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Microscopy of Indoor Environmental Particles

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The identification of particles in an environment provides information on the types of activities at that location, the sources of make-up air, fugitive emission in the area, the efficiency of air filtration systems, and the condition of the ventilation system. It also provides information on agents in the environment that could have a detrimental effect on the building's occupants. The use of this type of information requires a shift in our way of thinking about the environment and about how analytical information is used. The identification of particles present in an environment allows us to verify data provided by individuals who occupy that environment. Information considered unimportant by an informant may come to light and provide the insight necessary to solve the problem. Two types of particle samples are needed to characterize an environment. The first, and most important, are samples of surface particulate matter. The second is airborne particulate matter. An explanation for this ordering is provided along with a body of references and case histories demonstrating the use of this approach.

INTRODUCTION

Indoor air quality is a misnomer that has often resulted in a very limited approach to the sampling of an environment. It is not the air at any given time that is the issue but rather the exposure over time of the occupants to those things in the environment that can interact with them detrimentally. The challenge for the environmental specialist is to assess the nature of the exposure in order to control the detrimental effects. Particles in an environment are markers that identify activities, ventilation sources, and the condition of the building with respect to its environmental control system. The subject of this paper is how these markers are read. It serves as an introduction to an analytical technique, light microscopy, and its application to environmental monitoring. Analytical light microscopy is so powerful a technique that entire libraries are dedicated to its various uses. Light microscopy is often discounted as trivial because anyone can look through a microscope and see an image. To the non-microscopist the image is the object being observed. To the microscopist the image is one manifestation of the interaction between the electron cloud that is the object and the high frequency alternating electrical field that is light. The difference is similar to that between "tooting" a horn and playing a symphonic instrument. The types of electron bounding and the orientation of those bonds, the average atomic number of the elements involved, the dielectric constant (relative conductivity) of the material, the artifacts of surface generation, persistence of precursor structure, and the effects of weathering and age are all

presented in the image of the object viewed by the microscopist. In
order to interpret the image the microscopist must have an appreciation for the fine tuning of the light beam impinging on the object. Failure to tune the microscope results in an image full of "noise" but appearing to convey information. Some information is still present in the noise such as general shape and color, and sometimes, for some particles, this is enough. To understand the sample, what it tells us about an environment, the microscopist must control the noise, extract the information, and interpret the information in a way that is useful and relevant to the problem that lead to the need for the analysis in the first place.

In the following case histories the nature of the particles as seen under the microscope will be stressed along with their interpretation. The manner in which these samples were collected and differences based on the sampling techniques will be mentioned in each case where multiple techniques were used. The sampling procedures are included as an appendix.

CASE HISTORIES

The Mesquite Barbecue

A restaurant moved into a business district and offered Mesquite fired barbecue. Businesses in the adjacent three story building began complaining of mesquite smoke in their work place within a short time. The restaurant contended that they were not the only source of smoke in the area and that the other sources should also be considered. Samples of airborne particles using slit air samplers and membrane filters and samples of surface particles using tapelifts were collected at the work stations in the three story building. The tapelifts immediately substantiated the complaint. Particles of charred mesquite were identified in the tapelifts from different areas in the office. The office air samples failed to provide particles identifiable as mesquite initially. Subsequent air samples from the roof near the building air intake and in the office substantiated the path of entry. The problem was resolved out of court.

When a material burns it generates fragments that can often provide very specific information about the original material. Wood shrinks and chars as it burns releasing fragments of cells and cell clusters that are often sufficiently characteristic to identify them as to the type of wood being burned. Wood from at least three other varieties of trees was identified along with leave and other non-fuel type plant char in this case. The particles that are specifically identifiable tend to be larger particles, in the range of 30 to 50 micrometers. These particles are transported less efficiently than smaller particles and as result are rare in ten minute type air samples. Horizontal surfaces at the target location typically contain these particles and if there has been an exposure it will be evident in the tapelifts. Transport mechanism and the route of entry can be determined once the exposure has been documented. Tapelift samples from the ventilation system and air samples from the roof were provided and helped to complete the story. In this case slit air samples collected over a period of hours were used to document the details. Slit air samplers that collect rows of particles sequentially (see Appendix: Allergenco MK-3) are especially useful in that ten minute air samples can be automatically collected at regular intervals over a twenty-four hour period. Each sample row can be documented as to the time of its collection.

In this case had tapelift samples not been collected mesquite smoke would not have been found in the initial survey. The client would not have had the evidence to pursue their claim. Tapelifts have proven to be essential to understanding the nature of the environment at any given location. Tapelifts have been used to evaluate crime scenes since the 193 0's. They are the core technique for evaluating the cleanliness of Aerospace Cleanrooms and of hardware such as contamination sensitive satellites. Slit air samplers, such as the Allergenco, Zefon, or Berkhart, are ideal for air samples that are to be analyzed under the light microscope because they concentrate the particles they collect into a narrow row that can be quickly examined. This is a much more efficient way to examine the thousands of particles collected in a ten minute sampling interval than the old membrane filter technique but it does not replace the membrane sample. Membrane filters collect by filtering the air whereas slit air samplers collect by impaction. They collect different types and sizes of particles and cannot be considered as equivalent sampling procedures. Membranes are much more efficient when collecting fume or smaller smoke particles and must be used for quantitative elemental analysis.

Bird Debris

A woman was experiencing respiratory problems and was convinced that local businesses were responsible for polluting the air in her home. Tapelifts were provided for analysis and the home was found to contain a high level of bird related debris. The bird debris include feather barbules and fecal matter. The feather barbules were not identified as to species but they were not from local wild birds and the fecal material ruled out down filled furniture as a source. The fecal material also indicated that the birds were eating a prepared feed rather than a natural food supply.

It turned out that this lady had been a breeder of parrots and she had raised the birds in her home. She had become allergic to the birds and had had to end this occupation. Her home had been thoroughly cleaned she claimed and her symptoms had subsided for a time and then returned. It was clear from these samples that the cleaning had been superficial. As she lived in the home and visited less frequented parts of the home or storage areas she had reintroduced a significant population of parrot debris.

In this case no information had been provided with the samples. The samples had been analyzed and the report indicated a large population of domesticated bird debris. A chicken farm or a heavy application of chicken manure was suggested as a source for the debris. When parrots were later mentioned the source was obvious. The degree to which each particle is characterized is dependent on the issue at hand. Every sample contains thousands of particles and every particle is in some way unique. During the analysis the particles are clustered into related groups, such as bird feather barbules. These groups are then gathered as assemblages. An assemblage indicates a source. In this case the bird fecal material (unique due to the avian waste elimination process) and the feather barbules indicated an intimacy with the creatures. The fact that the fecal material was from a prepared feed clearly suggested a domesticated bird. The amount of material was inconsistent with a few pet birds. The barbules were not consistent with local wild bird barbules and at that the analysis was halted. The barbules could have been more specifically identified if the issue of parrot breeding had been mentioned. Similarly in the earlier case, had mesquite not been specifically mentioned when the samples were provided only charred wood would have been mentioned. Background information or materials of special interest should be provided if possible to increase the amount of information in the final analysis. In some cases, such as where litigation is involved, the information may be provided after the analysis to refine the data. Samples analyzed by light microscopy are not destroyed or significantly damaged by the analysis. The samples become a permanent record and can be reanalyzed or quantified for specific particle types at a later date if necessary.

Black Particles

No single case history would do justice to all the complaints involving black particles. Black particles are a common complaint in both the workplace and in the home. Contrary to popular belief black particles do not constitute a unique, single particle type. Combustion particles are typically black but every fuel creates its own unique distribution of particle types as already presented in the case of plant fuels. The combustion need not be local. Soot and charred products can travel considerable distances and deposit over time creating a black particle traffic arteriales nearby. Electric motors generate fine black metal wear and graphite particles that can become a black particle problem. Electric heating elements in baseboard heaters generate both metallic oxides and charred particles in the environment. When an electric heating element first heats up it both chars the particles that collected on the element since its last heating cycle and the element expands thus dislodging the particles into the convective air flow. The odor noticeable when the heater first heats up is the result of this initial burst of charred particles and volatilized pyrolysis products. Many fungal species generate black or dark spores that look black on light surfaces. Computer printers or copy machines can generate large amount of free toner particles. Toner particles can be a significant health risk. This is just a partial list of black particle types common in home and office environments. Each particle type is associated with its own health implications. Charred materials indicate incomplete combustion; carbon monoxide testing may be required. Black spores may be a localized Cladosporium population, possibly a problem; or Stachybotrys, a more serious situation.

At any given location multiple sources of black particles are present. The sample collected must be the black particles that cause the concern and not just any deposit of black particles. Black particles on the bathroom wall, black particles above an electric heating register, black particles on the window sill, and black particles collecting on white plastic surfaces in the kitchen are often all different. If the concern is the black particulate matter in the kitchen then that is the sample that should be taken. Sampling the air in this situation will only confuse and complicate the issue. The question in this case relates to a very specific population of surface particles. That is the sample that needs to be analyzed.

Airborne Sewage

Around a large international airport brown particulate matter fell from the sky whenever a large jetliner took-off an analysis of the material at a local university identified the material as some type of modified fecal material. Electron microscopy confirmed that the material was a globular carbonaceous particulate matter consistent with fecal material. Local residents were furious. Apparently the aircraft was dumping sewage, or, at the least leaking sewage during take-off. Samples of the brown material were received by this laboratory and examined to determine if fecal material was present. Indeed fecal material was present; bee fecal material. Honeybees eat pollen and nectar. As with most insects the pellet they defecate can be a substantial percentage of their body weight. In the case of honeybees the pellet can be a third of their body weight. Bees defecate while flying and typically on the flight back to the hive after they have eaten. The pellet consists of the emptied pollen grains that they have been eating, waxes, and fragments of bee "hair" from their grooming activities. When an aircraft takes off it needs much more power than when it lands and it makes much more noise. The area around the airport had been left wild because it would be unsafe for people to live too close to the airport. Bee keepers had taken advantage of the natural flowers in this area to keep their hives close to their market. The result was that when a large jet took off it frightened the bees that had been feeding and as they approached their hive they dropped their little brown pellets. Bee hives are no longer allowed around this airport. No technique other than light microscopy could have identified this material correctly.

Glass Fibers

Glass fibers can often be identified as to their source based on the materials adhering to their surface and the specific shape of the glass fiber itself. As many as six distinct sources of glass fiber in a single environment have been identified and quantified microscopically from tapelifts. Glass fiber related problems are another example of the importance of tapelifts for evaluating an environment. Air samples in areas with glass fiber problems often fail to collect glass fibers. Tapelift samples seem to track well with the incidence of glass fiber related complaints.

CONCLUSION

This is a very abbreviated paper for which I apologize, but hopefully, along with the talk, it will serve to indicate the value of analytical light microscopy and of the importance of surface particles in an environment. The attached appendix provides additional information on sampling techniques referenced in this paper.

APPENDIX: SAMPLING ENVIRONMENTAL PARTICLES

The techniques provided below are the preferred procedures when analytical light microscopy is to be used for the analysis.

1: Environmental Sampling Using Tapelifts

Scope:

The purpose of a tapelift sample is to evaluate the particulate burden of an environment. It is a time averaged sampling technique that provides information on sources that have impacted the environment since the surface was last cleaned. It has the advantage of providing historical data as well as data on short term cycles which may have a major impact at the site but for very short periods of times. Tapelifts also provides a baseline exposure history against which other types of samples can be compared to determine if they are typical of the exposures in this environment. Particle types are identified through the analysis of the tapelift which then indicates the types of sources that may be impacting the site. The ability to suggest sources allows improved test and monitoring design for a more detailed assessment of exposures if required.

Equipment:

The following equipment is required for sampling:

1. 3M Brand Magic Tape, Standard (not Removable), 3/4 inch wide
2. Sandwich or Snack size sealable plastic bags (e.g. "Ziplock")
3. Notepad
4. Pen or Pencil

Sample Site Selection:

The sample site should be selected based on the following criteria

1. Sample the site where the problem was first noticed.
2. Sample the surface of concern if there is a surface that caused concern.
3. Sample a surface that has been collecting particles over the history of the problem.
4. Sample a surface that is cleaned on a weekly or monthly basis.
5. Carefully document the location of the sample, the time, and date of sampling.
6. Collect at least three samples from the homologous location. In a home that may be three different rooms. In an office or industrial area they would all be from the same shop or

office.

Collecting the Sample:

Once the locations has been selected the samples can be collected using the tape.

1. Pull the tape from the roll so that about three inches (3”) of tape are exposed. Be careful not to touch the free end of the tape. The end of the tape being held is contaminated with finger debris.
2. Place the tape onto the surface to be sampled and press it down evenly. The end held with the fingers can be folded under on itself to simplify the removal of the tape from the surface. The tape can be applied to the surface more than once if the surface is very clean. If the tape is applied more than once lift the tape and place it down on the adjacent surface leaving the tape on the surface after the last contact.

With the sample tape of step 2 still affixed to the surface being sampled open the plastic bag and invert the bag by pressing the bottom of the bag through the opening to exposed the interior surface of the bag.

Now remove the sample tape from the sample surface and stick it onto the exposed inside surface of the clean plastic bag and reinvert the bag.

Place a note in the bag with the sample that identifies the sample location, date, time, and the one taking the sample, then seal the bag.

Repeat steps one through *5* for the next two samples of this set placing each sample in its own bag with its own identifying note before moving to the next home or to the next office or shop environment.

Environmental Sampling Using The Allergenco MK-3 Slit Air Sampler

Scope:

The Allergenco MK-3 slit air sampler is an impaction collector. The collection efficiency is dependent upon the air velocity, sticking coefficient of the collecting substrate, and aerodynamic particle size. It concentrates airborne particles into a zone approximately 1.1 mm by 14.5 mm in dimension. It samples at a fixed rate of 15 liters per minute. It is programmable and can collect up to 24 samples at selected intervals per substrate. Each sample is spaced at 2mm, center to center. It has the advantage of providing current data on the airborne particle load as a function of time of day at a fixed location. Many environmental exposure are cyclical and can only be documented with this type of sampling program. The system requires access to 120 volt AC power or 12 volt DC battery power. The unit weighs approximately 4 pounds and has a footprint of approximately 6 by 4 inches and is about 5 inches high. The sample substrate is a 25 mm wide microscope slide (1 inch wide slides will not fit) with either a section of 3M Brand Magic Tape mounted adhesive side up or treated with a layer of silicone grease.

Equipment:

The following equipment is required for sampling:

1. Allergenco MIK-3
2. Microscope Slides, 25mm by 75mm
3. 3M Brand Magic Tape, Standard (not Removable), 3/4 inch wide
4. Hexasilicon media (water free silicon grease)
5. Notepad
6. Pen or Pencil
7. Sandwich or Snack size sealable plastic bags (e.g. "Ziplock")

Sample Site Selection:

The sample site should be selected based on the following criteria

1. Sample the site where the problem was first noticed.

Sample the exterior of the building or an area not reporting the same problem to provide a background for comparison.

3. Carefully document the location of the sample, the time, and date of sampling, the programmed sampling interval, and any unique, time constrained activities at the site.
4. Collect at least over one complete operation cycle at the site. In a home that is typically 24 hours. In an office or industrial area the cycles may be shorter or longer, from minutes to days depending on the activities at the site.

Collecting the Sample:

Once the locations has been selected the samples can be collected.

1. Program the unit for the sampling interval (typically 10 minutes) and the time between samples. The time between samples will depend on work cycles or operation cycles at the location. If these are not known then 50 minutes may be selected for hourly 10 minute samples.

2a. If tape was used as the sample substrate remove the sample slide with the tape from the sample rack in the MK-3 and stick it on to the exposed inside surface the clean plastic bag and reinvert the bag.

2b. If the Hexasilicon medium was used remove the sample slide and place it in a plastic slide carrier that protects the sample surface. Place the slide carrier in the clean plastic bag.

3. Place a note in the bag with the sample that identifies the sample location, date, starting time, sampling program intervals, and the one taking the sample, then seal the bag.

Environmental Sampling Using The Zefon Slit Air Sampler Cassette

Scope:

The Zefon slit air sampler is a cassette impaction collector. The collection efficiency is dependent upon the air velocity, sticking coefficient of the collecting substrate, and aerodynamic particle size. It concentrates airborne particles into a zone approximately 1.1 mm by 14.5 mm in dimension. It should be used at a fixed sampling rate of 15 liters per minute. It has the advantage of being portable and of providing current data on the airborne particle load at the time of sampling. The system will attach to standard battery powered pumps and comes with the sampling substrate already prepared and in position.

Equipment:

The following equipment is required for sampling:

1. Zefon Cassette
2. Pump Capable of Drawing 15 Liters per Minute through the Cassette
3. Notepad
4. Pen or Pencil
5. Sandwich or Snack size sealable plastic bags (e.g. "Ziplock")

Sample Site Selection:

The sample site should be selected based on the following criteria

1. Sample the site where the problem was first noticed.
2. Sample the exterior of the building or an area not reporting the same problem to provide a background for comparison.
3. Carefully document the location of the sample, the time, and date of sampling, the duration of sampling.

Collecting the Sample:

Once the locations has been selected the samples can be collected.

1. Attach the cassette to a calibrated pump, remove the sealing film from the sampling cassette and begin collecting the sample. Typically 10 minute samples

are taken at a sampling rate of 15 liters per minute.

2. After the sample has been collected seal the cassette with tape or the supplied sealing film, detach the cassette from the pump, and place the cassette in a plastic bag.
3. Place a note in the bag with the sample that identifies the sample location, date, starting time, sampling time, sampling rate, and the one taking the sample, then seal the bag.

ANNOTATED BIBLIOGRAPHY

The following list of books and articles is provided as an indication of the unique role of light microscopy in the analysis of environmental quality. It is a very small sampling of references from my personal library and is provided both as an indication of what is required to perform this type of analysis as well as a starting point for anyone interested in beginning this adventure. Classes in these techniques are taught by McCrone Research Institute in Chicago, IL and by Microlab Northwest in Redmond, WA. Cornell University is the only university of which I am aware that has tried to reintroduce analytical light microscopy to its curriculum.

THE POWER OF LIGHT MICROSCOPY

Crutcher, E. R., “The characterization of particles on spacecraft returned from orbit”, PARTICLES ON SURFACES, K.L.Mittal (ed.), Marcel Dekkeer Inc., pp. 2 19-252, 1995.

Light microscopy is used to identify 10 discrete contamination episodes in the life of a satellite by characterizing the contaminants recovered from the surface of spacecraft. Six different types of glass fiber are identified in these samples, each related to specific sources.

Crutcher, E. R., “Light microscopy as an analytical approach to receptor modeling”, RECEPTOR MODELS APPLIED TO CONTEMPORARY POLLUTION PROBLEMS, Specialty Conference Proceedings, Air Pollution Control Association, October 17-20, 1982, pp. 266-284.

Optical techniques for the identification of particles under the microscope are described The role of the microscope in the characterization of airborne transport and identification of unknown sources of pollution.

Crutcher, E. R., “Assemblage analysis - identification of contamination sources”, PROCEEDINGS OF THE USAF/NASA INTERNATIONAL SPACECRAFT CONTAMINATION CONFERENCE, NASA CP 2039, pp. 763-778, 1978.

A definition with examples of how assemblage analysis is applied to solve particle source problems. It also illustrates how air volumes from different sources are labeled by the particles they transport to surfaces.

Hopke, Philip K., RECEPTOR **MODELING** IN ENVIRONMENTAL CHEMISTRY, Vol.76 in Chemical Analysis Monographs (Chap. 3 on Optical Microscopy), John Wiley and Sons, New York, 1985.

Light microscopy has been an essential tool for the resolution of urban dust and pollution problems. Quoting the introduction “The specificity of the light microscope may make it the single most powerful tool available for the qualitative characterization and identification of particles”.

McCrone, Walter C., “The case for polarized light microscopy”, AMERICAN LABORATORY, pp. 12-16 and 19-21, June, 1996.

The power of light microscopy over all “blind” techniques; ESCA, GC, XRD, IR, MS, etc., with examples, is provided A very interesting, and unfortunately brief autobiographical case history of projects.

BACKGROUND IN LIGHT MICROSCOPY

Chamot, Emile Monnin and Clyde Walter Mason, HANDBOOK OF CHEMICA MICROSCOPY, Second Ed., John Wiley and Sons, Inc., New York, 1940.

Originally published in 1930 this is still one of the most complete texts on inorganic chemical microscopy. The methods provided are for the chemical analysis of individual particles under the microscope. These tests are often desirable over microprobe analysis because of their speed and reliability and because hetero-atomic *anions are easily identified.*

Deer, W. A., R. A. Howie, and J. Zussman, AN INTRODUCTION TO THE ROCK-FORMING MINERALS, Longman Scientific & Technical, 1992.

The optical properties of all the main families of minerals are contained in this reference. The relationship between chemical composition, crystallography, density, optical properties, and paragenesis can be very useful in characterizing a particle's source.

Hallimond, A. F., THE POLARIZING MICROSCOPE, Vickers Instruments, York, United Kingdom, 1970.

This book covers both transmitted polarized light methods and reflected polarized light methods. These two techniques are entirely different with respect to how a crystalline material effects the light beam. This is one of the very few books that details the analytical use of both techniques.

Insley, Herbert and Van Derck Frechette, MICROSCOPY OF CERAMICS AN]) CEMENTS INCLUDING GLASSES, SLAGS, AND FOUNDARY SANDS, Academic Press Inc., New York, *1955*.

Herbert Insley had been Chief of the Mineral Products Division, U.S. National Bureau of Standards. This volume contains a wealth of information on the formation of various phases in manmade inorganic matrices. It is very useful in determining the source or sources of these materials and whether they are the product of direct activity (cutting, grinding, etc.) or a weathering product.

McCrone, Walter C. and John G. Delly, THE PARTICLE ATLAS, Ann Arbor Science, Ann Arbor, Michigan, 1973.

This is a six volume set that provides basic information on analytical methods using the light microscope and electron beam instruments (Scanning Electron Microscope, Microprobe, etc.) followed by volumes of photographs and descriptions of particles. Beware of pretty pictures. The particle descriptions are very useful but a single picture can never do justice to the range of variability within any specific group of materials or express the visual overlap of non-related compounds. This is just as true with non-living materials as it is with living materials (spores, pollens, etc.). As long as the pictures are viewed with that caution in mind they are useful.

Needham, George Herbert, THE PRACTICAL USE OF THE MICROSCOPE INCLUDING

PHOTOMICROGRAPHY, Thomas, Springfield, I11, 1977.

This is the only book 1 am aware of that presents a chapter by chapter of discussion of the range of optical techniques of analysis available to the microscopist. It was published in 1958 and reprinted in 1977 and is still unique. New techniques in light microscopy have been developed since 1958 so this book is not as all inclusive as it was, but no other text even comes close to the same range of subject matter.

Nesse, William D., INTRODUCTION TO OPTICAL MINERALOGY, Oxford University Press, N.Y., 1991.

This is one of many texts on the identification of minerals using the polarizing light microscope. Each text has its own strengths and weaknesses. This text is currently popular for classes in optical crystallography at the university level.

Smith, E. Grant, SAMPLING AND IDENTIFYING ALLERGENIC POLLENS AND MOLDS, Blewstone Press, San Antonio, Texas, 1990.

This is another particle atlas full of pictures. There is much valuable information on seasonal exposure and the photographs are excellent but the same caution regarding the use of photographs for identification given before must be repeated here: a single picture can never do justice to the range of variability within any specific group or express the visual overlap of non-related groups. Basic reference texts on pollens and fungi must be consulted to determine the degree of confidence that can be placed in the identification.

U.S. Geological Survey Bulletin 1627, MICROSCOPIC DETERMINATION OF THE NONOPAQUE MINERALS, United States Printing Office, Washington, D.C., 1984.

The optical properties of many thousands of minerals are presented in tables keyed by optical properties. Using measured optical properties alone these specific minerals can be identified from a sample of particles.

Winchell, Alexander Newton, THE MICROSCOPIC CHARACTERS OF ARTIFICIAL INORGANIC SOLID SUBSTANCES OR ARTIFICIAL MINERALS, John Wiley and Sons, Inc., N.Y., 1931.

The optical properties of chemicals by anion "family" (mono-valent metal nitrates, di-valent metal nitrates, etc.) are given. Data on thousands of chemicals is provided in *this reference. By chemically identifying the anion and measuring the optical properties even complex reaction products can be identified. This is often the only way these materials can be correctly identified.*

TAPELIFTS

Crutcher, E. R. and W. W. Wascher, “Particle types and sources associated with LDEF”, NASA CP 3134, pp. 101-120, 1991.

LDEF, the Long Duration Exposure Facility satellite was a bus-sized satellite returned from orbit for a detailed analysis of orbital effects on materials Tapelifts were used extensively for the analysis of surface deposits and to monitor contamination in the processing facility at Cape Kennedy. This procedure had been used by the authors in one form or another for over twenty years.

Gallup, J., P. Kozak, L. Cummins, S. Gillman, “Indoor mold spore exposure: characteristics of 127 homes in southern California with endogenous mold problems.”, ADVANCES IN AEROBIOLOGY, Birkhauser Verlag Basel, 1987.

Clear Scotch brand tape is used to collect molds from suspected contaminated surfaces for comparison to air samples. Air samples are collected until evidence of the mold spores found on the tape are discovered The tape used here is not appropriate for particle identification and as used in this article degrades rapidly.

Gruber, C. W. and G. A. Jutze, “The use of sticky paper in an air pollution monitoring program”, JOURNAL OF THE AIR POLLUTION CONTROL ASSOCIATION, Vol.7, pp. 115-117, 1957.

The application in this paper involves the use of tape to collect larger particles from air streams for direct analysis. It’s a larger version of a “Pin Sampler."

Kirk, Paul L., CRIME 1I4VESTIGATION—PHYSICAL EVIDENCE AND THE POLICE LABORATORY, Interscience, 1953.

Tape is used to collect particles from surfaces as part of the criminal investigation. This technique was more widely used by Dr. Frie, a famous criminalist in Switzerland at the same time (1950 ‘s and 60 ‘s).

American Society for Testing and Materials (ASTM), “E 1216: Sampling for surface particulate contamination by tapelift”, ANNUAL BOOK OF ASTM STANDARDS, 1998.

The procedure presented here is for the counting of particles and not for identification. The tapes recommended are all optically active and so mask essential particle characteristics. This is included just to illustrate another broad application of this technique.

SURFACE PARTICLES

Hamberg, Otto, "Particulate fallout predictions for clean rooms", JOURNAL OF ENVIRONMENTAL SCIENCES, pp. 15-20, May/June 1982.

Particle fallout at 5 micrometers and larger per 24 hours ranged from two to five orders of magnitude greater than predictions based on airborne particle counts per cubic foot of air.

Hamberg, Otto and E. M. Shon, "Particle size distribution on surfaces in clean rooms", PROCEEDINGS OF THE INSTITUTE OF ENVIRONMENTAL SCIENCES, pp. 14-19, 1983.

In this paper the shape of the surface particle distribution curve is shown. The distribution roughly follows a log normal curve.

Peters, Sally M., "Particle fallout in a class 100,000 high bay aerospace cleanroom", PROCEEDINGS OF THE INSTITUTE OF ENVIRONMENTAL SCIENCES, pp. 279-282, 1994.

The lack of correlation between airborne particle population and fallout particle population is reported Fallout particles correspond to activities in the room with the particle types documenting the types of activities and the particle number showing the relative level of activity. The airborne particle population as monitored by a light scatter type automated particle counter was relatively insensitive to activities in the room.

Selby, E. E., "A review of the gravity settling technique for measuring airborne dust in electron device processing areas", AMERICAN SOCIETY FOR TESTING *AND* MATERIALS (ASTM) SPECIAL TECHNICAL PUBLICATION STP #342, pp. 29-34, 1962.

Demonstrated that airborne particle counts correlate better to the filtration efficiency of the filters in the ventilation system than to room activities. Petrie dish fallout samples did not correlate well with particle populations on surfaces of interest but did better reflect activities in the area. Recommended sampling surfaces directly rather than either of the other techniques if the surface cleanliness was of concern.

Wu, Jin Jwang, Robert J. Miller, Douglas W. Cooper, James F. Flynn, Douglas J. Delson, and Robert F. Teagle, "Deposition of submicron aerosol particles during integrated circuit manufacturing: experiments", JOURNAL OF ENVIRONMENTAL SCIENCES, p. 27, Jan/Feb, 1989.

The deposition of submicrometer particles onto horizontal surfaces is dominated by static effects. An order of magnitude more submicron particles were collected by an electrically isolated silicon wafer than were collected by a grounded silicon wafer.