Mold Clean-Up Projects

Post-remediation criteria are crucial to success

By Michael A. Pinto, Mike Davis and Sara Eager

AS CONCERNS ABOUT INDOOR MOLD contamination become more prevalent, the need for standards—to cover both mold remediation and post-remediation—grows rapidly within the industry. Nonstandardized post-remediation inspections cause several problems, including project failure, contractor confusion, increased liability, limited comparisons between projects, and a breakdown in the public's confidence. Although the post-remediation evaluation process includes many parts, including sample collection and analysis procedures, this article focuses on the importance of logical and effective post-remediation sample interpretation from a macro approach.

Post-remediation evaluation is a critical component of any mold remediation project [AIHA(a) 38]. Often, due to the lack of concrete standards, remediation work is performed incorrectly or ineffectively. This can excacerbate the problem and spread the contamination [ACGIH(b) 15.2]. For example, if a proper decontamination unit is not correctly set up, the risk of contaminating clean areas increases dramatically. In other situations, more than one mold source may be contributing to the problem. If all sources are not revealed and properly cleaned, mold will continue to be an issue even after remediation. A post-remediation evaluation process can identify poor-quality remediation efforts as well as undiscovered mold sources that may continue to affect indoor air quality.

Despite the obvious need for generally accepted criteria to use as a comparison for post-remediation samples, no universally recognized document currently exists. In fact, many industry professionals have taken the stance that such criteria are impossible to develop as too many variables are involved [ACGIH(a) 2; Tiffany, et al 523]. It is important to recognize and address multiple impacts—and to acknowledge that "difficult" does not equate to "impossible." Therefore, the first step in the process is to identify and categorize the critical variables to be addressed in the development of a clearance criterion.

Lack of Standard Post-Remediation Procedures

Consider the number of different approaches and methodologies an industrial hygienist or indoor environment professional can use to collect a sample. For surface samples, one might use swab, tape, bulk or dust collection methods. For air samples, gravitational sedimentation plates, air impact cassettes, spore trap on slides, collector sieves, liquid impingers or agar impaction methods could be used.

Now consider the various ways to analyze and interpret the sample data: cultured, noncultured, chemical (to identify mycotoxins or microbial volatile organic compounds) and others. Furthermore, diverse geographic locations have very different spore levels as a normal part of their environment. In addition, many argue that any post-remediation criteria must also take into account the considerable range in individual susceptibilities to mold [ACGIH(a) 2]. Finally, and most important, the manner in which contractors conduct remediation varies widely, often failing to combine effective work practices with proper isolation and containment, engineering controls, decontamination procedures, and effective air flow and pressure management. Consequently, the difficultly in creating clear, concise mold remediation criteria is no surprise.

Past Efforts

Because mold spores are naturally occurring organisms found in all environments, it is difficult to pinpoint an exact number on exposure limits. Furthermore, selection of specific sampling locations has a direct impact on what spore levels might be found. While most agree that mold growth indoors is unacceptable (Pinto and Janke 5-15), what exactly con-

Michael A. Pinto, Ph.D., CSP, *is CEO of Wonder Makers Environmental Inc., a firm based in Kalamazoo, MI. He holds a bachelor's and a master's degree from Western Michigan University and a Ph.D. in Environmental Engineering from Kennedy Western University. Pinto has written three books, including* Fungal Contamination: A Comprehensive Guide for Remediation, *more than 90 technical articles and 18 commercial training programs. He is an instructor of the three levels of mold remediation courses certified by the Assn. of Specialists in Cleaning and Restoration (ASCR), and other environmental health and safety courses. Pinto is a professional member of ASSE's West Michigan Chapter.*

Mike Davis *is the indoor air quality laboratory manager at Wonder Makers Environmental Inc. He holds a B.S. in Microbiology from Montana State University and has several years' experience conducting indoor air quality investigations, specializing in the identification of both viable and nonviable biological samples. In addition, Davis is an instructor of the mold remediation technician course certified by ASCR.*

Sara Eager *is an administrative support specialist at Wonder Makers Environmental Inc., with duties including technical research and writing. She is concurrently pursuing degrees in communications and computer technology.*

stitutes appropriate levels of mold spores in indoor air or dust is vigorously debated (Johanning 19).

A large body of relevant data exists for post-remediation sampling. Personal research, guidance documents, peer-reviewed studies and articles all contribute to the wide range of information available. Tables 1 through 4 organize—by sample type and in chronological order—much of the currently available data related to indoor mold levels. Most of these data consist of qualitative numbers concerning health issues, building and structure contents, and exposure limits (for both building/home occupants and workers).

A wide range of questions is also addressed in the data. For example, what determines normal spore levels (backgrounds)? What spore levels are indicative of an impacted environment? What levels are appropriate to determine whether remediation is necessary? What spore levels determine whether an area is clean (post-remediation)?

After collecting and reviewing the data sources cited in the tables, highlights were charted, categorized by analytical method, and a simple statistical analysis was applied to find the mean (average), median (center value) and mode (most frequent value) of the collective data.

Tables 1 through 3 address cultured air samples, the most prevalent sample technique of all the data collected. However, noncultured air sample analysis (Table 4) has been used frequently in the recent past and has gained considerable acceptance in the industry (Tiffany, et al 527). The resultant data have increased the debate about which method is most appropriate. With noncultured air samples, analysis can be performed directly with a microscopic exam, with results reported in counts per cubic meter of air; turnaround time is faster as well. One drawback to these samples is that the analysis is less-detailed, producing identification only to the genus level. By comparison, cultured sample analysis can identify to the species level; however, such analysis requires a longer processing time, and imposes media limitations and difficult handling demands.

Examination of the tables reveals some common deficiencies among past studies and their approach to post-remediation sampling: 1) a small number of the approaches focus on post-remediation sampling; 2) there is a heavy reliance on sampling; and 3) a broad approach is lacking. In other words, most of the studies focus on trying to apply a single number to spore levels everywhere and anywhere, placing a heavy emphasis on sample results. These deficiencies suggest that the mold industry needs to realize that many factors must be considered when conducting post-remediation clearance sampling.

Past recommendations for post-remediation values include suggestions for reviewing data by comparing types of fungal spores and their relative proportion in a sample (called a rank/order review); comparisons to out-of-doors levels; and requirements that no pathogenic organisms be detected in post-remediation sampling [ACGIH(b) 7.4.2]. To apply rank/order values to a mold remediation project, one would collect an air sample from out-of-doors and another sample from the remediated area within the building. Analysis results of each sample would then be compared, listing spore types from the most common ones observed to the least common.

In a healthy environment, the most common spore types identified within the structure should also be the most plentiful in the out-of-doors sample. Building on this, the indoor sample should reflect similar spore type occurrences at a reduced level. For example, if an unusually high count of an uncommon spore type is found on the indoor sample that is not prevalent on the out-of-doors sample, it is feasible to conclude that an active mold source exists indoors. The rank/order method seems logical because it accommodates the issue of different geographic locations with different naturally occurring types of spores.

Interpreting the Data

In examining the body of data available on cultured fungal air sample analysis summarized in Tables 1 through 3, it is clear that the level of 1,000 colony forming units per cubic meter of air (CFU/m^3) is considered significant. This amount was most frequently mentioned (the mode) as the appropriate indicator of background levels of mold (e.g., Burge; OSHA). Indeed, a tight range of numbers emerged from the statistical analysis with 1,341 CFU/m^3 as the mean and 650 CFU/m^3 as the median. According to the collective data, results below 1,000 CFU/m^3 of common types of outdoor molds indicate no evidence of water intrusion and that no heath effects would be expected.

However, target fungal types are discussed in many documents, with an overall agreement that further investigation should be conducted if fungal types do not mimic the variety seen in proximate outdoor samples. Many of these cited authors agree that significant consideration should be given to the presence of even small amounts of target organisms which have been found in conjunction with water-damaged or contaminated buildings. In particular, many authors suggest that elevated levels of Penicillium and Aspergillus mold species are not only health concerns, but coincide with water-damaged building materials [AIHA(b) 9]. In addition, many mold types that are associated with elevated levels of mycotoxins (e.g., Stachybotrys, Fusarium, Memnoniella) are also tied to water-damaged buildings, even if they are detected only in small quantities [AIHA(b) 9].

As shown in Table 4, historical interpretations of "normal" (background) levels for noncultured air samples ranged from 2,000 counts per cubic meter of air (c/m^3) as the mode, to 4,786 c/m^3 as the mean; 2,500 c/m^3 was the median value; its similarity to the mode gives it increased validity as the dividing line between background levels and those found when contamination is present. Again, many studies implied that no health effects are expected if fungal

Table 1

Cultured Air Sample Analysis Guidelines: Part 1

Date	Source [Reference]	Guidelines Cultured Air Sample Analysis for Fungi (CFU/m³*) Normal	Impacted	Remediated	Interpretation
1979	Berk, et al [A]	<700	>700**		
1979	Graveson (General) [B]	<3,000 Cladosporium; <100 Alternaria—threshold for evoking allergic symptoms.	3,000 Cladosporium; 100 Alternaria—threshold for evoking allergic symptoms.		
1983	Berstein, et al [B]		5,000 to 10,000		
1984	Solomon, et al [A]	<1,600	>1,600		
1984	Holmberg [A]	<2,200	>2,200**; 10,000 to 15,000—surface mold present.		
1984	Morey, et al [A]	<1,000**	>1,000—need to investigate.		
1986	AIHA: *Biohazard Reference Manual* [A]				No safe level of an uncontained pathogenic organism.
1986	Morey, et al [B]	<10,000 total fungi or <500 one species.**	>10,000 total fungi or >500 one species—need for investigation or improvement.		
1987	Burge, et al [B]				Indoor spore levels one-third of outdoor, same species spectrum recommended indoor limit, rank/order assessment.
1987	Ohgke, et al [A]	<100**	>100		
1988	WHO: IAQ—Biological Contaminants [A]	<150 mixture of species or <500 Cladosporium or other common phylloplanes.	>50 of one species—investigate; >150 mix of species**; >500 common phylloplanes.**		
1988	Canada Mortgage and Housing Corp.: Determination of Fungal Propagules in Indoor Air [A]	<200 if several species; <500 if mainly Cladosporium and Alternaria.	>50 if one species; >200 if several species; >500 if mainly Cladosporium and Alternaria (investigate further for all).		
1988	Hunter, et al (Homes) [B]	<5,000**	>5,000 level most often exceeded when surface mold present.		
1988	Miller, et al (Homes) [A]	<150 mixture of species or <300 common phylloplanes.	>50 of one species of concern—investigate; >150 mix of species**; >300 common phylloplanes.**		Toxic/pathogenic unacceptable.
1989	ACGIH: Guidelines for the Assessment of Bioaerosols [A]	<100	>100**		Indoor/outdoor ratio <1 is okay if similar taxa or complaint area/non-complaint area ratio >10 is unusual.
1989	Netherlands: Research Methods in Biological Indoor Air Pollution [A]	<10,000 total fungi or <500 of one species of a potentially pathogenic nature are a health threat.**	>10,000 total fungi or >500 of one species of a potentially pathogenic nature are a threat to health.		

**Colony forming units per cubic meter of air.*
***Interpreted levels.*
References are listed in Table 3.

Table 2

Cultured Air Sample Analysis Guidelines: Part 2

Date	Source [Reference]	Guidelines Cultured Air Sample Analysis for Fungi (CFU/m³*) Normal	Impacted	Remediated	Interpretation
1989	AIHA: Practitioner's Approach to IAQ Investigations [A]	<1,000**	>1,000		High indoor/outdoor ratio indicates indoor amplifier, rank/order assessment.
1990	Burge [A]	<1,000**	>1,000—investigate		If indoor microbial aerosols qualitatively different from outdoors and indoor levels consistently more than double outdoor and exceeding 1,000 CFU/m³ should be investigated.
1990	Reponen, et al (Homes not farms) [A]	<500 (winter only)**	>500 (winter only)		Indoor/outdoor ratio >1 may indicate abnormal indoor level in summer.
1990	Reynolds, et al [A]	<500**	>500—indoor source indicated		Significant indoor/outdoor differences indicate indoor source; speciation and rank ordering recommended.
1991	Godish [A]	<1,000**	>1,000	<100 "mold-free environment"	
1991	Nordic Council: Criteria Documents from the Expert Group [A]	10 to 10,000 typical in "sick buildings"	10 to 10,000 typical in ambient air		
1991	Canada Mortgage and Housing Corp.: Testing of Older Houses for Microbial Pollutants [A]	<200 variety of species or <500 including Alternaria and Cladosporium**	>200 variety of species or >500 including Alternaria and Cladosporium—investigate.		
1992	Miller, et al [A]				Indoor mycoflora qualitatively similar to outdoors is okay or indoor mycoflora quantitatively lower than outdoors is okay.
1992	OSHA—Technical Manual [A]	<1,000**	>1,000		
1993	Council of the European Community: Report #12: Biological Particles in Indoor Environment [A]	For houses: <50 (very low); <200 (low)** Nonindustrial indoor: <25 (very low); <100 (low)**	<1,000 (intermediate); <10,000 (high); >10,000 (very high)** <500 (intermediate); <2,000 (high); >2,000 (very high)**		
1993	Yang, et al [A]	<200	>200**		Critical analysis of results is required if pathogenic or toxigenic fungi are detected.
1993	AIHA: Industrial Hygienist's Guide to IAQ Investigations [A]				Rank order assessment, indoor/outdoor comparison recommended.
1994	National Health and Welfare, Canada: IAQ in Office Buildings: A Technical Guide [A]	<150 mixture of species,<500 if common tree/leaf fungi.	>50 if one species—investigate; >150 mix of species**; >500 common tree/leaf fungi**		Toxigenic/pathogenic unacceptable.

**Colony forming units per cubic meter of air. **Interpreted levels. References are listed in Table 3.*

Table 3

Cultured Air Sample Analysis Guidelines: Part 3

Date	Source [Reference]	Guidelines Cultured Air Sample Analysis for Fungi (CFU/m³*) Normal	Impacted	Remediated	Interpretation
1994	Cutter Information Corp.: IAQ Update: Biocontaminants in Indoor Environments [A]	<300 common fungi; <150 mixed fungi; <200 total fungi; <100 if immunocompromised population**	>300 common fungi; >150 mixed fungi; >200 total fungi; >100 unless immunocompromised population		
1994	OSHA: Proposed IAQ Standard [A]				Levels of bioaerosols in the indoors would reflect those outdoors, rank/order assessment.
1994	Healthy Buildings International [A]	<750 if species not infective or allergenic	>750 if species infective or allergenic**		
1995	ACGIH: Air Sampling Instruments for Evaluation of Atmospheric Contaminants [A]	<100 (low)**	100 - 1,000 (intermediate)**; >1,000 (high)**		
1995	IAQ Association Inc.: IAQ Standard #95-1 Recommended for Florida [A]	<300 common fungi; <150 mixed	>300 common; >150 mixed**		
1995	Health Canada: Fungal Contamination in Public Buildings: A Guide to Recognition and Management [C]	<150 mix of species; <500 if Cladosporium or other tree/leaf fungi	<150 mix of species; <500 if Cladosporium or other tree/leaf fungi**		
1995	NYCDH: Guidelines on Assessment & Remediation of S. atra in Indoor Envirnmts. [A]		103-104 S. atra immediate evacuation		Indoor/outdoor ratio indicates contamination.
1997	Robertson [D]	<300 total fungi; <50 individual species (excepting Cladosporium)	>300 total fungi; >50 individual species (excepting Cladosporium)—investigate		
1999	Analytical Services Inc. [I]	<550	>550**		
1999	Mycotech Biological Inc. [J]	<300; <50 individual contributing excluding Cladosporium	>300—investigate		
2001	Godish: Indoor Environmental Quality [E]	>300 - <1,000	>1,000		
2001	Clark [F] Residential Buildings	<500	500-1,000 (possible); >1,000 (probable)		
	Commercial Buildings	<250	250-1,000 (possible); >1,000 (probable)		
2002	Mold Free [G]	<250	>250		
2003	Auburn Environmental [H]	<1,000	>1,000		

*Colony forming units per cubic meter of air.
**Interpreted levels.

Mean:	1341.666667	1476.394737
Median:	650	700
Mode:	1000	1000
SD:	2324.727327	2320.562811

References

[A] *Rao, C.Y., et al. "Review of Quantitative Standards and Guidelines for Fungi in Indoor Air."* Journal of Air and Waste Management Assn. *46(1996): 899-908.*

[B] *Singh, J., ed.* Building Mycology: Management of Decay and Health in Buildings. *London: Chapman and Hall, 1994.*

[C] *Health Canada. "Fungal Contamination in Public Buildings: A Guide to Recognition and Management." Ontario: Health Canada, Federal-Provincial Committee on Environmental and Occupational Health, 1995.*

[D] *Robertson, L.D. "Monitoring Viable Fungal and Bacterial Bioaerosol Concentrations to Identify Acceptable Levels for Common Indoor Environments."* Indoor Built Environments. *6(1997): 295-300.*

[E] *Godish, T.* Indoor Environmental Quality. *Boco Raton, FL: CRC Press LLC, 2001.*

[F] *Clark, G. "Assessment and Sampling Approaches for Indoor Microbiological Assessments."* The Synergist. *Nov. 2001.*

[G] *Mold Free: A Division of Integrated Microbiological Services. www.1877moldfree.com/index.html.*

[H] *Auburn Environmental. Akron, OH. www.auburnenvironmental.com.*

[I] *Analytical Services Inc. Huntsville, AL. www.asihsv.com.*

[J] *Mycotech Biological Inc. Jewett, TX. www.mycotechbiological.com.*

[K] *Wonder Makers Environmental Inc. Kalamazoo, MI. www.wondermakers.com.*

Table 4

Noncultured Sample Analysis Guidelines

Date	Source [Reference]	Guidelines Noncultured Air Sample Analysis for Fungi (spores/m³) Normal	Impacted	Remediated
1988	Lacey, et al [A]	1,000 to 10,000		
1993	Russian Federation: MAC of Harmful Substances [A]	1,000-10,000 cells/m³	>10,000 cells/m³*	
1999	Mycotech Biological Inc. [J]	<2,000	>2,000—investigate	
2001	Godish: Indoor Environmental Quality [E]	>3,000 to <10,000	>10,000	1,000 to 3,000
2001	Clark [F] Residential buildings Commercial buildings	<5,000 <2,500	5,000-10,000 (possible), >10,000 (probable) 2,500-10,000 (possible), >10,000 (probable)	
2003	Wonder Makers Environmental [K]	<2,000 mixed types, <1,000 Aspergillus, Penicillium; <500 outdoor types	>2,000	
2003	Auburn Environmental [H]	<2,000	>2,000*	***Mean:*** *4,786* ***Median:*** *2,500* ***Mode:*** *2,000* ***SD:*** *3,718*

**Interpreted levels.*

References

[A] *Rao, C.Y., et al. "Review of Quantitative Standards and Guidelines for Fungi in Indoor Air."* Journal of Air and Waste Management Assn. *46(1996): 899-908.*

[B] *Singh, J., ed.* Building Mycology: Management of Decay and Health in Buildings. *London: Chapman and Hall, 1994.*

[C] *Health Canada. "Fungal Contamination in Public Buildings: A Guide to Recognition and Management." Ontario: Health Canada, Federal-Provincial Committee on Environmental and Occupational Health, 1995.*

[D] *Robertson, L.D. "Monitoring Viable Fungal and Bacterial Bioaerosol Concentrations to Identify Acceptable Levels for Common Indoor Environments."* Indoor Built Environments. *6(1997): 295-300.*

[E] *Godish, T.* Indoor Environmental Quality. *Boco Raton, FL: CRC Press LLC, 2001.*

[F] *Clark, G. "Assessment and Sampling Approaches for Indoor Microbiological Assessments."* The Synergist. *Nov. 2001.*

[G] *Mold Free: A Division of Integrated Microbiological Services. www.1877moldfree.com/index.html.*

[H] *Auburn Environmental. Akron, OH. www.auburn-environmental.com.*

[I] *Analytical Services Inc. Huntsville, AL. www.asi-hsv.com.*

[J] *Mycotech Biological Inc. Jewett, TX. www.mycotechbiological.com.*

[K] *Wonder Makers Environmental Inc. Kalamazoo, MI. www.wondermakers.com.*

counts are at or below background levels as long as no target fungal types are present.

Learning from History

Despite the controversy over acceptable levels and numbers, post-remediation guidelines that include numbers are feasible. However, numbers are only part of the solution; process and interpretation must also be considered. One must understand that initial post-remediation criteria will not be set in stone. Once any criteria gains substantial industry acceptance, it is prudent to expect that experience with those criteria will lead to future adjustments. For example, consider historical issues concerning acceptable levels of asbestos, radon and lead. Initially, exposure limits for these substances were controversial, but eventually the impacted industries adapted work procedures to meet the criteria. As the acceptable control level became more commonplace, research validated its effectiveness. Many substances that are considered contaminants in buildings have gone through multiple cycles in which the acceptable level was adjusted based on continuing application and research. These same trends can be expected for the mold remediation industry.

Clarity Is Needed

It is not unusual for post-remediation sampling to fail to meet clearance criteria. Communication problems, along with failure to follow specifications, have a significant impact on post-remediation clearance. Since many industry guidance documents recommend that a mold remediation work area be left free of visible dust (Pinto and Janke 5-17), obvious visual problems are the first clue that something has not gone according to specifications.

For example, if visible dust is present within the containment, the isolated area has not been carefully cleaned, and unacceptable levels of mold spores may still be present. Clearance testing need not be conducted if the area is obviously not clean. In addition to identifying visual mold growth, hidden mold that may be impacting the area must be considered. Work plans must consider multiple aspects of a remediation project—specifically the possibility of hidden mold. EPA and AIHA documents warn about hidden mold in remediation projects [EPA 8; AIHA(a) 8]. Without careful reference to documents such as these, crucial information could be missed, potentially causing a multitude of problems later in the project.

Post-Remediation Evaluation Criteria for Mold Contamination

Step 1: Visual Inspection
Were specifications followed? Was the moisture source identified and corrected? Were the contents and debris removed? Was the work area white-glove dust-free?

Step 2: Total Spore Concentration
Is the total spore concentration less than 2,000 c/m^3 (typical of normal fungal ecology)? If less than 800 c/m^3, go to Step 4.

Step 3: Comparison to Make-Up Air Source
Is the total spore concentration on the inside sample below that on the comparison sample? *Comparison sample collected from out-of-doors or inside building but outside work area, depending on location of containment entry point.*

Step 4: Rank/Order Comparison
Is the level of each fungal type (and hyphae) recovered inside less than 100 c/m^3 above the level of the same fungal type (and hyphae) in the comparison sample?

Step 5: Indicator Organisms
Was Aspergillus/Penicillium on the inside sample less than 200 c/m^3?

Step 6: Target Organisms
Was the inside sample free of target fungal types, both counted and observed? *Zero tolerance of Stachybotrys sp., Fusarium sp., Trichoderma sp., Memnoniella sp., Chaetomium sp.*

Source: Wonder Makers Environmental Inc.

Improper setup of remediation projects can also impact post-remediation sampling results. Consider an isolation area without a decontamination chamber. Something that seems as trivial as a sheet or two of 6-mil plastic could cost the contractor several more days on the site (and substantial additional costs) after the post-remediation sampling failed due to an improper setup that caused recontamination of the project site. Remediation project specifications must be created and followed with care; small details can determine the project's success.

The easiest way to satisfy post-remediation evaluation criteria is to make the containment or work area a nonvariable. If contractors consistently establish effective engineering controls, such as isolation barriers and negative pressure enclosures, the surrounding environmental factors should not matter. Proper isolation of the work area will provide a uniform baseline between remediation projects, regardless of the type of building.

Professionals in the mold industry want clarity. Contractors, building owners and occupants, insurance adjusters, industrial hygienists and SH&E professionals are all directly impacted by the lack of clarity often found in regulations. As such, contractors must understand the expected endpoint before beginning a remediation project. When all parties understand that remediated areas are to be dust-free and meet a predetermined criterion for levels of fungal material, the communication process between contractor and client is drastically improved. Having a clear endpoint also reduces surprises at the end of a project, and helps contractors and consultants work together with the same goals in mind, ultimately reducing costs. It is also an important concept that must be considered when developing the industry's standard of care.

General Recommendations for the Post-Remediation Sampling Process

Contractors and SH&E professionals need to take a macro approach to any jobsite before post-remediation sampling begins. Having an independent or third-party consultant write specifications and aid in the facility inspection is usually a good idea (IICRC 4.2.1). In the event of legal action, having a third-party consultant helps ensure that actions taken during remediation are agreed on and documented.

The post-remediation process should always start with a visual inspection. Small indicators such as dust and debris should immediately alert the inspector that specifications were not followed. Understanding that post-remediation samples would most likely not meet clearance criteria due to the unclean condition of the site, such sampling would be senseless.

To ensure that the data collected at a project site are valid, sampling and analytical techniques should be consistent. Using different techniques for post-remediation samples as compared to earlier project sampling may alter the results and, ultimately, cause additional problems, expenses and frustration. Therefore, the same sample collection and analysis methods should be used at the beginning and the end of the project.

The final general recommendation is to remember that people's health is involved. If any concerns are raised, err on the conservative side to protect building occupants. On any remediation project, contractors' primary concern should be protecting themselves, the work crew and the building occupants. One must also recognize that mold remediation occurs in a wide range of situations. These recommendations are designed to be applied to normal residential and business environments. Structures with immunocompromised occupants or other at-risk populations may require the application of more-stringent standards on fungal contamination clean-up efforts.

Putting It All Together

At some point, the historical data and general concepts must be distilled into a workable process. The sidebar above is based on the authors' ongoing research and mold remediation project experience; it is based on noncultured sampling. All procedures for a post-remediation evaluation are captured in a

six-step process. In Step 1, a visual inspection is conducted before any samples are collected. This inspection helps determine whether project specifications were followed; whether the moisture source was identified and corrected; and whether the work area is dust-free (white-glove test). Only after the area passes a visual inspection are noncultured samples collected.

In Step 2, initial interpretation of the sample data compares the total fungal spore concentration to the set number of 2,000 c/m^3. This number is derived from the supporting reference data (Table 4) in which the mode value is 2,000 c/m^3. As the table shows, several studies agree that this value is typical of an environment that is not impacted by adverse interior fungal growth—in essence, a "normal fungal ecology." Data also show that very low total counts are possible based on seasonal variability or location. The authors' experience is consistent with that expressed by many others: When comparing samples from various areas, the reliability of a gross comparison (i.e., total fungal spores) drops off considerably at low spore concentrations. Therefore, an exemption from Step 3 is provided for samples from inside the contained area that have a total spore concentration of less than 800 c/m^3.

In Step 3, evaluation of the remediation process continues with a comparison of the total spore count inside the work area to the total spore count in the makeup air source, based on the location of the containment entry point. Subsequently, a rank/order comparison of the fungal types (to the genus level only) and concentrations, including hyphal fragments inside the work area, are compared to the types and amounts naturally occurring in the comparison sample (Step 4).

At this point, it is recommended that the levels of hyphal fragments be reviewed. Hyphal fragment is a term that many laboratories use to describe fragments of fungal organisms which are not spores. Since hyphal fragments generally do not have enough characteristics to allow them to be correlated with a specific genus of fungi, they are recorded separately. The authors' experience indicates that when concentrations of hyphal fragments found inside are higher than those found out-of-doors, an indoor source of fungal growth is usually present. Thus, this secondary comparison is included in Step 4.

The levels of fungal spores and hyphal fragments recovered in the work area sample(s) must be not more than 100 c/m^3 higher than the levels of corresponding fungal spores or hyphal fragments in the comparison sample. This limit is based on the principle that all analytical methods have a limit of detection which must accommodate the limitations of the equipment used in the laboratory and for sample collection. In an indoor environment with a normal fungal ecology, the ranking of the spores types found inside the work area should reflect the ranking of the comparison sample. For example, if Cladosporium was the most common spore type identified in the comparison sample, one would expect to find Cladosporium as the top-ranking spore type inside the work area, only at a significantly lower level.

During Step 5, indicator fungal types are considered. Fungal types are designated as "indicator" if they are associated with water damage to building or indoor finish materials. One must keep in mind that these fungi may also come from outdoors and make up a natural part of the existing flora. While several molds are discussed as potential indicators of water-damaged environments, Aspergillus/Penicillium types are mentioned frequently in the reference documents.

Aspergillus and Penicillium spores are lumped together when analysis is performed by direct microscopy because the spores are indistinguishable from one another. Oddly, this turns out to be a benefit in the post-remediation evaluation process. Certain species of both are early colonizers of water-damaged materials that grow quickly and disperse many spores. When these growth properties are matched with the negative health effects associated with these spores, their value as an indication of acceptable mold remediation procedures is enhanced. Experience with post-remediation criteria and the documents referenced in the tables has led the authors to the conservative but achievable criteria that indicator fungal types must be recovered at levels below 200 c/m^3.

In Step 6, target organisms are considered. These organisms are identified by their characteristic need for high moisture content and/or water activity to grow, their ability to naturally produce toxins and their common degradation of cellulose-containing materials. Spores from these target organisms are not typically found in clean indoor environments so the criterion for them is zero tolerance. The presence of these organisms in a cleaned work area indicates ineffective remediation and can result in continued issues with the structure or ill health effects for occupants.

Any time one step in this process exceeds the criteria, the area must be recleaned and retested as many times and as thoroughly as needed to meet the criteria for that step before proceeding to the next step. When the work area has met the criteria in all six steps, it is considered to be clean with a normal fungal ecology, and the project has been successfully completed.

Key Points

Throughout the effort to collect and review historical data, develop post-remediation criteria, then field-test the process, several overarching concepts emerged.

Lack of standardization creates problems. Projects often fail due to incorrect or subpar efforts to follow specifications. However, many projects are currently categorized as ineffective because no widely recognized verification protocol or criteria is available for comparison of post-remediation samples. As a result, the project becomes seemingly endless, costs skyrocket and liability becomes an issue.

Previous efforts have not focused on post-remediation as a separate subset of data, which leaves the field wide open. Much research has been related to

Industry Trends: Examples of Post-Remediation Protocols

As the mold remediation industry grows, many are recognizing the need for a commonly accepted post-remediation protocol. A literature search found several examples of post-remediation guidelines. Two examples are U.S. Micro-Solutions Inc. (Greensburg, PA; www.usmicro-solutions.com) and P&K Microbiology Services Inc. (Cherry Hill, NJ; Miramar, FL). While the details differ, it is reassuring that the industry seems to be moving in the same direction in terms of establishing criteria for post-remediation.

U.S. Micro-Solutions Inc.: Spore Trap Samples (Previously Affected Area)

A spore trap sample will be collected in the area(s) of concern. These samples should show no Stachybotrys conidia. The total spore count should be below background (outdoor) air (certain exceptions apply to this guideline, particularly when outdoor spore counts can be negatively impacted by snowfall and other factors). On total spore counts over 3,000, no one genera or grouping may exceed 75 percent of the total spore count. Where prior air results exist, the total spore counts should be reduced by 70 percent where unusually high spore counts (greater than 10,000 spores per cubic meter) have existed in the past. Otherwise, a general reduction in total spore count is favorable with a marked reduction in any predominant spore type. Older buildings, with poor HVAC filtration or heavy outside air infiltration may be evaluated at the discretion of the site visitor. (Total sample volume should be 75 liters on Air-O-Cell cassettes, 25 liters on Micro5 cassettes or 60 liters on Cyclex-D cassettes.) Areas corresponding to air samples not meeting these guidelines will be recommended for further action.

Like the authors' proposal, total spore counts are compared to an outdoor sample or, when they exist, to earlier air results. While both guidelines set a total spore count limit, U.S. Micro-Solutions proposes a limit of 3,000 c/m^3 as compared to 2,000 c/m^3. In addition, rather than a rank/order comparison, this group adds the condition that no one genera or spore type may exceed 75 percent of the total spore count. The goal is a general decrease in the total spore count and a "marked" reduction in any predominant spore type. While both protocols indicate that no Stachybotrys conidia is acceptable on post-remediation samples, the approach detailed in this article proposes an enlarged list of zero tolerance indicator/target organisms. This list includes species that grow in environments similar to Stachybotrys, are early colonizers of water-damaged materials and/or produce toxins.

P&K Microbiology Services Inc.

This firm has also developed an interpretation for fungal bioaerosol samples. It proposes a 12-step process, similar to the authors' proposal in many respects. Both set an acceptable total spore concentration, involve comparison samples (indoor to outdoor, complaint to noncomplaint areas) and involve a rank/order comparison between samples. Many of the later steps in the P&K protocol look for indicator or "signature" fungi, similar to the indicator/target organisms in Steps 5 and 6 of the process described in this article.

The main difference between the two protocols is that P&K relies on culturable air samples. Rather than a limit, this protocol sets an upper range of 150 to 250 CFU/m^3 for acceptable total spore counts, and the list of marker or "signature" fungi reflect cultured air sample results.

identifying background levels or levels that can be linked to specific health effects. Few studies have focused on identifying post-remediation criteria that verifies the effectiveness of the remediation and cleaning techniques—even if those criteria cannot be clearly linked to health risk. History has shown that many times a "best guess" must be made so that research can validate the effectiveness of a particular level or criterion. Separating post-remediation criteria from the debate over background levels or other confounding issues would allow the industry to advance while further scientific data are collected.

Conclusion

Developing post-remediation evaluation criteria for mold projects should be a process. Comparison numbers are only a small part of the process. However, the endpoint must be clearly detailed and communicated before the project begins. The proposed strategy for post-remediation criteria includes six steps. Failure in any step means the evaluation process must start over at Step 1. Incorporation of visual criteria and interpretation of sample data is crucial to the success rate of remediation projects.

Controversy continues to surround indoor air quality, especially related to mold and its effects. Setting and using post-remediation evaluation criteria in all remediation projects is an effective way to strengthen the industry and, in the long run, help define industry standards. Each mold remediation project should be viewed from a macro perspective, considering all related factors. ■

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