5-0 POLLUTION

> ***"There is substantial evidence that indoor air pollution causes significant damage to cultural property."***
>
> ***- Norteb S. Baer and Paul N. Banks*** [1]

Pollution and the damage from pollutants are not new concerns. Over 700 years ago, in 1284 a Royal Commission was appointed to investigate air pollution from coal burning in London and Southwark.[2] Unfortunately the commission could only study the problem and propose restrictions on coal burning. Since then, pollution issues have moved slowly and steadily to the forefront of public awareness. Depressingly, most research has focused on exactly those same 700-year-old tactics; documenting damage and trying to reduce or eliminate pollution at its sources.

Museum professionals need to understand that pollution is and will remain a threat to collections. Pollution is universal. All of the things that are outside a museum are bound to work their way inside. We also have a plethora of things inside the gallery, often including the artifacts themselves that are in fact pollution sources. These things, like the other dangers to our artifacts, light, temperature and humidity can operate very slowly and their damage is quite often not immediately apparent. As Barbara Appelbaum points out:

> "Deterioration of objects caused by impurities in the air is difficult for people to take as seriously as deterioration from other sources, because it is seldom as easy to detect."[3]

It is sad but true. Many conservation efforts are undertaken only after there is visible damage to an artifact. Fingerprints irrevocably etched into a brass object teach us to wear gloves. A split piece of ivory teaches us about cycles in humidity or temperature. A bleached watercolor teaches us about photochemical damage. A dark crumbly piece of parchment or leather teaches us about acid absorption from polluted air. We must learn to anticipate dangers and take preventative action <u>before</u> damage becomes apparent.

To do this, and at the risk of following the procedures of the 700-year-old Royal Commission mentioned above, we need to review some of the pollution

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[1] Norteb S. Baer and Paul N. Banks, "Indoor Air Pollution: Effects of Cultural and Historical Materials" in <u>Care of Collections</u>, Leicester Readers in Museum Studies, ed. Simon Knell (London and New York: Routledge, 1994), p. 144.

[2] Norteb S. Baer and Paul N. Banks, p. 135.

[3] Barbara Appelbaum, p. 97.

dangers to museum collections. As mentioned above these are from a variety of sources, inside and outside our galleries and often include the artifacts themselves. A very incomplete list of these pollutants is given below. They have been listed in two groups, particulate and chemical.

The distinction may appear at first to be somewhat fuzzy. Some particulate pollutants do chemical damage and some chemicals (chlorides in particular) form particulates. The distinction is due to the methods used to dealt with them. Particulate pollutants are dealt with mechanically, by filtering, trapping or physically preventing contact. Chemical pollution is usually in the form of an airborne gas or vapor that must be chemically treated or neutralized. The divisions will roughly follow the treatment processes, mechanical entrapment or chemical neutralizing. Within each group they are listed in alphabetical order. Conditions and exposures can vary so wildly, even within our strictly controlled museum environments, that it is impossible to classify pollutants by their relative threat to exhibits.

5-1 Particulate Pollutants

Alkaline aerosols are tiny particles emitted from new concrete and new plaster. These particles are so small (.01 micron range)[4] that they act more like gas molecules than particles. Barbara Appelbaum states “even in well-ventilated spaces, concrete has been said to release alkaline materials into the air for about two years after it is poured.”[5] Alkaline pollutants in a museum environment can fade organic dyes, damage textiles, produce a haze on paintings and other surfaces, and even affect the accuracy of humidity sensors.

Bacteria present a problem in classification. They can be both a form of pollution and an infestation. They can be seen as chemical and particulate. They are classified here as a form of pollution because like other forms we are examining, they are constantly being introduced to the museum environment. While bacteria can produce hydrogen sulfide, that in turn can cause acid damage to metals and other materials, bacteria should primarily be considered a health hazard.

Bacteria, like molds, tend to thrive in warm, humid environments. As with molds, this can be any damp place in a museum building or within an air conditioning system.

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[4] Garry Thomson, p. 133.

[5] Barbara Appelbaum, p. 101.

> "Normal bacteria require a very high RH, about 90%, to grow best, with halophic bacteria a notable exception at 75% RH."[6]

This should not be taken however as meaning that lower temperature and humidity will maintain a bacteria free environment. Bacteria are surprisingly versatile. They have been discovered in some amazing places.

A major source of bacteria often overlooked in the museum environment is the visitor. The average human being exhales one-half of a cup of saliva in vapor each day. Whatever bacteria are present in your visitor will be present in this vapor. (Digestive enzymes, amino acids, ketones and other visitor products are mentioned elsewhere.)[7]

These bacteria can survive quite nicely in the controlled light levels, temperature and humidity of a museum environment. As a matter of fact, hospitals deal with bacteria by providing almost exactly the opposite of the ideal museum environment; high light levels, extreme UV, high temperatures and exposure to highly reactive materials including ozone. All this means that the risk of bacterial pollution in your facility is directly related to your attendance numbers.

A second surprising source of bacterial pollution (infection) can be from the artifacts themselves. Shin Maekawa at the Getty Institute found *Aspergillus niger, Aspergilus flavus, Penicillium commune, Actinomyces sp., Bacillus sp.*, *Streptomyces sp.* and other aerobic and anaerobic bacteria on the skin of a 3,000-year-old adult female mummy on loan from the Egyptian Antiquities Organization.[8] These bacteria were cultured and grown in Getty tests.

Another Egyptian mummy, this one of a five-year-old-boy was tested. This mummy had been on display in Spain since 1886. Maekawa found *Penicillium, Aspergillus, Ulocladium, Stachybotrys, Bacillus, Streptococcus, Actinomyces, Mucor, and Streptomyces.*[9] These pollutants were in the artifact and in fact concentrated inside the display case. Case breathing would expose gallery air (staff and visitors) to the case contents.

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[6] Shin Maekawa, p. 21.

[7] With some simple but gross math you can calculate your museum's saliva load. Dividing 0.5 cups per person per day by 24 hours gives you 0.02 cups per visitor hour. Multiply this by your daily attendance and adjust for your average length of stay. If you have 100 visitors a day who stay an hour and a half, they will leave 3 cups of saliva vapor in your museum. This vapor (and everything in it) will condense out on the walls, paintings, cases, sculptures and every surface cooler than body temperature. The rest will enter your air conditioning system to remain a part of the RH in your musuem.

[8] Shin Maekawa, p. 20.

[9] Shin Maekawa, p. 24.

This could give entirely new meaning to the old movie title, *"Revenge of the Mummy."* Maekawa did not track staff illnesses in Spain or during the Getty's decontamination procedures. We can only hope that the 3,000 year-old *Penicillium* was viable enough to deal with the 3,000 year-old *Streptococcus*.

Chlorides are a serious cause of corrosion in metals. They are usually encountered as airborne particles in crystalline form. Chlorides are hygroscopic and can maintain a high local RH even in a much dryer environment. Sodium chloride (NaCl), common salt, is present in significant quantities in seawater, sea air, human perspiration, fingerprint residue, impurities in clay casting cores and burial soils. Salt is present in any artifact recovered from the ocean. Salts may also be present in many soils far from the ocean, especially in irrigated areas with high evaporation and in materials including iron that have been long buried.[10]

Chlorides cause severe corrosion in silver, copper, bronze and accelerate corrosion in other metals. Do not think that this type of pollution is limited just to metal objects. Chlorides can dramatically affect things we would never consider as "metal." Pigments in paintings often contain metals and metal oxides. Chloride pollution can cause painting pigments to change color. Chlorides attaching to metals in inks can corrode holes in both fabrics and documents. Hidden metal fasteners in furniture and even gilding are prime candidates for attack.

Crystal formation due to evaporation and cycles in humidity in articles contaminated with salt can cause structural damage. The power of crystal formation inside a structure is awesome. In high salt desert areas telephone poles leach chlorides out of the soil swelling to 2 or 3 times their diameter before literally coming apart in a years-long slow-motion explosion. Chlorides can destroy artifacts by much the same process, especially where humidity cycles are extreme.

Dust is probably the most common and most universal pollutant. In areas with strong winds, dusts can include particles the size of grains of sand. Dusts settle on surfaces. They are abrasive and can be difficult to remove. Dusts attract and hold moisture.[11] Dust can be filled with nutritious materials for pests and often provides ideal microclimates for fungus, molds and mildews.

Besides creating a danger to artifacts, dusts can represent a sizable investment in museum labor. Removing artifacts, dusting and cleaning each of them without damaging them, cleaning their display

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[10] Suzanne Keene, "Real-Time Survival Rates for Treatments of Archaeological Iron," in Ancient & Historic Metals: Conservation and Scientific Research, ed. David Scott, Jerry Podnay, and Brian B. Considine (Los Angeles: The Getty Conservation Institute, 1994), p. 250.

[11] Marjorie Shelley, p. 8.

cases and then replacing the artifacts requires planning, care and time. Measures to remove dust are often cost effective simply in terms of cleaning budgets.

Fingerprints are a source of water, oils, acids and salts. With16 years in law enforcement, many years of that as a crime scene investigator and evidence officer, I can assure you that although initially these deposits are invisible, they will last for weeks or months and in some cases for years. Although roughly 98% of the residue of a fingerprint is water, the sebaceous oils and amino acids in fingerprints are mildly hygroscopic. They will re-hydrate in an environment with sufficient RH. Even when dried, the amino acids in fingerprints remain chemically active. Fingerprints can cause irreversible etching on metal surfaces.[12] They can attract dust and dirt and soak into porous surfaces where they cannot be cleaned.

Museums should have a strict rule that clean gloves be worn whenever handling any artifact. Cloth gloves are better than latex or plastic gloves. It is possible to touch your face or hair wearing plastic gloves and then leave beautiful classifiable (identifiable) fingerprints on a surface. Don't let them be your fingerprints. Even when using cloth gloves, change them often and launder them well.[13]

Gloves are also valuable to protect you from the exhibits. See the sections on bacteria and poisons.

Fungi like molds thrive in warm temperatures, high humidities and dusty conditions. (Mold is a form of fungus. See the description of mold following.)

Micro-carbon particles come primarily from auto exhaust, tires, brakes and industrial sources. Carbon particles range in size from heavy industrial dusts to impurities so small that Brownian motion will keep them suspended in the air forever (unless they impact a surface). There are many materials in museum collections that cannot be effectively cleaned. William Nazaroff writes:

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[12] Janet L. Schrenk, "The Royal Art of Benin: Surfaces, Past and Present," in Ancient & Historic Metals: Conservation and Scientific Research, ed. David Scott, Jerry Podnay, and Brian B. Considine (Los Angeles: The Getty Conservation Institute, 1994), pp. 51-62.

[13] For an interesting demonstration, draw your thumb and index finger down your nose and then pick up a piece of photocopy paper. Then look at the paper for your fingerprint. You will probably see nothing at all. Now take a soft paintbrush and a little bit of Xerox® toner from the same machine from which you got the paper. Brushing the powder lightly across the spot you touched will develop a beautiful fingerprint. You can do this same experiment, and leave the same fingerprint, while wearing disposable latex or plastic gloves. We recommend that museums have all of their key staff go through these steps as an example of how easy it is to leave fingerprints. To add impact, you may ask them to sign their papers and then tell them you'll be keeping them to compare to fingerprints on artifacts.

> "It is doubtful that once small particles settle on certain surfaces – such as feathers, fur, botanical specimens, large unframed tapestries and rugs, and unvarnished paintings – they can ever be removed."[14]

Very small particles, especially carbon-based particles may be impossible to remove from any porous surface.

> "Once these small particles become imbedded in the surface texture, they become a permanent part of the structure."[15]

Some micro-carbon particles are actually a chain of carbon molecules. Active Brownian motion and thermophoresis[16] can literally drive these into the surface structure of an artifact. In organic materials, this penetration can be relatively deep. Careful cleaning will remove the material protruding from the surface, breaking off the chain, leaving the remainder a permanent part of the artifact. Micro-carbon pollution is ubiquitous in any city environment. Infrared control is vital to controlling micro-carbon pollution.

Mold spores are universal. Sources of mold in a museum can vary from the artifacts themselves, to air conditioning systems, to damp areas in basements or other parts of the building. Mold is a kind of fungus. As with any plant, it requires water and "soil". Mold is usually associated with high temperatures (above 70°F) coupled with high RH (above 70%). As Barbara Appelbaum points out anyone who has left food in their refrigerator for too long knows that with the right nutrients mold can grow at significantly lower temperature and humidity.[17] Cleanliness (controlling dust) is an important factor in controlling mold. Dust coupled with IR surface heating and the condensation resulting from heating and cooling cycles will practically guarantee problems with mold.

Pollen is a particle naturally present everywhere. Pollens are relatively large particles, 10 to 100 microns in diameter. They are also naturally "sticky", that is they are designed to adhere to surfaces. These characteristics make them both relatively easy to filter and relatively difficult to clean from objects.

Remember that pollens can in some circumstances be considered an important part of authenticating the origin or history of a particular artifact. Pollens are identifiable and often area specific. The relative recent scientific arguments over the pollens found on the Shroud of Tourin,

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14 William Nazaroff, et al. P 6.

15 William Nazaroff, et al, p. 6.

16 See section 3-7.

17 Barbara Appelbaum, p. 138.

if nothing else, give us an example of the rationale of preserving “historic” pollens on an artifact and protecting an artifact from current contamination.

Skin cells are not only one of the sources of dust and pollution in a museum environment, but they provide the base for the insect food chain from carpet mites to those higher up. An average human sheds 1.5 grams of skin cells a day. These cells come equipped with all of the amino acids and sebaceous oils that make fingerprints so dangerous to art and artifacts.[18]

5-2 Chemical Pollutants

Acids in mounting and storage materials can leach into art and artifacts they contact. This causes damage. All materials that come into contact with any item in a collection must be acid free and suitable for museum use.

Acetic, tannic and formic acid vapors are given off by a number of woods, including oak and Douglas fir.[19] Such acids have been implicated in the corrosion of lead, zinc and other metals. The Queensland Museum found that acetic acid vapor outgassing from plywood and PVA wood glue used in new case construction was causing significant destruction to egg shells in their collection.[20] A major museum in the southeastern United States identified acetic acid from visitor exhalation as cause of a similar problem. (See the notes on saliva vapor in the section on bacteria.)

Acids can accumulate in artifacts and even in “acid free materials” when they are exposed to acid gasses like sulfur dioxide, nitrous oxide and even carbon dioxide in the atmosphere. Test housing materials on a regular basis to insure that they remain acid free. (See the sections on these acid gasses below.)

Ammonia is very common in glass cleaners, floor cleaners, and other household cleaners. It is also present in many water based latex paints, and in many types of self-curing silicon rubber. Ammonia vapors from these materials can cause corrosion. Ammonia combines readily with sulfur dioxide. This can create an ammonium sulfate “bloom” on surfaces. (See the section on sulfur dioxide.)

Choose materials for cases and exhibits carefully. Request and refer to Manufacturer’s Material Safety Data sheets available for all materials used in your facility. Take regular and careful inventory of

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[18] For another case of simple but gross math you can calculate your museum’s skin cell load. It will come out to .0625 grams per visitor hour.

[19] Norteb S, Baer and Paul N. Banks, p. 140

[20] Agnew, Neville, The Corrosion of Egg Shells by Acetic Acid Vapour, (Queensland: Queensland Museum).

materials used in maintenance areas and janitorial closets. Talk regularly with your cleaning crew and volunteers. It is surprising how often these valuable allies are ignored.

Aromatic oils and vaporized alcohols from perfumes, colognes, deodorants and after-shave lotions are highly volatile organic compounds. These things are chosen for their ability to last, to vaporize and to spread through the air.[21] This may or may not be good for bystanders in a crowd, but it is terrible for artifacts.

Carbon monoxide and carbon dioxide are again both byproducts of combustion and natural causes. Carbon monoxide is primarily a health hazard in anything but minor concentrations. Carbon oxides like nitrogen and sulfur oxides are acid gasses and react with water to form acids.

Chlorine is a highly reactive and very, very common pollutant. Chlorine was the active ingredient in the mustard gas that caused such devastation and loss of life in World War I. Straight liquid laundry bleach is a relatively dilute 5% hydrogen hypo-chloride solution. You might cringe at the thought of treating museum artifacts with straight liquid bleach, but the fact is that chlorine is a significant ingredient in a number of commonly used materials, cleaning products and insecticides that may be present in your facility.

Chlorine is present in some amount in the atmosphere as a natural product of oceans and volcanic action. Your biggest sources of chlorine pollution may well be materials used in construction and day-to-day maintenance. Fountains and reflecting pools can introduce significant chlorine into a museum environment. Again, talk with your maintenance and custodial staff about conservation issues. Be on the lookout for materials with “chloro,” “chloride,” or “bleach” in their ingredients.

Digestive enzymes are present in saliva exhaled by visitors. (See the comments on human saliva in the section on bacteria.) In a limited way these chemicals can have all of the effects on organic artifacts that they have on the organic materials we eat. They break them down and reduce them to waste.

Formaldehyde is found in a number of common construction materials including urethane foams, foam insulation, fabric finishes, and adhesives, particularly the urea-formaldehyde resins used in most common plywood and particle boards. Formaldehyde is classified as a volatile organic solvent. Formic acid is a byproduct of formaldehyde.

Formaldehyde corrodes lead, raises acidity, bleaches and discolors paper and textiles, damages protein materials and can cause

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[21] One very sophisticated pollution detection devise that is available to every conservator is a nose. If you can smell an odor in a gallery or especially inside a case when you first open it, you probably have a serious pollution problem.

efflorescence on glass.[22] Because the most common sources of formaldehyde in a museum are from the off gassing of case construction materials, very high concentrations are possible. When exposed to outgassed formaldehyde, lead objects can show the formation of lead formate crystals within weeks.

Hydrogen sulfide is another product of combustion (and natural decay). Hydrogen sulfide is a precursor to sulfur dioxide and sulfuric acid.

Ketones are technically an organic chemical compound containing a carbon monoxide (CO) molecule in combination with two hydrocarbon radicals. Acetone is one of the most commonly known ketones. It may well be used in some quantity in your shop or lab. Acetone or other solvents should never be used in gallery spaces. Fume hoods and exhaust fans may or may not be effective. If you can smell the solvent in use, they are not. To protect against gallery contamination, shop and lab spaces should not share air conditioning with gallery spaces. Ketones are also present in visitor exhalation, perspiration and fingerprints.

Nitrous oxide is another by product of combustion from automobile exhaust. Nitrous oxide and nitrogen dioxide can also be produced within an exhibit by the deterioration of cellulose nitrate in photographic film and other products.[23] Nitrogen oxides when exposed to UV in sunlight or artificial sources seem to be a major part of the production cycle of ozone. Nitrous oxide is also the precursor of PAN (peroxy acyl nitrate).[24] Simply stated, nitrogen oxides, like sulfur dioxide, are classified as acid gasses. They result in the creation of acids and other highly reactive chemicals. These pose a danger to museum artifacts.

Sulfur dioxide results from auto exhaust, combustion and some natural sources. The primary danger of sulfur dioxide is its ability to be very readily converted into sulfuric acid both in the atmosphere and on surfaces in the presence of moisture. Garry Thomson relates that most of the sulfur entering a museum in a city environment can be expected in the form of sulfur dioxide. Only 2% - 3% of the sulfur entering the National Gallery in London entered as sulfuric acid.[25] Other studies have shown that this atmospheric sulfur dioxide can result in serious problems with acid accumulation in leather, textiles paper and even stone.

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[22] Barbara Appelbaum, p. 98.

[23] Barbara Appelbaum, p. 97.

[24] Garry Thomson, p. 259-61.

[25] Garry Thomson, p. 257.

> "It has been observed that leather initially free of sulphuric (sic) acid will accumulate up to 1 per cent acid by weight per years if exposed to an atmosphere containing SO_2."[26]

Additionally, sulfur dioxide can react with ammonia in the atmosphere creating ammonium sulfate. Ammonium sulfate is a salt that participates into dry crystals below 80% RH mostly less than 1 micron in diameter. It becomes an invisible deposit on attractive surfaces (shellac and natural resin). Cycles in humidity over 80% RH will cause these crystals to dissolve and then recrystalize into much larger (5 micron) crystals forming a visible bloom on the surface.[27]

Ozone (O_3) is a very strong oxidant. Ozone generators are used industrially to bleach materials, to kill bacteria and to remove odors. Ozone will destroy almost any organic material.

Ozone is produced naturally in the upper atmosphere. Sunlight (primarily UV) acting on sulfur dioxide and other products of combustion in the air also produces ozone. Lastly, some types of electrical equipment can produce ozone. These include photocopy machines with high UV output and electrostatic participators that generate strong static charges. Garry Thomson has a strong opinion on ozone and the use of electrostatic participators in museums.

> "Since ozone is a very undesirable contaminant… electrostatic precipitators *should not be used in museums*." (Emphasis in the original.)[28]

Ozone is a wonderfully effective bactericide and highly reactive. While ozone in gallery spaces might indeed be a bad idea, some ozone in heating and air conditioning ducts where mold, mildew and bacteria can breed can be a good thing. This is especially true if a system was designed to react any ozone produced before it entered gallery spaces. The dangers of bacteria growing in ductwork have been made famous by outbreaks of Legionnaire's Disease. Thomson's opinion must be balanced against the actual design specifications of modern HVAC equipment.

Poisons are very, very common in older collections. They are usually residues of past fungicide and pesticide treatments Museum staff must be aware of the dangers of residual fungicides present on many museum artifacts. Chances are you are not the first person to deal with your artifact. You may, however, be the first to document your treatments. Many treatments used in the past are toxic to the point of being dangerous to those handling the materials and most are illegal to use today because of that

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[26] Norteb S. Baer and Paul N. Banks, p. 141.

[27] Garry Thomson, p. 258.

[28] Garry Thomson, p. 135.

danger. You should treat every artifact as if it was extremely toxic. This is especially true of natural history exhibits or any artifact that shows signs of previous damage from mold or fungi. They may well have been treated in the past with some very potent poisons. Treat taxidermy specimens like they were packed with arsenic. Many of them were (and are). Treat the air in, and the exhaust from, cases containing these materials in the same way.

Polyvinyl Chloride (PVC) is already covered, but added to this list, because plastics that outgas can so easily slip into a museum case or environment. Polyvinyl Chloride as well as other fire-retardant or self-extinguishing plastics are common and very corrosive. Many objects like door guides, lifters, knobs, bumpers, wire wraps, spacers, plastic fasteners, seals, foams, hinge pivots, edge trims, furniture corners, shelf brackets, plate easels, gemstone rings, trays, holders, small stands, plastic boxes, pads, hole trims, small vents, slot trims, small machined parts, custom parts, die cut shapes, molded letters, etc. are made of PVC. It is a durable, inexpensive plastic. It is also a very reactive plastic. Added into any plastic, especially PVC a self-extinguishing or flame retardant chemical, and it is a toxic cocktail. A PVC or self-extinguishing plastic is a source of pollution for years when sealed inside a case.

What is interesting is that PVC is a very common jacketing or sheathing for glass and plastic fibers. PVC is ideal to support glass and stranded fibers as it is a cheap, strong plastic. Add in a self-extinguishing formulation and you have the typical jacketing for fibers from the communication industry.

But fiber optic lighting is often specified for the most sensitive and valuable of artifacts. Yet many fiber optic systems, through most likely through ignorance of both the seller and the specifier, have been found to have PVC jacketing including a flame extinguishing binder added to the PVC installed inside the case using the fiber optic lighting system. This material should not be in the gallery.

5-3 Combinations of Pollutants

The chemistry of pollution can be very complicated and the number of possible pollutants is immense. Adding to the complexity of conservation problems is the amazing numbers of different materials (and the different conditions) present in collections. Because of this, the only practical way to effectively study the effects of pollution is by simplifying issues and examining the effects of a particular pollutant on a particular material.

Additionally, the individual problems that conservators are called to deal with that drive a lot of this study most commonly involve the impact of a particular contaminant on a particular material. As a result, most of the research material available follows exactly this line, individual pollutants affecting individual materials. We need to note the limitations of this type of study. Remember the following things:

First, consider the variety of materials in our collections. Even highly specialized collections are made up of a huge number of differing materials. Identical materials within collections have different shapes, sizes, surfaces and conditions. They have different histories of exposure and will have differing reactions to pollution contamination. This is why almost none of the information on particular pollutants will specify "safe" pollutant levels within classes of objects. The only truly "safe" level is zero.

Consider also the variety of pollutants present in our environments. Just as each of these solvents, oxidants, alkalis or acids will react with the materials in our artifacts, each of them will also react with each other. It is impossible to guess or to examine all of the possible permutations of pollutants possible, or the possible effect of each of these permutations on all of the various materials in our museums. Again, eliminating pollutants as completely as possible is the only practical plan of defense.

5-4 External Sources of Pollution

Because pollution is universal, we tend to think of pollution primarily in terms of very large issues in our external environment. Air pollution and its accompanying acid rain are a major factor in environmental conservation. We know that whatever pollutants are in the air outside will certainly find their way into our gallery spaces and then into our display cases.

Because of this, environmental pollution issues become museum conservation issues. You should be aware of the large pollution issues of your region or locale. If you are in a major city in the northeastern United States, you might find your major concerns to be sulfur dioxide, ozone and photochemical smog. In Maui, on the other hand, you will probably be more concerned about the chlorides and chlorine from seawater.

On top of these big issues, it is important to be aware of more local external sources of pollution. In the area where NoUVIR Research is located, the major farm products are corn and chickens. Each spring it is impossible to ignore the impact of natural fertilizers as the chickens are called upon to assist with raising their own feed. In an agricultural area you are going to need to know about farming. When do they plow? When do they harvest? When do they spray? How do they spray? And what do they use? Is burning allowed? What are the restrictions? And what are you going to do when they do these things directly upwind from your institution?

Local issues are not any less important in metropolitan areas. What does that up plant make? When and where are they going to tear up the street, put in a parking lot, build a building or begin a highway project? Following 9/11, facilities in New York City have had to be concerned with concrete dust and alkaline particulates in ways and in amounts that no one ever expected. Yet any institution in any major city should have the plans and the hardware in place to deal with nearby demolition. This is a fact of life in any city.

Closer yet are the conditions immediately external to your building. What is the gardening staff using? What pollens or duff do your trees produce? What are they going to use to paint the building? Good heavens, is that sand blasting or just chemical pressure washing and what chemicals are they washing with? To be effective in protecting your collection, you are going to need to be part detective and part nosey neighbor.

5-5 Internal Sources of Pollution

A look at individual pollutants and their sources shows that internal sources of pollution can be quite serious. A great deal has been written about case and building construction materials. Outgassing (which is simply the evaporation of gas molecules from a surface) has become a familiar term to museum personnel.

Extensive lists are available elsewhere of materials considered safe for museum use and the precautions that should be taken with this use. The important point is that while building systems may protect and buffer their contents from external sources of pollution, they may also act as sources of pollutants. Even when they are of entirely benign materials, buildings tend to concentrate and contain internal pollutants.

Visitors are a significant source of pollution. Each visitor hour represents 0.02 cups of saliva and 0.0625 grams of skin cells.[29] Visitors bring in alcohols and aromatic oils in the form of perfumes, colognes, deodorants and after-shave lotions.

They either exhale or perspire vapors, oils, alcohols, acetones, salts, digestive enzymes, acids and bacterias. Clothing can contain chemical residues of everything from cleaners, whiteners, and brighteners to spot removers and lunch items. Visitor movement and radiant energy[30] keeps all of these and other pollutants suspended in the gallery air.

Conservators themselves routinely use a number of very strong and toxic chemicals.

> "Many conservation procedures involve the use of such toxic solvents as acetone, benzene, *N, N-* Dimethylformamide, toluene, trichloroethylene and xylene."[31]

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[29] See the footnotes on the sections for Bacteria and Skin Cells.

[30] Each visitor represents a 300 watt heater radiating energy into cases and gallery spaces.

[31] Norteb S. Baer and Paul N. Banks, p. 138.

Experience has shown all of us that no matter what rules are made or what the level of concern of those involved, not all of this use is in appropriate areas or under appropriate conditions. This is true even when it involves significant health risk to the person using the materials. If the thoughts of “I’m just using a little bit”, “its just this once”, “I’ll be careful” or “it was O.K. last time” can justify personal health risks, they will certainly be used to justify risks to artifacts. Don’t allow it!

Significant internal sources of pollution can be found in maintenance and cleaning operations. Chlorine and ammonia are very common in cleaning products. There are a number of very strong solvents marketed under a number of names for removing spots, gum, stains, etc. from carpets.

These things migrate into cleaning material inventories. Cleaning supplies are usually thought to be relatively benign. They may not be.

The cleaning staff can be very conscientious. They want things to look nice. They want to do a good job.

Quite often they have special tricks they learned at home or at another job. Sometimes they have custom solutions for particular cleaning situations. Teach them a little about chemical damage and the symptoms for which they might watch. Enlist their help.

The cleaning staff may look at your collections more often and more closely than any other staff. They may also spend more time in your galleries than almost anyone else. (This might also apply to docents and security staff. Enlist their aid too.) Think about how tragic it would be to find that the acetic acid destroying a part of your collection came from the vinegar a cleaning staff member’s mother taught him or her to use when cleaning windows.

5-6 Artifact Pollution

As we have seen in examining individual pollutants, artifacts themselves are quite often sources of pollution. From the natural outgassing of acids by wooden objects to bacteria from organic materials several thousand years old to toxic residue from earlier and perhaps undocumented preservation practices, artifacts can be a danger to themselves and to those around them. Recognizing this danger Shin Maekawa suggests filtering the air *that comes out* of cases when preparing for inert gas environments.

> “The exhaust port of the case can be fitted with a microfilter to prevent bacteria and fungal spores on the object from being dispersed to a museum atmosphere during flushing.”[32]

If artifacts themselves are a source of pollution, hermetically-sealed cases will act to contain and concentrate these pollutants. Such cases must contain the

[32] Shin Maekawa, p. 40.

internal means to deal with the accumulation of these pollutants. Traditionally that means identifying all possible pollutants and then choosing an environment tolerable to the artifact and intolerable to bacteria, insects, or chemicals dangerous to the artifact.

The problems inherent in hermetically-sealed cases are covered later. The important point here is that isolating artifacts from their environment may not be an effective pollution control. Another solution is needed.

5-7 Cycles of Pollution

We have already examined in some detail the processes that drive case breathing. We know that small changes in temperature (or barometric pressure) drive case breathing and that a normally-sealed case can be expected to exchange its entire volume with the surrounding gallery every 72 hours. We can therefore readily expect that any pollutant in the gallery will be equally present in a display case.

We know that IR radiation provides the energy that drives cycles of case breathing. Infrared energy also drives cycles of temperature and humidity that effect art and artifacts. These cycles of temperature and humidity are the primary means by which pollutants in the air infiltrate and contaminate materials in collections.

The buildup of pollutants in and on materials happens by evaporation. This is how acid free leather exposed to sulfur dioxide in the air can absorb 1% of its own weight in sulfuric acid each year.[33] It happens as a result of evaporation.

Cycles of surface heating and drying along with fluctuations in humidity caused by temperature cycles cause porous objects to expand and contract. They expand and contract by absorbing and releasing water vapor. The science is simple.

What we seldom consider is that water molecules are almost always attached to particulate or chemical contaminants in the air. Water vapor tends to condense around these contaminants. When our objects absorb water vapor they will also absorb all of the material that may be dissolved or suspended in that water.

The problem is that these contaminants become imbedded in and react with the material of the object as the water is absorbed. When the humidity cycle swings the other way and the object dries. Its water evaporates. But the contaminants remain.

Granted, the quantities of contaminants in water vapor are very small, but the cycles of absorption and evaporation are frequent and endlessly repeated. The end effect of these repeated cycles in humidity is the collection and

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[33] Norteb S. Baer and Paul N. Banks, p. 141.

concentration of pollutants in any absorbent material. The truth is that if you are not controlling temperature and humidity cycles you may well be using your artifacts as air filters.

The only solution to pollution that could be worse would be to use your lungs as air filters. If you work around contaminants or toxic chemicals without proper protection, you may be doing just that. One advertisement actually asks, “Are your lungs your lab’s air filter?” This idea may seem facetious, but conservation literature actually suggests it (at least with visitor’s lungs and ozone).

> “Hopefully one may suppose that the visitors may in this case help conservation, since every inhalation is likely to destroy all the ozone in the breath.”[34]

5-8 Building Defenses Against Pollution

There have been tremendous advances in technology for air conditioning and air purification systems for buildings over the last few years. This is one reason that we might question some of the published conservation information regarding these systems. What was inefficient, unreliable or dangerous 10 or 15 years ago may or may not be so today. Consider the information given here, talk with HVAC designers and suppliers, and get solid (and guaranteed) performance information.

In this section we have discussed Garry Thomson’s very strong aversion to the use of electro-static precipitators in a museum environment because of the danger of ozone to collections. There are however a number of museums today that have spent a very considerable amount of research and money on air purification and made electro-static precipitation a part of their systems. Ask for and look at the technical data on ozone output for possible systems just as you would ask for and look at the spectral output of a considered lighting source.

In the last section we dealt with a number of dangers and considerations involving building wide environmental control systems, particularly dealing with RH controls. The same considerations mentioned above ought to apply to these systems.

A major difficulty with building-wide pollution control systems is the huge number of pollutants that originate inside a museum environment. Lighthearted references to calculating museum saliva and skin cell loads should not deflect us from the importance of protecting artifacts from these chemical and biological hazards. Buildings tend to concentrate and contain these materials. The most effective pollution filtering systems in the world will only result in establishing some kind of equilibrium in a constantly polluted environment.

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[34] Garry Thomson, p. 151.

5-9 Case Defenses Against Pollution

The ability of casework to protect artifacts from pollution within a gallery space should be evident. It should also be evident that this protection is only effective when air exchange between the case and surrounding area is controlled. Lastly, it should be obvious that casework will localize and concentrate internal pollutants in exactly the same way a building does.

If the artifact itself outgasses, or has been treated with pesticides or is subject to mold, or bacteria, these things will be concentrated within a sealed case. The same holds true for pollutants from case construction materials. Or from things added into the case as artifact or story support.

The section on case breathing provided the mathematics to calculate case breathing based on both temperature variation and barometric changes. We found that a normally-sealed case would exchange its entire volume with a gallery every 72 hours. What this tells us in terms of pollution is that the interior of a normally-sealed case will reflect the average of gallery pollution levels over a 72 hour period.

This is unless, of course, air exchange with the gallery is curtailed or filtered. (Completely ending case-air exchange with a gallery is simple. It is inexpensive and described in the use of NoUVIR's AIR-SAFE™ system. Look for the pdf files on AIR-SAFE Micro-climate control.)

Toby Raphael (and others) suggest placing filters over case vents.[35] This can be an effective solution under certain conditions. First, case seals must be tight enough to insure that air will circulate through the filter materials and not through gaps in the case.

In other words, the case should be sealed against normal air movements. But it need not be sealed against pressure. Second, the filter materials must be effective against all of the known forms of pollution, particulate and chemical.

That means that they must incorporate a number of different kinds of chemical filters. The filters have to be stacked. That means moving air through the filters is critical.

Lastly, such filtering will be effective only against outside pollutants. There can be no pollution sources inside the case, either from case materials or artifacts. The filters will not clean the case's internal air.

Figure 5-1, on the next page, shows the relative sizes of common pollutants. It also shows the effective ranges of particulate filters including HEPA filters. The chart demonstrates the difficulties involved in filtering pollutants.

It also shows that smoke, the very small particles that remain suspended in air and gas molecules, easily pass through particulate filters. While frequently replaced HEPA particulate filters over vents in adequately-sealed cases should

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[35] Toby Raphael, 2:10, p. 1-2.

be considered the absolute minimum precaution taken against pollution, it must be understood that this is a minimum. HEPA filters provide effective dust control. But they are very ineffective as overall pollution controls.

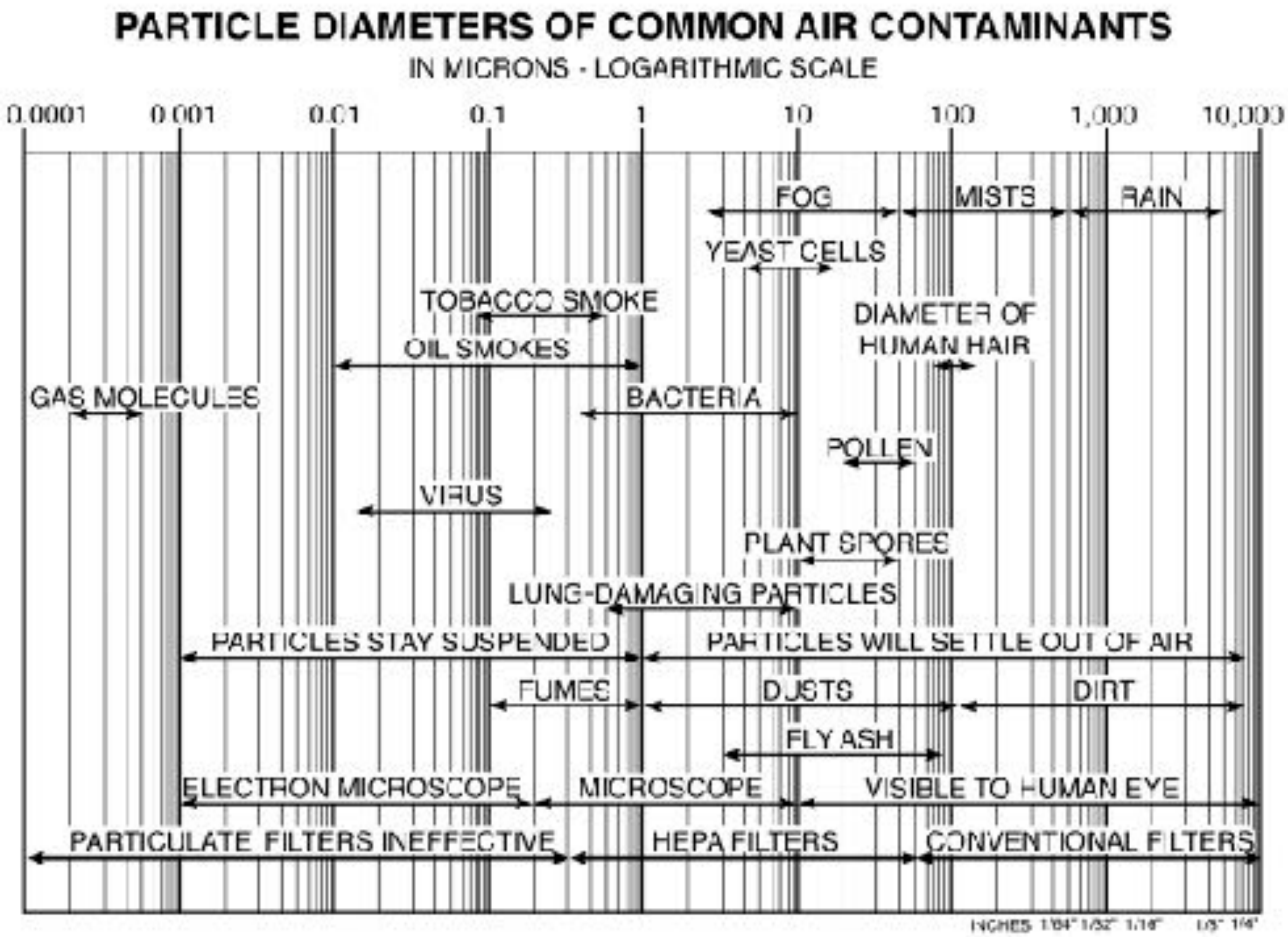

Figure 5-1. Chart shows the difficulties involved in filtering pollutants.

To put particle sizes into a clearer perspective for those who are not used interpreting logarithmic scales or measuring things in microns, see Figure 5-2 on the next page. It shows the relative diameters of a human hair, the smallest particle visible with the human eye and the smallest particle effectively filtered by a HEPA filter.

Again, the very, very tiny sizes of the pollutants we are concerned about and their dispersal through the large volume of air present in a gallery demonstrate the challenge of controlling pollution. It is a challenge. But simple technology can be used to handle that challenge.

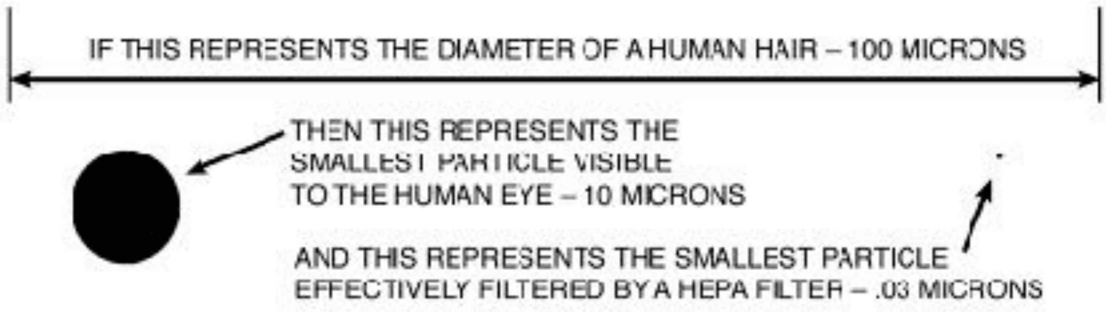

Figure 5-2. Representative particle size.

Toby Raphael lists several chemically active materials that can be placed in cases to absorb pollution. There are a number of proprietary products available in several forms. Almost all of them are based on either activated charcoal or potassium permanganate.[36]

Simply placing these materials inside a case helps, but it involves the same difficulties involved with placing silica gel inside casework as an RH buffer. The system depends primarily on Brownian motion to move pollutants through hidden holes or screens into a secondary chamber within the case to the activated chemical's surface. As discussed in the section on silica gel buffers, this is very inefficient.

You can partially compensate for this inefficiency by using much greater quantities of chemicals. But of course this drives costs up. And, as Toby Raphael points out, they are quickly exhausted if the case exchanges air with the gallery. Using an AIR-SAFE System is a much better way to handle the problem, because it uses pressures already exerted on the case to move air through the silica for treatment.

Interestingly, Toby Raphael mentions silica gel's ability to absorb a number of pollutants. He does not follow up with what happens to these pollutants when silica gel is dried and reused. It has to end up somewhere. We know now that it remains in increasingly larger concentrations in recycled silica gel. Like our example of repeatedly-dried but never-washed socks, reused silica gel will become a significant source of pollution.

[36] Toby Raphael, 2:10, p. 2.

5-10 Pollution Summary

Pollutants pose a significant danger to artifacts in collections. Particulate pollutants range from alkaline aerosols, salts, micro-carbon particles, simple dusts and dirt to organic materials like molds, pollens, fungi and bacteria. Gaseous pollutants include acid gasses, organic vapors, formaldehyde and ammonia. These pollutants originate from a huge number of sources both outside and inside a museum environment. Thermally driven cycles of temperature and humidity move these pollutants into casework and then into the very structure of the artifacts.

There is no such thing as a permanent exhibit. This axiom is almost a universal law. It effects the spread of pollutants through a collection. Because artifacts on display are themselves often sources of pollution and because exhibits are always changing, pollution residues can be passed from object to object, from object to case and from case to object, even with tightly-sealed casework.

It is impossible to eliminate all of the various sources of pollution. Even when the artifacts pose no pollution dangers themselves, it is impractical and extremely expensive to attempt to prevent the incursion of pollutants into the exhibit environment. While efforts should be made to reduce pollution within the building, pollution control is most effective at the case level. Pollution controls should provide positive continual air filtering for both particulate and gaseous pollutants.