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TECHNICAL ARTICLE: Zinc Contamination in High Technology Facilities©

THE PROBLEM

To ensure the proper function of equipment in today's high-tech facilities, it is imperative that a clean, contaminant free environment be provided. Demand for continuous "up-time" and prohibitively high cost of replacing sensitive equipment that has been damaged by contamination; mandate the control and elimination of dust, dirt and other contaminants within a facility.

A concern that has been gaining recognition worldwide is the formation of zinc crystals (also known as "Zinc Needles" or "Zinc Whiskers") in high tech environments with access flooring. Development of these needles on surfaces with a galvanic zinc-electroplated passivation coating has been recognized for over half a century within the electronics industry. It is the damage potential posed by the formation of these crystals that gives reason for substantial concern. A further cause for concern is long-term exposure of workers to these contaminants with the accompanying potential for massive litigation due to deleterious effects. Equipment replacement and down time costs pale in significance when compared to the potential costs to companies operating facilities with corroding access flooring systems.

In clean room and data center environments, most of the access floor tiles are fabricated with a bottom "pan" that is formed from sheet metal that was originally coated with a zinc-galvanized coating. This coating is designed to act as a sacrificial layer that can corrode slowly while protecting the iron or steel substrate below it, maintaining the structural integrity of the metal. This galvanized metal surface is what enables zinc needles to be formed. Not all-metallic components of access flooring systems are subject to formation of zinc needles on galvanized metal surfaces. Some system manufacturers have begun to utilize metallurgic technologies that counter the development of problem zinc needles.

Concern is increasing over the formation of zinc needles (ZN) contaminant damage caused by airborne distribution in cleanrooms, pharmaceutical facilities, data centers, and electronic component fabrication centers. There is no technology that can eliminate the potential for development of ZN. For many companies ZN formation is an absolute certainty because the access tiles in facilities were produced with metal components that are galvanized by a method that utilized pure zinc technology.

HOW ARE ZINC NEEDLES FORMED?

Zinc needles are zinc crystals formed by the degradation (corrosion) of the galvanized metal surface and commonly form on the bottom and sides of zinc-electroplated access floor tiles. ZN can form on any metal surface where zinc electroplating is present such as the sheet metal frames that support the electronic back panels on some computers. Additionally, ZN can form on the internal face of the galvanized bottom pan of the floor tile. These metallic formations are thoroughly conductive to electrical current and static discharges. Due the continuous forced airflow, brittle ZN can break free and migrate throughout a facility within the plenum area and above the flooring. Once airborne, ZN can settle on any surface, including internal computer components, hardware with moving mechanical parts, and equipment sensors. Even a minimal accumulation is capable of causing severe operational disruption, or worse, total equipment failure. Additional concerns arise over potential health risks to workers exposed to these contaminants over an extended period of time.

GALVANIZING TECHNOLOGIES

Galvanizing is the common name given to the various processes used to apply a thin surface coating of zinc to iron and steel articles and components. This is one of the most commonly used protective coatings, second only to paint, for ferrous metal. Applications using zinc galvanization include structural steel work for construction purposes, sheet metal coating, wires, bolts, nuts and fasteners.

Depending on the cleanliness of the operation and the thickness of the galvanic layers, protection benefits are adequate to prevent corrosion of the steel substrate for up to 60 years. Zinc coatings produced by either method will produce a series of six-sided (hexagonal) cells across the treated surface. This network of zinc cells is appropriately referred to as the zinc lattice.

HOT DIP GALVANIZING PROCESS

Pure zinc can be utilized for protective galvanizing at relatively low temperatures, sometimes referred to as zinc electroplating or CPG (cold process galvanization). The galvanizing process (also referred to as "pickling") utilizes both acidic and alkaline chemical processes. Pure galvanic zinc reacts with air immediately to produce a relatively stable, oxide film that inhibits corrosive decay of the substrate materials, including the pure zinc layer below, from which the zinc oxide layer is formed. Unfortunately pure zinc is highly susceptible to electrochemical attack. For this reason, an alloyed mixture is preferred, preferably a mixture including nickel, titanium, and/or aluminum.

A properly balanced "hot" galvanizing (HDP) formula will provide greatly enhanced protection against abrasion damage, corrosion, and result in an extremely elastic galvanic layer. Alloyed galvanizing formulations with a ratio of 78% zinc and 22% aluminum exhibit superplastic characteristics, ideal for high stress applications.

Alloyed ("hot") zinc galvanizing requires considerably more energy than a "cold" process system. However, the corrosion inhibiting results make this method far more desirable for critical applications. Newer access floor tiles demonstrate the application of advanced engineering principles, including modern alloyed hot galvanizing. These tiles will have a corrugated "pan", providing minimal deflection under stress loads. The galvanized film is much cleaner and more consistent, lacking the "spangling" or irregular pattern of older, non-alloyed technologies.

The "hot dip" galvanizing process (HDG) is often utilized for fabricated components such as joists, girders, and pipe. The first step is a cleaning process to ensure that the article to be galvanized is free of oils and dirt. If the surface is not free of all contaminants, the zinc will not react with the steel to form the galvanized coating. The article is first immersed in an alkali bath. It then has any surface oxides and carbonates removed (called descaling) in a bath of hydrochloric or sulfuric acid. This is followed by the application of a fluxing solution consisting of zinc ammonium chloride, just prior to coating with the zinc alloy materials.

The second step is the process where the article is submerged in two baths of molten zinc alloy followed by a final immersion in pure molten zinc. Immediately after a zinc chromate quench to cool and harden the zinc alloy. Quenching causes the metal to reduce, forming a crystallized lattice instantly. The chromate radical serves to neutralize the chemical reactive nature of the zinc surface to prevent early oxidation. This is called passivation.

The zinc coating resulting from the HDG process is actually a series of three layers. The original steel material is covered with two layers of iron-zinc alloys. The layer in contact with the steel surface is very low in zinc content ($FeZn_3$), while the second layer has a higher zinc content ($FeZn_7$). Finally, the outer coating of the article is pure zinc. The surface of this pure zinc layer that has contact with air immediately oxidizes into zinc oxide (2ZnO). The goal is to create all three layers as thin as possible to prevent flaking. The foundation layers of iron-zinc alloys are very brittle. Ferric-Zinc alloys may require working temperatures from above 880F to nearly 1400F, the basis for the "hot" process terminology. Temperatures required for this process can be twice as hot as those required for "cold" process galvanizing.

Traditionally, hot dip processes were not utilized extensively for sheet metal stocks since adequate protection could be created by means of less costly Cold Process Galvanizing. More recently, HDG technologies are being utilized for sheet metal stocks. HDG produces a finer more sophisticated protection barrier and provides an esthetically more appealing surface. HDG metals are easier to coat and provide a more stable foundation for paint, epoxy, and powder coatings.

COLD GALVANIZING PROCESS

A commonly used galvanizing method is a form of "cold" process galvanization (CPG), also referred to as Zinc Electroplating. The "cold" process term is actually only referring to the lower working temperatures required to produce molten zinc. In this process, a single coiled sheet of metal is annealed (tempered by heating and allowed to gradually cool to reduce stress within the metal) and then fed into a galvanizing line. As the sheet moves through the line it is degreased, pickled (treated with both acidic and alkaline chemical processes), rinsed, fluxed. The steel sheet stock is then dried prior to immersion in the pure zinc-galvanizing bath. An high energy electrical current is supplied through the steel sheet stock which creates a clean, molten reaction between the steel and the zinc bath. Within seconds of removal from the pure zinc bath, the zinc surface in contact with air reacts to form zinc oxide, a stable, dull gray material that is only a few molecules thick. Below the new, zinc oxide layer is a protective substrate of 100% pure, unreacted zinc.

It is metals that have been treated by means of this Cold Process Galvanizing (CPG) that is the source of ZN problems in high-tech environments.

HOW GALVANIZING ASSISTS IN CORROSION PREVENTION

It is important to recognize that galvanization does not prevent corrosion. Rather, it is a means of controlling to some extent the target material and rate of corrosion. Galvanized coatings are intended to corrode over time.

Zinc based material corrosion is initiated by either of two catalysts:

1. Moisture
2. Oxygen

It is the humidity level maintained in critical environments that enables the corrosive reaction with oxygen in the atmosphere. Ozone will accelerate the formation rate of ZN. The zinc coating provides a protective layer that protects galvanized ferrous metals. Zinc inhibits, but cannot completely eliminate the corrosive effects of atmospheric water vapor (humidity) and oxygen.

Zinc galvanizing protects ferric metals in two ways:

1. It is a physical barrier that protects the iron or steel from contact with the surrounding air.
2. If there is a break in the zinc coating, the zinc surrounding the break provides a type of *cathodic protection* to the encased metal. This is because zinc is more electropositive than the metal it encases; it is more likely to lose its *valence electrons* (electrons in the outer shell of the zinc atom that transfer to the oxygen molecules creating corrosion products).

The minute amount of moisture in the air causes the zinc to become the actively corroding metal (anode). Corrosion is accelerated as the decaying zinc surface releases remaining electrons through the lattice to the iron or steel below (the cathode). This continues until the anode (zinc) oxidizes and corrodes completely away.

These crystalline corrosion byproducts are six sided and rod shaped in form. These crystalline rods are commonly referred to as zinc whiskers, although the more appropriate term is zinc needles (ZN). Zinc crystals will continue to grow without oxidizing since the crystals are actually discharge points for releasing excess electrons that may gather at the tip. This induction process acts to prevent decay or oxidation destruction of the zinc needles.

All metals are based on a lattice structure of positive metal ions that is neutralized by a surrounding cloud of electrons. The electrons are free to move throughout the lattice and give rise to the high optical reflectivity and electrical and thermal conductivity characteristics of metals.

All solid materials can be divided into two types, amorphous and crystalline. Zinc based materials may exist in either form. High purity zinc in ZN is a result of a regular arrangement of the atoms in a consistently orderly way. This is a result of consistently uniform environmental conditions over an extended period of time; exactly what a cleanroom environment is designed to support.

ZINC-ELECTROPLATING OF ACCESS FLOOR SYSTEM COMPONENTS

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 stocks utilized to produce their products. The resulting situation "An ounce of incompatible prevention is worth a pound of corrosion".

This has resulted in a catastrophic failure of the integrity of galvanized materials applied to flooring components, although galvanized coatings are commonly viewed to have a useful life of 50 to 60 years. It is the programmed oxidation of the galvanized surface that is precisely the problem.

Specifications for critical environment construction materials have obviously improved much in the years since these products were first introduced. Unfortunately, this is of little comfort to companies with facilities that are outfitted with construction materials that are incompatible with the environmental properties of the facility.

Many access floor systems have tiles with a electroplated zinc coating on the tile pan. Corrosion can begin quickly around stress points (screw holes or bent portions of the pan) and where contaminants have adhered to the galvanized surface (dirt, cleaning products, and moisture).

As corrosion begins, the protective barrier has served the purpose for which it was designed. That is, the galvanized coating is corroding at a faster rate than the metal it encases. The result of this corrosion is not a loose powdery substance, like iron rust. Instead, it is an oxide film that adheres strongly to the surface. It is at these points where a break in the protective lattice (the zinc-galvanized coating) occurs and pure zinc crystal formations are forced out to the surface.

Maintaining the integrity of the galvanic film or lattice is critical to insure protection of the substrate, thus minimizing corrosion and crystal formation. Any moisture will provide a basis for gradual deterioration of the galvanic barrier. The small amount of moisture in air is enough to "activate" the oxidized zinc film. Over time, by means of electrolytic reactions between the pure zinc and the ferric substrates, ions will transfer through the lattice to the surface of the zinc oxide film. These ions will congregate to form high purity zinc, which is crystalline and very uniform in structure. Ions will gather at the apex of any raised portion of the surface and this location is where the formation of needles begins. Over time, these needles will continuously grow as new ions gather at the tip. Given enough formation time, these needles can grow to a considerable length, exceeding 2 centimeters.

Pure zinc is normally very unstable and will readily oxidize to become a stable byproduct. However, due to the electrolytic condition created by the moisture, the high purity zinc needles will not oxidize in the presence of air. An electrical cell structure has developed, with free flowing static created electrons preventing oxidation of the zinc needles.

As the integrity of the galvanized surface begins to decay while at the same time the needle cluster grows, ion transfer accelerates, increasing the formation rate of the crystals. Samplings from galvanized panels in high-energy environments have demonstrated that needle formation can begin in as little as three months. How fast ZN form is determined by the composition of the galvanizing material and the method of application. Additional variables include the cleanliness of the long-term environment, contaminants within the long-term environment, and the humidity and airflow within the long-term environment.

It is the growth of these needle-like zinc crystals that presents the largest problem for technological facilities, their equipment and the personnel within them. As the crystals grow, they can break off and be spread throughout the facility by the continuous forced airflow within the plenum (the area below the floor tiles) and the forced airflow above it. ZN can then settle on any surface with the potential to cause catastrophic failures. Failure and down time for the facility represent huge expenses in the form of emergency repair costs and possible damage claims due to interruption of service to the client.

ADDITIONAL CONCERNS

We feel that there is a far more pressing area of concern that has yet to be addressed by the industry as a whole. Generally, any discussion of the potential for hazard to humans is kept under wraps. Proper functioning of the equipment is an important focus. However, it is also necessary to consider the "human factor", damage that could possibly result from the inhalation, contact with, and ingestion of high purity zinc needles by personnel within the facility. Due to the controlled and constant airflow within these high-tech facilities, a contaminated facility demonstrates a thorough distribution of the zinc needles throughout the contamination area. Zinc needles are light enough to be carried in the airflow and can therefore be conveyed to any point in the facility that is exposed to the common air source. This means that they can settle on equipment just as easily as they can be inhaled from the air.

In times past, workers were not typically in an environment where zinc whiskers would occur, much less a "sealed" environment.

Worker exposure to zinc needles will result in an environment where the following exist:

1. A confined, electrochemically active environment that enables the formation of these crystals.
2. Moisture. Over a prolonged period of time, even trace amount of moisture in the environment can result in total migration of an oxidized, high purity galvanic zinc into high purity zinc crystals (needles).
3. The presence of high purity zinc galvanized metals especially when developing over a relatively large surface area (high square footage facilities of 10,000 ft^2 or more.
4. Time for the crystals to grow.
5. Potential for the airborne relocation of the crystals from the zinc surface to the breathing area.

Zinc oxide is a skin treatment utilized to sooth and protect healthy skin. In contrast, pure zinc is classified as an irritant, even for skin contact. Scientific studies have not yet been conducted to conclusively identify zinc needles as a health risk. Consideration of similar materials and hazards based exclusively on the form (crystalline needle), dictates that caution be urged. Consider fiberglass needles, gypsum, or asbestos. It is the shape of these materials that presents a risk to workers.

OSHA policies for employee exposure to any airborne contaminants in a confined environment should bring immediate focus to addressing this problem at facilities with ZN contamination. Pure zinc needles in the moist environment of the lungs will react readily due to body electrolytes, thus producing any of numerous byproduct contaminants. Also of concern is the fact that microbial life forms have an affinity for light metals in moist environments. Zinc needles in the lungs may provide a perfect "farm bed" for development of active microbial colonies and sporiform propagation.

The hermetic environment of today's high-tech facilities is unusual and prohibits dispersion and promotes the accumulation of the zinc needles. This raises the probability of serious health risks, to include occupational asthma, allergic alveolitis, interstitial fibrosis, or pneumoconiosis. Long term exposure could possibly lead to development of emphysema and chronic bronchitis.

Symptoms may be similar to those of silicosis and the severity of risk is directly related to the duration of exposure and the amount of crystal inhaled. Even minimal exposure may create acute reactions in sensitive individuals. "Zinc Fever" can develop in individuals who have had exposure to inhalation of high concentrations of zinc. This syndrome is already well documented. Individuals who have experienced threshold exposure to inhalation of zinc develop flu-like symptoms including elevated body temperature, coughing, nausea, and profuse perspiration. Exposure thresholds vary between individuals.

Though these findings are only recently being investigated, the hazardous potential for any airborne contaminant must be acknowledged and addressed by responsible officials within the industry. Failure to initiate a remedy to current contamination problem contributes to the potential for future litigation over system failure and health related injuries.

Airborne ZN will be maximized during the remediation procedure. Therefore, technicians involved in the removal of contamination in cleanroom and other high technology environments should utilize asbestos abatement personal protection protocols as necessary to prevent aspiration of zinc needles 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 needle contamination.

DETERMINATION OF WHETHER OR NOT A FACILITY HAS ZINC NEEDLE CONTAMINATION

With the preceding factors in mind, it is necessary to consider all aspects of the corrective measures to be made for the control and abatement of the ZN within a facility.

Before any refurbishment or replacement can take place, it is important to determine to what extent zinc needles have contaminated the area. A sampling needs to be taken by competent personnel who understand the importance of avoiding spreading ZN 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.

Tiles from several locations within the facility should be removed and forwarded to a qualified lab for analysis. Floor tiles that are uniformly flat across the bottom and have a dark gray appearance are the most common for ZN formation. Often there will be distinct darkened areas where staining from fingerprints or cleaning solutions have been deposited and facilitated rapid attack of the galvanic coating.

Newer galvanizing technologies do not demonstrate accelerated needle formation. These materials will usually have a semi-gloss green/gray to blue/gray appearance. Usually, properly protected, "hot dipped" galvanized surfaces will have the appearance of powder coated metals. The texture will feel smooth and somewhat resilient, almost plastic.

Both high purity and alloyed, cold and hot process galvanic metals are readily conductive to electricity. The "pan" assembly may initially have good contact with the support stringer assembly, providing a conductive discharge conduit that serves to prevent static accumulation. Over time, in the case of flat pan tiles, the corrosion will be most pronounced along edge of the tiles where contact is made with the support stringers. Often this is highlighted by the development of rust along the edges of the tile, indicating total degradation of the galvanic barrier in these areas. Where rust is present, the substrate steel material has been exposed. The exposed steel then begins to corrode and rust due to ion transfer facilitated by the humid environment. Ultimately, this leads to scaled rust, which becomes brittle and eventually will be released as particulate contamination in the ambient environment. The more contamination that exists in the environment, the more likely and sooner that zinc needles will form.

The sample tiles should be tested using High Frequency Radiography and High Energy Pulse Conductivity testing methods. If the sample tiles test positive it will be necessary to evaluate the extent of contamination. If the contamination is widespread, the decision between replacing or refurbishing the tiles must be made.

REFURBISHING VS. REPLACEMENT

When any contamination is found, it is necessary to act quickly in order to minimize any existing or potential damage to the facility and its equipment. What action should be taken depends on several factors.

Some individuals have the opinion that access flooring systems with ZN development should be replaced due to prohibitively high cost of remediation. Quite to the contrary, we feel that a sensible and effective remediation will provide substantially better overall results than replacement alone. Decontamination cleaning during a refurbishing procedure can actually provide enhanced results over merely replacing tiles with ZN contamination.

Additionally, if the same cleaning procedures are utilized for treatment of access flooring support fixtures and decontamination of the plenum area, refurbishing can provide substantial savings while virtually eliminating disruption of the facility and the need for shimming tiles to remove lippage.
Factors which must be addressed to determine which method is most suitable for dealing with ZN:

- The extent of the 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. Can it be powered down temporarily, or is there a zero tolerance for shutdown?
- Management commitment to minimize any potential for equipment failure and health risks to workers.

Although a facility may only be affected in specific areas with minimal corrosion development, a complete cleaning of the facility is necessary to include areas above and below the access flooring system. Tiles in areas with ZN development must be replaced or refurbished utilizing the Formula Science Corporation's MATRIX SYSTEM™ remediation procedures.

In facilities where there are older access floor tiles or have atmospheric conditions that have hastened and facilitated the formation of zinc needles, the larger issue of cost comes into play. Is it more cost effective to replace or refurbish the tiles? This decision must be made on a case-by-case basis. In any event, the entire facility needs to be treated with specific techniques and equipment to prevent cross contamination and ensure that all contaminated areas are properly cleaned and treated.

SUMMARY

Cost effective ZN remediation is a function of careful planning and efficient operations. Costs of remediation can be carried out quickly, greatly minimize the impact on client operations. Additionally, the cost of the refurbishing ZN contaminated components is far less than the cost of replacing the affected tiles.

Beyond this, contamination of any kind in high technology environments will essentially lead to more and more corrosion and increased potential for damage. Essentially, companies operating facilities with access flooring in hermetic environments have three choices:

- Do nothing at all on the chance that the problem will not manifest itself.
- Adopt a short-term remediation initiative which will provide a known level of security immediately.
- Develop a meaningful maintenance operation procedure that ensures a consistently non-contaminated environment throughout the future.
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Additionally, the question of liability provides considerable reason to act quickly. Once a company becomes aware of the high risks associated with the development of ZN, the question of negligence in the event of a catastrophic failure or injury to workers cannot be overlooked.

Intelligent utilization of available technologies will provide maximum control of contamination, including ZN in high technology environments. Utilization of the full spectrum of the Formula Science Corporation MATRIX SYSTEM™ control measures ill provide a solid basis for establishing efficient and simplified maintenance programs throughout the future due to the fact that all potential problem surface materials are of known chemical structure and physical property.

It is always better to provide a clean, contaminant free environment for personnel and for equipment. Many companies move into older facilities that are structurally and geographically ideal for their needs but contain older or contaminated flooring and air conditioning systems. In this instance, it is imperative that determinations be made prior to introducing any equipment into the facility. If the contamination exists, make the preparations to minimize or eliminate it first.
By understanding the extent of the problem and the potential difficulties it can cause in the future, a proactive effort can be made to eliminate them before they happen saving the facility time and money. Ongoing maintenance will serve as an essential part of an intelligent facility maintenance program.

We must reemphasize the importance of a regular, comprehensive cleaning program in high technology environments. These facilities are unique in many ways. These facilities were designed to control contaminants. Many facilities utilize the best technologies available to prevent external contaminants for entering these areas. The reality is that these environments are ideal for trapping contaminants inside the sealed areas as these develop. Air turnover alone will do nothing to eliminate disease, static, or rust. In fact, all of these are supported by the presence of air. Airflow has more to do with contamination than cleanliness. High airflow merely ensures good distribution of air AND CONTAMINANTS.

ZN development can be “seeded” by the presence of foreign contaminant materials, including paper dust, cellulosic and gypsum debris, calcium dust, etc. Virtually any contaminant in the environment can begin the process of ZN development, simply by triggering the gathering of electrons to a particular area of zinc electroplated metallic surfaces. Although ZN may not be a problem in every facility, it is a fact that debris is present in the plenum area which can and is being distributed throughout the facility. This is true for facilities with maintenance cleaning programs as well. Controlling accumulation of that debris becomes the focus of intelligent maintenance. Virtually all harmful contaminants that become apparent in theses environments can be traced to airborne distribution.

Regular decontamination procedures will prevent most foreign matter related equipment failures. Most importantly, regular, properly conducted decontamination cleaning will ensure the safety of workers that must spend long hours in such environments, especially over many months or years.
Sick Building Syndrome (SBS) is a reality that cannot be overlooked. Legislation is before U.S. Congress this year. Bills under consideration in Congress include those that require massive investments to retrofit commercial and public facilities. All of this has come about because of unseen airborne impurities. Addressing these issues intelligently will provide a basis for minimal legislative interference.

Initiating a meaningful facilities maintenance program is costly. However, far less costly than the massive costs of down time due to equipment failure, or worse, worker litigation due to damaged health because of negligence in dealing with these considerations.

Organizations that adopt a focus toward maintaining a clean, safe, healthy working environment for workers and equipment will often never realize just how much they have actually saved by investing instead in scheduled maintenance. We never appreciate the cost of accidents that we are able to avoid.

We encourage all companies that operate high technology cleanroom and data facilities to enlist the services of qualified professional organizations specializing exclusively in supporting such environments. Survey the entire facility thoroughly, including inside the air handling systems other than the floor plenum area. Keep a log of inspection results and deal with problem areas quickly and responsibly.

Formula Science Corporation® offers complete sample analysis and on-site survey assistance. Our goal is to assist you with all environmental issues that are encountered in the built environment.