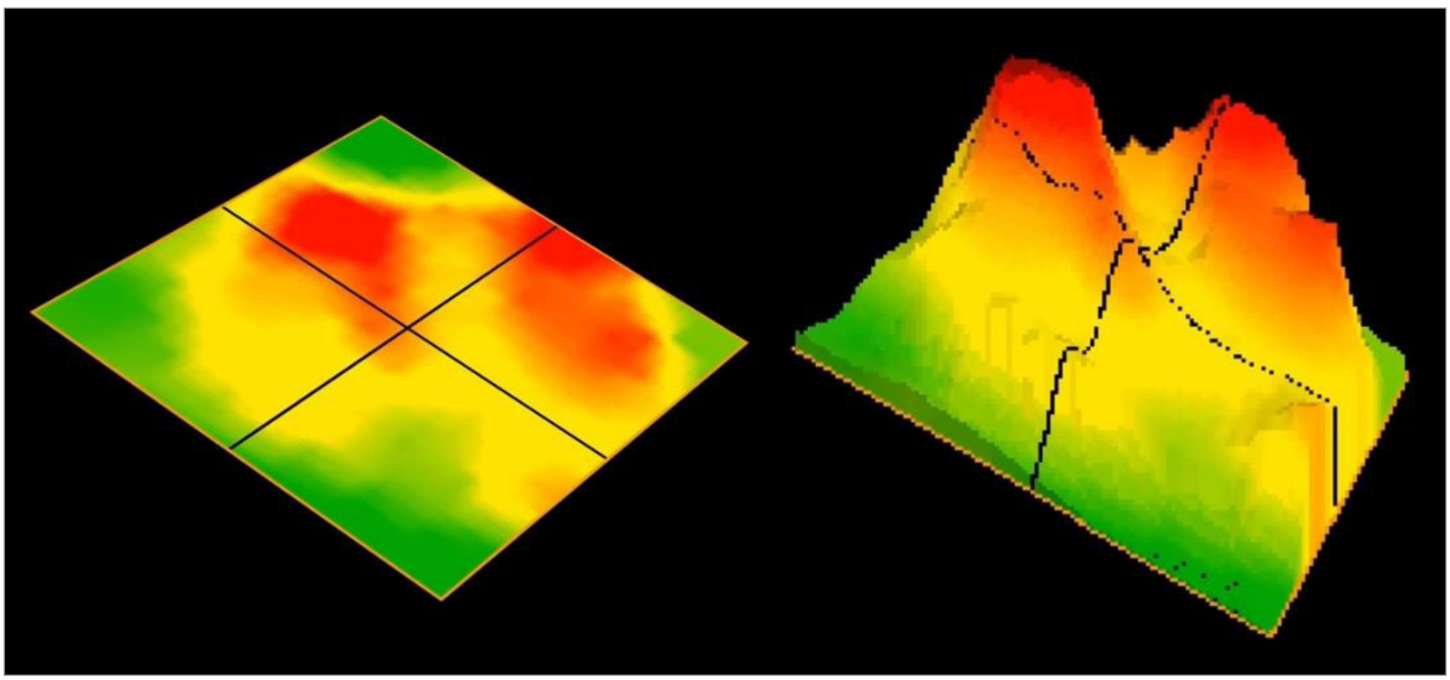

Figure 5.0 – AREPA 3D equivalent salt density map exhibiting conductive matter on a contaminated surface. Conductive areas are shown in red.

7. Thermal dissipation – Contamination deposited on circuit boards does not allow for heat to dissipate as designed by the original equipment manufacturer (OEM).

Following a loss, if the equipment has not been powered on or operated, these effects will not cause damage. The contamination will need to be removed through professional decontamination to ensure that the equipment will continue to operate with the same longevity as before. If the machines have been/are being operated, damage may occur and repairs may need to take place in addition to decontamination. These effects should be weighed against the need to restart the equipment.

CONTAMINATION LEVEL STUDIES AND STANDARDS

To determine whether contamination is detrimental as well as how to set cleanliness targets for technical recovery, we turn to several studies and standards. The Department of Energy (DOE) explained in a study that the problem of fire-induced damage to electrical and electronic equipment can be further broken down into short-term equipment failures occurring during or immediately after an incident, which potentially compromise safety systems or longer-term failures impacting equipment reliability.

In the DOE Fire Protection Handbook, Volume II, under “Fire Effects on Electrical and Electronic Equipment”, it is shown that the probability of failure of equipment increases exponentially with increasing corrosive contamination levels. The study provided scientific data regarding the corrosive contamination level below which the contamination-related failure drops to zero and also levels above which restoration may not be a viable option depending on surface degradation such as pitting. A graphical representation of the DOE study is shown in Figure 6.0.

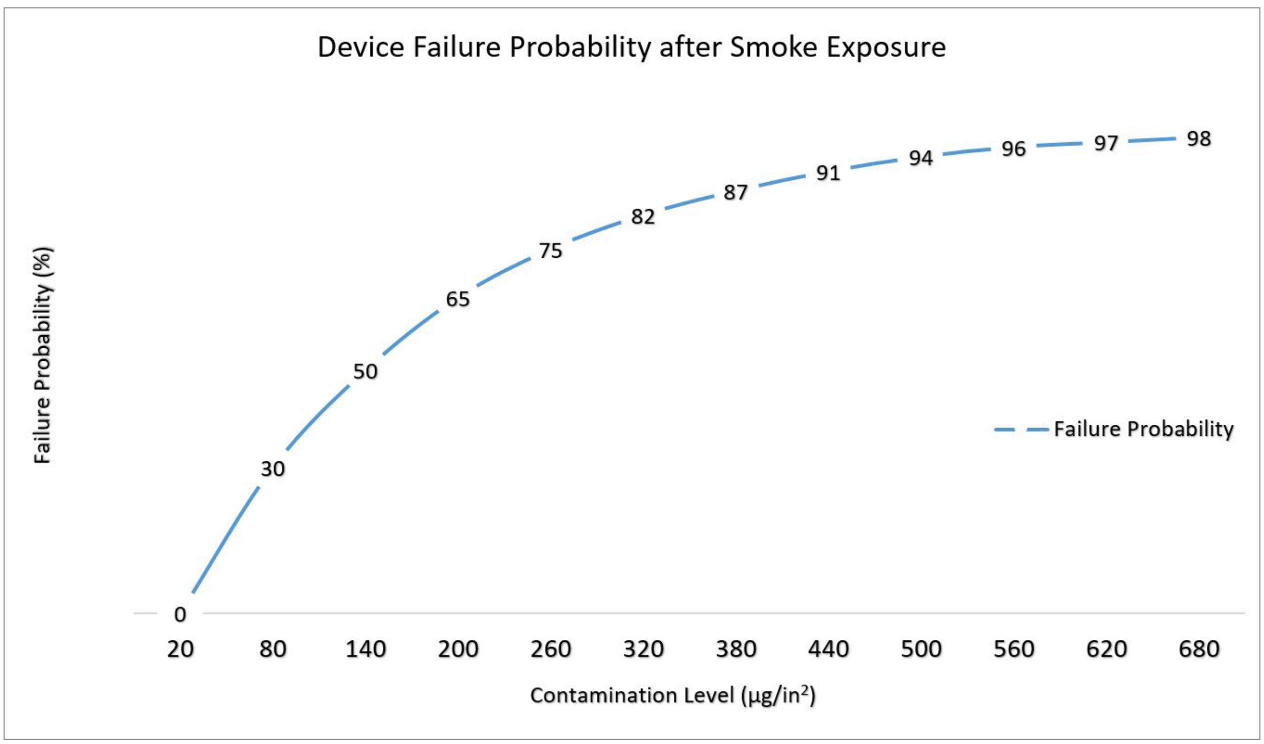

Figure 6.0 – DOE Fire Protection Handbook, Volume II

As exhibited in the graph above, the DOE study shows that equipment with contamination levels that exceed 500 $\mu g/in^2$ (micrograms per square inch) of aggregate chloride equivalent will experience higher rates of failure if the equipment resumes production prior to removal of corrosive matter. The study also shows that at contamination levels of 20 $\mu g/in^2$ or less, the probability of contamination-related failure drops to zero. Therefore, based on the DOE study, for equipment to operate properly with little to no risk of shortened life expectancy, the level of corrosive particulate must be reduced to below 20 $\mu g/in^2$. This reduction in contamination levels occurs through professional decontamination.

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PROFESSIONAL DECONTAMINATION

Professional decontamination accomplishes two goals. First, it ensures that further damage will not occur as a result of loss-related contaminants. Second, it allows service representatives to properly diagnose and repair circuitry without concern for electrical short circuiting as a result of conductive particulate. Following the decontamination, equipment meets the same industry cleanliness threshold required by the OEM. Analytical lab samples harvested after the decontamination provide the empirical cleanliness measure.

Figure 7.0 through 7.5 – Circuitry with matted pre-existing dust and a new layer of soot before and after decontamination

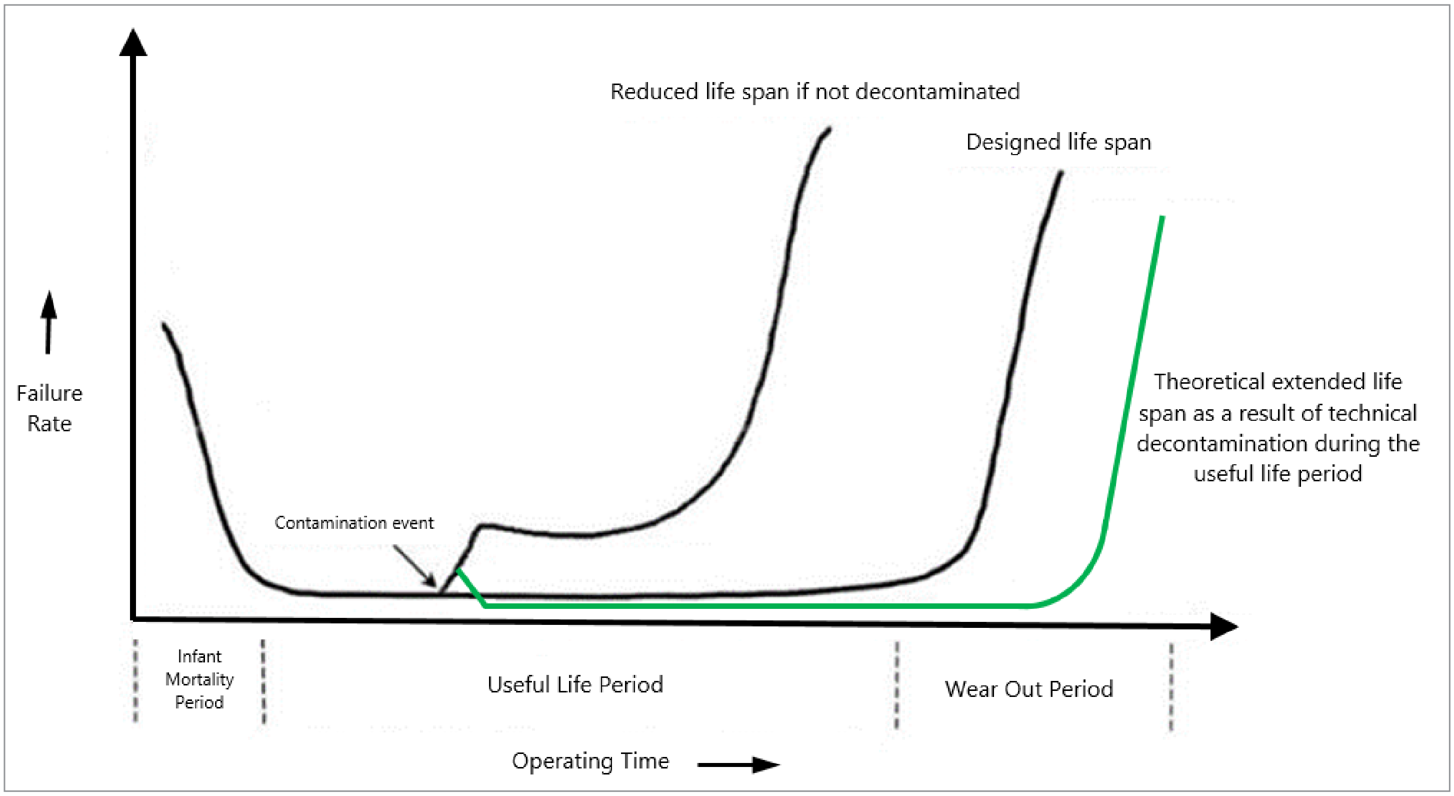

Figure 8.0 – A contamination event illustrated on a bathtub curve

To highlight what will happen during a contamination event, consider a theoretical piece of machinery that has been operating and then subject to a disaster. Figure 8.0 illustrates a contamination event on a bathtub curve. A loss causes foreign particulate to settle on equipment during its useful life period. The equipment has been in production for a while as it is well past the infant mortality stage. Unless an operator employs a maintenance program that includes decontamination of electronics, at this point, circuitry will have pre-existing production debris as well as environmental dust. Loss-related particulate will settle on the existing matter.

Equipment that continues to operate with an added layer of loss particulate, which could be conductive and corrosive, can experience failures almost instantly. Other surfaces may withstand exposure without failures for a longer period of time, as some circuitry is protected with coatings such as conformal coating or other protective finishes such as paint. Such a coating does not prevent the harmful effects of higher operating temperatures, now that the circuitry has more than its “usual” layer of debris preventing thermal dissipation. Therefore, the expected life of that piece of equipment will be measurably less per the DOE study that shows the increased probability of failure with the increase levels of contamination. Thus, the “reduced life span if not decontaminated” line shown in Figure 8.0 has therefore been researched and proven.

As discussed in the studies above, if contaminants from the loss event are removed, probability of failure from the contamination is zero. When professional decontamination takes place, loss-related contaminants are removed in addition to the dust and debris that accumulated over the life of the machine. Thus, the surfaces are back to the same cleanliness levels as when they were first fabricated.

Figure 8.0 also shows a green line with a note that states, “Theoretical extended life span as a result of technical decontamination during the useful life period”. This line accounts for both the zero probability of failure due to removal of loss-related contaminants, as well as improvement in the system by removal of accumulated operational dust and debris.

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The author of this paper is not aware of research showing that by removing pre-existing and loss-related contaminants, followed by testing, repair and recalibration, life expectancy of circuitry/equipment would actually be improved. There are industry professionals that believe this to be the case, arguing that since circuitry will operate at designed temperature levels, and the equipment was thoroughly tested and repaired (to include pre-existing problems), the equipment is as good as new, and as a result, the green line should be considered correct from a technical perspective.

Equipment that has operated for any duration of time, even if maintained properly, will experience normal operational/component wear. The wear may be as expected by the manufacturer, or accelerated if equipment was not optimally maintained. By performing professional decontamination, circuitry is able to dissipate heat as designed. Repairing pre-existing and loss-related functional problems, and ensuring the system functions as specified by the OEM, places the equipment on a favorable path to meet its designed useful life. Life expectancy of electronic equipment post-loss will therefore not diminish if proper mitigation and reconditioning steps are taken immediately following the event.

CONCLUSION

Government entities, universities and the private sector have researched electronic equipment failure modes for decades. While equipment is originally designed to meet a certain lifespan, in many industries the need to maximize production overshadows routine maintenance and equipment is only serviced when it fails.

When a loss occurs, contaminants with corrosive, conductive, or at times just benign properties, settle on pre-existing debris. Pre-existing is a relative term. Data center computer servers are not exposed to the same production debris that exist in a steel mill. Regardless of the environment, loss contaminants on top of anything pre-existing place a greater strain on sensitive electronic and electrical equipment.

Dust accumulation on heat sinks, power connectors, or active devices can act as an insulator and cause overheating. An often quoted rule of thumb in electronics reliability for capacitors is that for every 10°C (18°F) increase, the lifetime approximately halves. For semiconductors, it is a similar change but lifetime is further reduced at higher temperatures. Moist or wet dust can act as a conductor and cause electrical short circuits that may immediately compromise electronic components.

Electrical and electronic equipment can end up with both pre-loss and post-loss contaminants. Professional decontamination followed by OEM or qualified personnel who test, repair and recalibrate the equipment, will restore affected items such that they meet design cleanliness and functionality. Compared to equipment that accumulates production debris and environmental dust, both of which shorten component life as temperatures continuously rise, the likelihood of equipment reaching its designed life is far greater following technical reconditioning.

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