

# Environmental Laboratories and Indoor Air Testing: A Primer



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## About APHL

The Association of Public Health Laboratories (APHL) works to safeguard the public's health by strengthening public health laboratories in the United States and across the world. In collaboration with its members, APHL advances laboratory systems and practices, and promotes policies that support healthy communities. Its membership includes state and local public health laboratories, environmental laboratories and others that conduct testing of public health significance. Individuals and international representatives also participate in the association.

APHL is a non-profit, 501(c)(3) organization with a history of over 50 years. APHL is located in Silver Spring, MD. More information is available at [www.aphl.org](http://www.aphl.org).

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## Executive Summary

People are paying more attention to “local” environmental conditions, such as residential indoor air conditions. However, in many instances, environmental laboratories do not have an indoor air-testing program. In other examples, laboratories may have a basic program, but are considering expansion to better serve their community.

This Primer provides basic information on the most significant residential indoor air pollutants. While the list of contaminants is not comprehensive, laboratories interested in launching a testing program will likely consider these ten areas first. In the context of the specific contaminants, the Primer addresses a number of basic issues for laboratories to consider, including screening methods, cost, and resources that may be necessary to start or expand an indoor air-testing program. Finally, the Appendices provide additional information on study design and referral sources for technical assistance and local housing partnership opportunities.

## Introduction

Indoor air contamination comes in many forms. Allergens, smoke, mold, radon and other pollutants all negatively impact the health of building occupants. In the residential setting, particularly susceptible populations, including children, the elderly and those with compromised immune systems, may be exposed to a variety of health risks. These pollutants are the result of gases or particles coming from sources located throughout the house.<sup>1</sup>

The US EPA,<sup>2</sup> CDC<sup>3</sup> and World Health Organization<sup>4</sup> provide information and conduct research into indoor air quality issues. In addition, most states conduct some level of work regarding indoor air quality investigation or assistance.<sup>5</sup>

Environmental Health Laboratories can play a critical role in determining the dangers posed to residents by instituting a testing program for indoor air pollutants. An indoor air-testing program may take specialized equipment or new methods in order to address its unique issues.

This primer provides the basic information needed to implement a new or expanded indoor air-testing program. The contaminants covered below are not a complete list of the various indoor air pollutants that a residential setting may encounter. Instead, the 10 pollutants or class of pollutants are the areas where Environmental Health Laboratories may receive the bulk of the testing requests. Specifically, this primer covers:

- Allergens
- Abestos
- Formaldehyde and Acrolein
- Isocyanates
- Lead
- Mercury
- Mold and Mildew
- Particular Matter
- Radon

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<sup>1</sup> US Environmental Protection Agency. An Introduction to Indoor Air Quality (IAQ). Retrieved from <http://www.epa.gov/iaq/ia-intro.html>, August 7, 2014.

<sup>2</sup> US Environmental Protection Agency. An Introduction to Indoor Air Quality (IAQ). Retrieved from <http://www.epa.gov/iaq/ia-intro.html>, August 7, 2014.

<sup>3</sup> US Centers for Disease Control and Prevention. Indoor Air Quality. Retrieved from <http://www.cdc.gov/healthyhomes/bytopic/airquality.html>, August 7, 2014.

<sup>4</sup> World Health Organization. Indoor air pollution and household energy. Retrieved August 20, 2014 from <http://www.who.int/heli/risks/indoorair/indoorair/en/>. For specific WHO guidelines on testing for common chemicals in indoor air, see: World Health Organization. WHO guidelines for indoor air quality: selected pollutants. 2010. Retrieved August 20, 2014 from [http://www.euro.who.int/\\_\\_data/assets/pdf\\_file/0009/128169/e94535.pdf?ua=1](http://www.euro.who.int/__data/assets/pdf_file/0009/128169/e94535.pdf?ua=1).

<sup>5</sup> US Centers for Disease Control and Prevention. Indoor Air Quality Information. Retrieved from [http://www.cdc.gov/nceh/airpollution/indoor\\_air.htm](http://www.cdc.gov/nceh/airpollution/indoor_air.htm), August 7, 2014.

Each section addresses the types of equipment, screening and analytical methods, costs, and other basic issues that laboratories should deliberate when considering a new or expanded indoor air testing program. Additionally, laboratories should be aware that they may not always receive pure air samples in every case. For example, with air contaminants such as mold, lead and allergens, the tested media may consist of vacuumed dust samples, tape samples, or wipe samples to analyze the particles causing a degradation of indoor air quality.

It should also be noted that emerging sensor technology may provide opportunities for air monitoring across many of the pollutants discussed below.<sup>6</sup> The US EPA's Air Sensor Guidebook provides detailed information on sensor technology and applications.<sup>7</sup> Government laboratories may consider assisting community efforts with regards to sensor technologies through citizen science efforts. Local public health systems may appreciate laboratory input when implementing air sensor programs, through programs like the Air Sensor Toolbox for Citizen Scientists.<sup>8</sup>

This primer addresses residential indoor air specifically. For information concerning occupational indoor air issues, the National Institute of Occupational Safety and Health (NIOSH)<sup>9</sup> and the Occupational Safety and Health Administration (OSHA)<sup>10</sup> both comprehensively address indoor air quality in workplace settings.

Finally, the Appendices provide additional information concerning indoor air testing study design as well as technical and community points of contact. Environmental Health Laboratories are encouraged to reach out to community organizations to determine local needs and areas of focus when considering the type of indoor air testing program to launch.

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<sup>6</sup> US Environmental Protection Agency. Next Generation Air Measuring. Retrieved August 19, 2014 from <http://www.epa.gov/research/airscience/next-generation-air-measuring.htm>.

<sup>7</sup> US Environmental Protection Agency. Air Sensor Guidebook. Retrieved August 19, 2014 from <http://www.epa.gov/research/airscience/docs/air-sensor-guidebook.pdf>.

<sup>8</sup> US Environmental Protection Agency. EPA's Air Sensor Toolbox for Citizen Scientists. Retrieved August 19, 2014 from <http://www.epa.gov/heasd/airsensortoolbox/index.html>.

<sup>9</sup> US Centers for Disease Control and Prevention. Workplace Safety & Health Tips: Indoor Environmental Quality. Retrieved from <http://www.cdc.gov/niosh/topics/indoorenv/>, August 7, 2014.

<sup>10</sup> US Occupational Safety & Health Administration. Indoor Air Quality. Retrieved from <https://www.osha.gov/SLTC/indoorairquality/>, August 7, 2014.

## Allergens

Allergens come in many forms and manifest in many different ways. Insects, plants, pets and other sources may cause irritation in both children and adults. Recent studies and Institute of Medicine recommendations indicated that in-house cleaning,<sup>11</sup> education for household, nurse case management and housing Interventions can significantly reduce allergen exposures, thus reduce the asthma in home environments.<sup>12</sup>

Screening methods and equipment vary by type of allergen.<sup>13</sup> Two methods provide a wide range of analysis options:

1. Enzyme-linked immuno-sorbent assay (ELISA)
2. Multiple Array for Indoor Allergens (MARIA®)<sup>14</sup>

ELISA can detect allergens (antigen-antibody reactions using monoclonal or polyclonal antibodies) from:

- animal allergens
  - Fel d 1 (cat, *Felis domesticus*)
  - Can f 1 (dog, *Canis familiaris*)
  - Mus m1 (mouse, *Mus musculus*)
  - Rat r1 (rat, *Rattus norvegicus*)
- common German cockroach (*Blattella germanica*- Bla g1, Bla g2)
- dust mites (*Dermatophagoides farina*- Der p1, Der f1)<sup>15</sup>
- foods
- molds
- pollen

However, only individual (single) target testing is available via ELISA, suggesting the need for specific targeting and confirmation testing. Additionally, ELISA is limited to select World Health Organization (WHO)-recommended allergens.<sup>16</sup> While ELISA is cost-effective, it is more time-consuming and requires more “hands-on time” from laboratory personnel.

<sup>11</sup> Institute of Medicine, Division of Health Promotion and Disease Prevention, Committee on the Assessment of Asthma and Indoor Air. Clearing the air: asthma and indoor air exposures. Washington: National Academy Press; 2000.

<sup>12</sup> Breyse, J., Wendt, J., Dixon, S., Murphy, A., Wilson, J., Meurer, J., Cohn, J., Jacobs, D.E. Nurse Case Management and Housing Interventions Reduce Allergen Exposures: The Milwaukee Randomized Controlled Trial. Public Health Reports, 2011; Supplement 1, Volume 126, p89-99.

<sup>13</sup> Specific allergen concentration of WHO and FDA reference preparations measured using a multiple allergen standard. J Allergy Clin Immunol 2012; 129:1408-1410.

<sup>14</sup> King, E.M., Filep, S., Smith, B., Platts-Mills, T., Hamilton, R.G., Schmechel, D., Sordillo, J.E., Milton, D., van Ree, R., Krop, E.J., Heederik, D.J., Metwali, N., Thorne, P.S., Zeldin, D.C., Sever, M.L., Calatroni, A., Arbes Jr., S.J., Mitchell, H.E., Chapman, M.D. A multi-center ring trial of allergen analysis using fluorescent multiplex array technology. J Immunol Methods 2013; 387(1-2):89-95.

<sup>15</sup> Chapman, M.D., Heymann, P.W., Wilkins, S.R., Brown, M.J., Platts-Mills, T.A. Monoclonal immunoassays for major dust mite (*Dermatophagoides*) allergens, Der p 1 and Der f 1, and quantitative analysis of the allergen content of mite and house dust extracts. J Allergy Clin Immunol 1987; 80:184-94.

<sup>16</sup> Specific allergen concentration of WHO and FDA reference preparations measured using a multiple allergen standard. J Allergy Clin Immunol 2012; 129:1408-1410.

Alternatively, MARIA can simultaneously detect multiple allergens in a single test. The test provides improved assay performance (primarily uses monoclonal antibodies, thus increased sensitivity and accuracy while achieving high throughput of samples by testing up to 11 targets that can consist of the following in combination:

- animal allergens
  - Fel d 1 (cat, *Felis domesticus*)
  - Can f 1 (dog, *Canis familiaris*)
  - Mus m 1 (mouse, *Mus musculus*)
  - Rat n 1 (rat, *Rattus norvegicus*)
- common German cockroach, Bla g 2 (*Blattella germanica*)
- dust mite
  - Der p1, Der f1 (*Dermatophagoides farina*)
  - Mite Group 2
- mold allergen Alt a 1 (*Alternaria alternata*)
- pollens
  - Bet v 1 (Birch, *Betula verrucosa*)
  - Phl p 5 (Timothy grass, *Phleum pratense*)

MARIA could provide substantial time savings, including overall improved turn-around-time, high throughput analysis, and cost-effective allergen testing (due to less use of disposable plastics, reagents, and man-hours). Additionally, MARIA can be automated via Luminex multiplex technology, but will still require extensive sample processing.

Both ELISA and MARIA have accepted analytical methods. As noted above ELISA relies on WHO standards as well as standards from the CDC. MARIA uses a Universal Allergen Standard to quantify the allergens. Both ELISA and MARIA are acceptable; however, ELISA is more widely used due to the low cost of analysis, and MARIA is considered a “relatively new” technique, thus, requiring extensive training and skilled staff with understanding and interpretation of test results.

Equipment options vary depending on the test platform chosen. ELISA requires plate readers, washers, and unique calibration standards, chemicals and reagents. MARIA utilizes either Luminex (200 or comparable software, plate-filtration manifold and related equipment) or Bio-RAD (Bio-Plex 200 system) technology. Commercial reagents are available and both require staff training and participation in proficiency testing.

## Asbestos

Asbestos is a naturally occurring mineral fiber used in insulation and other building materials.<sup>17</sup> During renovation or maintenance operations in homes, asbestos may be dislodged and become airborne. Asbestos is normally not a source of acute health effects; however, long-term exposure to asbestos can result in a variety of lung diseases.<sup>18</sup>

In order to conduct asbestos monitoring and measurements, laboratories need: air samplers, filters, phase contrast microscopy (PCM) with polarized light microscopic (PLM) filtering capabilities, and access to transmission electronic microscopy (TEM) services to confirm the identity of fibers using TEM methods.<sup>19</sup>

Phase contrast microscopy (PCM) is the analytical method for measuring airborne asbestos, and should be done in accordance with the proper OSHA Standards. Air is drawn through a filter to capture airborne asbestos fibers. A portion of the filter is removed and a measured area is viewed by PCM. All the fibers meeting defined criteria for asbestos are counted and considered a measure of the airborne asbestos concentration.<sup>20</sup> There are two specific methods for PCM (currently, there are no sensor technology for asbestos):

- ASTM 7201<sup>21</sup>
- NIOSH 7400<sup>22</sup>

There are four main advantages of PCM:<sup>23</sup>

1. Phase contrast is a fiber counting technique and excludes non-fibrous particles from the analysis.
2. The technique is inexpensive and does not require specialized knowledge to carryout the analysis for total fiber counts.
3. The analysis is quick and can be performed on-site for rapid determination of asbestos fiber concentration in the air.
4. The technique has continuity with historical epidemiological studies so that estimates of expected disease can be inferred from long-term determinations of asbestos exposures.

<sup>17</sup> US Environmental Protection Agency. An Introduction to Indoor Air (IAQ): Asbestos. Retrieved August 7, 2014 from <http://www.epa.gov/iaq/asbestos.html>.

<sup>18</sup> US Environmental Protection Agency. Learn About Asbestos. Retrieved October 21, 2014 from <http://www2.epa.gov/asbestos/learn-about-asbestos#effects>.

<sup>19</sup> [https://www.osha.gov/pls/oshaweb/owadisp.show\\_document?p\\_table=STANDARDS&p\\_id=10005](https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10005) OSHA. Polarized Light Microscopy of Asbestos

<sup>20</sup> Occupational Safety and Health Administrations. Detailed procedure for asbestos sampling and analysis - Non-Mandatory. Retrieved August 28, 2014, from [https://www.osha.gov/pls/oshaweb/owadisp.show\\_document?p\\_table=standards&p\\_id=9997](https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=standards&p_id=9997).

<sup>21</sup> ASTM International. ASTM D7201: Standard Practice for Sampling and Counting Airborne Fibers, Including Asbestos Fibers, in the Workplace, by Phase Contrast Microscopy (with an option of Transmission Electron Microscopy). Retrieved August 25, 2014 from <http://www.astm.org/Standards/D7201.htm>.

<sup>22</sup> National Institute of Occupational Safety and Health. Asbestos and Other Fibers by PCM (7400). Retrieved August 25, 2014 from <http://www.cdc.gov/niosh/docs/2003-154/pdfs/7400.pdf>.

<sup>23</sup> Occupational Safety and Health Administrations. Detailed procedure for asbestos sampling and analysis - Non-Mandatory. Retrieved August 28, 2014, from [https://www.osha.gov/pls/oshaweb/owadisp.show\\_document?p\\_table=standards&p\\_id=9997](https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=standards&p_id=9997).

There are, however, disadvantages:<sup>24</sup>

1. PCM does not positively identify asbestos fibers. Other fibers which are not asbestos may be included in the count unless differential counting is performed. This requires a great deal of experience to adequately differentiate asbestos from non-asbestos fibers.
2. The smallest visible fibers are about 0.2  $\mu\text{m}$  in diameter while the finest asbestos fibers may be as small as 0.02  $\mu\text{m}$  in diameter. For some exposures, substantially more fibers may be present than are actually counted.

To positively identify asbestos, or differentiate among different types of asbestos, analyses must be performed by polarized light microscopy (PLM) or transmission electron microscopy (TEM).

PLM can be used to distinguish between asbestos and non-asbestos fibers.<sup>25</sup> PLM equipment and procedures are far less expensive than TEM, which identifies specific asbestos fiber type.

The advantages of PLM are:

- Basic identification of the materials was first performed by light microscopy and gross analysis. This provides a large base of published information against which to check analysis and analytical technique.
- The analysis is specific to fibers. The minerals present can exist in asbestiform, fibrous, prismatic, or massive varieties all at the same time. Therefore, bulk methods of analysis such as X-ray diffraction, IR analysis, DTA, etc. are inappropriate where the material is not known to be fibrous.
- The analysis is quick, requires little preparation time and can be performed on-site if a suitably equipped microscope is available.

The disadvantages of PLM are:

- Even using phase-polar illumination, not all the fibers present may be seen. This is a problem for very low asbestos concentrations where agglomerations or large bundles of fibers may not be present to allow identification by inference.
- The method requires a great degree of sophistication on the part of the microscopist. The mineralogical training of the analyst is very important. It is the basis on which subjective decisions are made.
- The method uses only a tiny amount of material for analysis. This may lead to sampling bias and false results (high or low). This is especially true if the sample is severely inhomogeneous.
- Fibers may be bound in a matrix and not distinguishable as fibers so identification cannot be made.

When asbestos fibers are present but not identifiable by light microscopy, TEM is used to determine the fiber identity.

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<sup>24</sup> Occupational Safety and Health Administrations. Detailed procedure for asbestos sampling and analysis - Non-Mandatory. Retrieved August 28, 2014, from [https://www.osha.gov/pls/oshaweb/owadisp.show\\_document?p\\_table=standards&p\\_id=9997](https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=standards&p_id=9997).

<sup>25</sup> Occupational Safety and Health Administration. Polarized Light Microscopy of Asbestos – Non-Mandatory. Retrieved August 28, 2014, from [https://www.osha.gov/pls/oshaweb/owadisp.show\\_document?p\\_table=STANDARDS&p\\_id=10005](https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10005).

Compared to PLM, the TEM equipment, maintenance and procedure are very expensive. If considering TEM, the following methods are available:

- ASTM D-6281<sup>26</sup>
- EPA Level II (Yamate)<sup>27</sup>
- ISO 10312<sup>28</sup>
- ISO 13794<sup>29</sup>
- NIOSH 7402<sup>30</sup>

Both PLM and TEM require expertise and proficiency to describe, measure, identify and count asbestos fibers.

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<sup>26</sup> ASTM International. ASTM D6281-09: Standard Test Method for Airborne Asbestos Concentration in Ambient and Indoor Atmospheres as Determined by Transmission Electron Microscopy Direct Transfer (TEM). Retrieved August 25, 2014 from <http://www.astm.org/Standards/D6281.htm>.

<sup>27</sup> Yamate, G.; Agarwal, S.C.; Gibbons, R.D. Methodology for the Measurement of Airborne Asbestos by Electron Microscopy, EPA's Report No. 68-02-3266. 1984. Retrieved August 28, 2014, from <http://www.epa.gov/region9/toxic/noa/eldorado/pdf/EPA-ERT-Asbestos-Sampling-SOP-2015.pdf>.

<sup>28</sup> ISO. ISO 10312:1995: Ambient air—Determination of asbestos fibers—Direct transfer transmission electron microscopy method. Retrieved August 25, 2014 from [http://www.iso.org/iso/catalogue\\_detail.htm?csnumber=18358](http://www.iso.org/iso/catalogue_detail.htm?csnumber=18358).

<sup>29</sup> ISO. ISO 13794:1999: Ambient air — Determination of asbestos fibers—Indirect-transfer transmission electron microscopy method. Retrieved August 25, 2014, from [http://www.iso.org/iso/catalogue\\_detail.htm?csnumber=22933](http://www.iso.org/iso/catalogue_detail.htm?csnumber=22933).

<sup>30</sup> National Institute of Occupational Safety and Health. Asbestos by TEM (7402). Retrieved August 25, 2014, from <http://www.cdc.gov/niosh/docs/2003-154/pdfs/7402.pdf>.

## Formaldehyde and Acrolein

Formaldehyde is a chemical widely found in building materials, household products, and which can be produced via a variety of combustion processes.<sup>31</sup> Acrolein may be formed from the breakdown of certain pollutants found in air, from the burning of organic matter including tobacco, or from the burning of fuels such as gasoline or oil. Airborne exposure to acrolein may occur by breathing contaminated air, by smoking tobacco or by being in the proximity of someone who is smoking, by being near vehicle exhaust, or by being near oil- or coal-fired power plants.<sup>32</sup>

To screen for formaldehyde or acrolein, contaminants can be collected using passive samplers or low-level (0.04-1 ppm) detector tubes to evaluate complaints of eye, nose, and throat irritation which may be due to off-gassing from insulation, building materials, carpets, drapes, or glues and adhesives.

Sensors are an option for formaldehyde with the Interscan Corporation 400 Series Portable Analyzer.<sup>33</sup> This sensor is a stand-alone monitor that is relatively simple to use; however, it is not a NIOSH or EPA approved method, and therefore requires further evaluation.

Both NIOSH and OSHA created analytical methods for measuring both formaldehyde and acrolein:

- NIOSH Method 2016<sup>34</sup>
- OSHA Method 52<sup>35</sup>

Both the sampling and analytical procedures permit the simultaneous determination of acrolein and formaldehyde. Additionally, samples can be collected using passive samplers or sampling pump and commercially available sorbent tube. One disadvantage is that organic solvent extraction is required. Extracts must be analyzed using a gas chromatograph coupled with a nitrogen selective detector.

EPA also created an accepted analytical method for both formaldehyde and acrolein:

- TO-11A<sup>36</sup>

<sup>31</sup> US Environmental Protection Agency. An Introduction to Indoor Air (IAQ): Formaldehyde. Retrieved from <http://www.epa.gov/iaq/formaldehyde.html>, August 7, 2014.

<sup>32</sup> Agency for Toxic Substances and Disease Registry. 2007. ToxGuide™ for Acrolein, CH<sub>2</sub>=CH-CHO, CAS # 107-02-8. Retrieved August 25, 2014, from <http://www.atsdr.cdc.gov/toxguides/toxguide-124.pdf>. See also, US Environmental Protection Agency. 2003. Toxicological Review of Acrolein: In Support of Summary Information on the Integrated Risk Information System (IRIS). Retrieved August 25, 2014 from <http://www.epa.gov/iris/toxreviews/O364tr.pdf>.

<sup>33</sup> Interscan Corporation. Formaldehyde Monitoring Instruments and Systems. Retrieved August 25, 2014 from [http://www.gasdetection.com/wp-content/uploads/hcho\\_monitoring\\_instruments\\_and\\_systems.pdf](http://www.gasdetection.com/wp-content/uploads/hcho_monitoring_instruments_and_systems.pdf).

<sup>34</sup> National Institute of Occupational Safety and Health. Formaldehyde (2016). Retrieved August 25, 2014 from <http://www.cdc.gov/niosh/docs/2003-154/pdfs/2016.pdf>.

<sup>35</sup> US Occupational Safety and Health Administration. Acrolein and/or Formaldehyde. Retrieved August 25, 2014 from <https://www.osha.gov/dts/sltc/methods/organic/org052/org052.html>.

<sup>36</sup> US Environmental Protection Agency. Compendium Method TO-11A: Determination of Formaldehyde in Ambient Air Using Adsorbent Cartridge Followed by High Performance Liquid Chromatography (HPLC) [Active Sampling Methodology]. Retrieved August 25, 2014 from <http://www.epa.gov/ttnamti1/files/ambient/airtox/to-11ar.pdf>.

For TO-11A, the sampling and analytical procedures permit the simultaneous determination of acrolein and formaldehyde. Additionally, samples can be collected using a sampling pump and commercially-available DNPH absorbent cartridge. However, this method requires organic extraction using acetonitrile and analysis of extracts by high performance liquid chromatography.

Finally, NIOSH has a method for detecting formaldehyde only:

- NIOSH 3500<sup>37</sup>

This spectrophotometric method is less expensive than chromatographic methods, but it may be difficult to set up the air sampler with impingers. Only those with proper chemical handling training should consider this method.

For laboratories considering any of these methods, they may need the following equipment:

- NIOSH 2016 and EPA Method TO-11A:
  - Air sampling pump
  - DNPH cartridges
  - HPLC
  - UV detector
- OSHA Method 52
  - XAD-2 adsorbent tubes
  - Air sampler
  - GC with a nitrogen selective detector
- NIOSH 3500:
  - Air sampler
  - Impingers
  - Spectrophotometer

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<sup>37</sup> National Institute of Occupational Safety and Health. Formaldehyde by VIS (3500). Retrieved August 25, 2014, from <http://www.cdc.gov/niosh/docs/2003-154/pdfs/3500.pdf>.

## Isocyanates

Isocyanates are chemicals that can cause occupational asthma, irritation of the skin, eyes, nose and throat, and cancer. Deaths have occurred due to both asthma and hypersensitivity pneumonitis from isocyanate exposure. Respiratory illnesses also can be caused by exposure to the skin.

Isocyanates react with compounds containing alcohol (hydroxyl) groups to produce polyurethane polymers, which are components of polyurethane foams, thermoplastic elastomers, spandex fibers, and polyurethane paints.<sup>38</sup> Isocyanates are the raw materials that make up all polyurethane products. Isocyanates are found in a number of commercial products, including paint, polyurethane foam, insulation materials, surface coatings, car seats, furniture, foam mattresses, under-carpet padding, packaging materials, shoes, laminated fabrics, polyurethane rubber, and adhesives. Do-it-yourself products containing isocyanates are available to homeowners to seal cracks themselves. Without proper ventilation indoor air exposure is likely.

While there are no screening methods available, there are two NIOSH methods that laboratories may select:

- Method 5525 Isocyanates Total<sup>39</sup>
- Method 5521 Monomeric Isocyanates<sup>40</sup>

The value of Method 5525<sup>41</sup> is the lower reporting limits that can be achieved, 50 ng for both the monomer and oligomer species, due to the strong fluorescence response of the 1-(9-anthracenylmethyl)piperazine (MAP) derivatives. Another benefit is the ability to calculate total isocyanate for the collected atmosphere even when all the possible isocyanate species are not known. This is due to the MAP isocyanate derivatives all exhibiting the same equivalent response in the ultraviolet analysis making it possible for the laboratory to calculate all confirmed isocyanate species. This is accomplished by comparing both the fluorescence and ultraviolet chromatograms and calculating the total using the response of one isocyanate species.

Conversely, the disadvantages associated with Method 5525 are having to use impingers for sample collection and the lack of commercial availability of the MAP derivatizing agent. Only those who are properly trained at chemical handling should attempt to use this procedure.

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<sup>38</sup> US Occupational Safety and Health Administration. Isocyanates. Retrieved August 25, 2014, from <https://www.osha.gov/SLTC/isocyanates/index.html>.

<sup>39</sup> National Institute of Occupational Safety and Health. Isocyanates, Total (MAP) (5525). Retrieved August 25, 2014, from <http://www.cdc.gov/niosh/docs/2003-154/pdfs/5525.pdf>.

<sup>40</sup> National Institute of Occupational Safety and Health. Isocyanates, Monomeric (5521). Retrieved August 25, 2014, from <http://www.cdc.gov/niosh/docs/2003-154/pdfs/5521.pdf>.

<sup>41</sup> Bureau Veritas. Isocyanates-A Sampling Primer. Retrieved August 25, 2014, from <http://www.us.bureauveritas.com/wps/wcm/connect/b181b395-3358-42ec-833c-14b1e497ac12/Isocyanates+-+A+Sampling+Primer.pdf?MOD=AJPERES>.

Advantages to Method 5521 include the ability to collect for the vapor and aerosol in one sampler without the need for field desorption.<sup>42</sup> However, disadvantages include the method determines the air concentration of specific diisocyanates. It uses impingers and has a short holding time (7 days) for the impinger reagent. Only those who are properly trained at chemical handling should attempt to use this procedure.

Laboratories considering either of these methods may need the following equipment:

- NIOSH 5525
  - Air sampler
  - 1-(9-anthracenylmethyl)piperazine (MAP) [5,6] impregnated filters
  - HPLC with gradient capabilities, coupled with UV and Fluorescence Detectors
- NIOSH 5521
  - Air sampler
  - Impingers
  - HPLC with gradient, coupled with electrochemical detector

Note that OSHA announced a new National Emphasis Program for occupational exposure to isocyanates.<sup>43</sup> “Workers exposed to isocyanates can suffer debilitating health problems for months or even years after exposure,” said Assistant Secretary of Labor for Occupational Safety and Health Dr. David Michaels. “Through this program, OSHA will strengthen protections for workers exposed to isocyanates.”

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<sup>42</sup> Bureau Veritas. Isocyanates-A Sampling Primer. Retrieved August 25, 2014, from <http://www.us.bureauveritas.com/wps/wcm/connect/b181b395-3358-42ec-833c-14b1e497ac12/Isocyanates+-+A+Sampling+Primer.pdf?MOD=AJPERES>.

<sup>43</sup> Occupational Safety and Health Administration. 2013. OSHA Announces new National Emphasis Program for occupational exposure to isocyanates. Retrieved August 25, 2014, from [https://www.osha.gov/pls/oshaweb/owadisp.show\\_document?p\\_table=NEWS\\_RELEASES&p\\_id=24273](https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=NEWS_RELEASES&p_id=24273).

## Lead

Lead has a long history of negative health impacts in residential settings. While lead-based paint remains a significant source of indoor air contamination, other sources include combustion and being tracked in from outside sources.<sup>44</sup>

Currently, there are no available screening methods for lead in air. Instead, the air must be collected and analyzed using reference methods, including indirect methods using wipe samples and similar collection methods.

There is one primary accepted analytical method, NIOSH Method 7303.<sup>45</sup> It involves digesting a filter (either MCE or PVC) with nitric and hydrochloric acids in a hot block at 95 °C. To collect the sample one would need a pump and filter cassette. The total volume collected will determine the reported concentration (mg/m<sup>3</sup> is a common unit used by OSHA). Analysis is then conducted by Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES), with a 1.8 µg/sample reporting limit.

There are other acceptable methods for lead analysis, which may be used by commercial laboratories.<sup>46</sup>

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<sup>44</sup> US Environmental Protection Agency. An Introduction to Indoor Air (IAQ): Lead. Retrieved from <http://www.epa.gov/iaq/lead.html>, August 7, 2014.

<sup>45</sup> National Institute of Occupational Safety and Health. Elements by ICP (7303). Retrieved August 25, 2014 from <http://www.cdc.gov/niosh/docs/2003-154/pdfs/7303.pdf>.

<sup>46</sup> See e.g.: ASTM International. ASTM E1613-12: Standard Test Method for Determination of Lead by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES), Flame Atomic Absorption Spectrometry (FAAS), or Graphite Furnace Atomic Absorption Spectrometry (GFAAS) Techniques. Retrieved August 25, 2014 from <http://www.astm.org/Standards/E1613.htm>.

## Mercury

Mercury is a chemical found in many household products and in some medicines or medical procedures. Household products can include family heirlooms, antiques, fluorescent light bulbs (including compact fluorescent light bulbs—CFLs), paint, thermometers, thermostats, batteries, switches and relays.<sup>47</sup> Mercury may also be found in dental fillings, skin creams, necklaces and other jewelry. It can be used in alternative medicine and cultural practices. When mercury is exposed to the air, it can evaporate into an invisible, odorless and potentially-toxic vapor, especially in warm or poorly ventilated areas.<sup>48</sup>

The main method used to perform analyses of mercury vapor is cold vapor-atomic absorption spectrophotometer (CVAA). Two primary tests use CVAA for mercury vapor testing, although both are for workplace environments.

- OSHA ID-140<sup>49</sup>
- NIOSH 6009<sup>50</sup>

These methods use a solid sorbent device to collect the samples, which are then digested and analyzed using the CVAA method. There are both passive and active sorbent collection devices that can be used in a variety of settings. The tests listed above are very similar to the Standard Methods for the Examination of Water and Wastewater by 3112B<sup>51</sup> or EPA Methods 245.1<sup>52</sup> and 245.2.<sup>53</sup>

The collected samples are stable for at least 28 days (30 days per the OSHA method), which allows adequate time for collection and testing. In addition the sampling and analytical techniques provide acceptable sensitivity to the various exposure limits.<sup>54</sup> For those laboratories considering this analyte for testing, the technique is well known and is not considered difficult to perform.

However, there are some concerns with the sampling devices. The passive dosimeter cannot collect particulate compounds with the device, and a separate sampling process should be used for particulate collection. In addition, passive dosimeters do not provide appropriate sampling where the air velocity is greater than 229 m/min (750 ft/min). When collecting samples using an active sampler, there is dependence on a calibrated pump to take the sample.<sup>55</sup>

<sup>47</sup> Mercury Consumer and Commercial Products. US EPA. Retrieved September 12, 2014, from <http://www.epa.gov/mercury/consumer.htm>.

<sup>48</sup> How People are Exposed to Mercury, Exposures to Elemental Mercury. US EPA. Retrieved September 12, 2014 from <http://www.epa.gov/mercury/exposure.htm>.

<sup>49</sup> OSHA Method ID-140: Mercury Vapor in Workplace Atmospheres. June 1991. OSHA. Retrieved September 15, 2014 <https://www.osha.gov/dts/sltc/methods/inorganic/id140/id140.pdf>.

<sup>50</sup> NIOSH Method 6009: Mercury. August 15, 1994. NIOSH. Retrieved September 15, 2014 <http://www.cdc.gov/niosh/docs/2003-154/pdfs/6009.pdf>.

<sup>51</sup> National Environmental Methods Index. Standard Methods: 3112B: Metals in Water by CV-AAS. Retrieved September 16, 2014, from [https://www.nemi.gov/methods/method\\_summary/9737/](https://www.nemi.gov/methods/method_summary/9737/).

<sup>52</sup> National Environmental Methods Index. ERPA-NERL: 245.1: Mercury by CVAA. Retrieved September 16, 2014 from [https://www.nemi.gov/methods/method\\_summary/4821/](https://www.nemi.gov/methods/method_summary/4821/).

<sup>53</sup> National Environmental Methods Index. ERPA-NERL: 245.2: Mercury by CVAA (Automated). Retrieved September 16, 2014 from [https://www.nemi.gov/methods/method\\_summary/4822/](https://www.nemi.gov/methods/method_summary/4822/).

<sup>54</sup> NIOSH Pocket Guide to Chemical Hazards: Mercury Compounds [except (organo) alkyls]. NIOSH. Retrieved September 15, 2014 <http://www.cdc.gov/niosh/npg/npgd0383.html>.

<sup>55</sup> OSHA Method ID-140: Mercury Vapor in Workplace Atmospheres. June 1991. OSHA. Retrieved September 15, 2014

Note that there are a number of EPA-approved methods for outdoor air testing and if interested, laboratories can investigate further at the following sites under EPA Technology Transfer Network:

- Emission Measurement Center: CFR Promulgated Test Methods<sup>56</sup>
- Emission Measurement Center: Other Methods<sup>57</sup>
- Ambient Monitoring Technology Information Center: Air Monitoring Methods – Inorganic (IO) Compendium Methods; IO-5<sup>58</sup>

There are also a number of sensors on the market listing their ability to test for chemicals, including household chemicals. However, the highlighted items for these sensors were volatile organic compounds, lead, and formaldehyde. This does not rule out mercury as a chemical that could be detected by these particular sensors, but further research is required. Portable mercury analyzers are available from some companies that provide the ability to detect mercury vapor in the field. These portable devices are primarily based on atomic absorption technology.

Laboratories considering the above OSHA and NIOSH methods would need the following equipment:

- Instrumentation
  - CVAA analyzer (mercury analyzer) **or**
  - Atomic Absorption Spectrophotometer
- Sampling
  - Calibrated air sampling pumps
  - Dosimeters

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<https://www.osha.gov/dts/sltc/methods/inorganic/id140/id140.pdf>

<sup>56</sup> EPA CFR Promulgated Test Methods. EPA Technology Transfer Network: Emission Measurement Center. Retrieved September 15, 2014 <http://www.epa.gov/ttn/emc/promgate.html>.

<sup>57</sup> EPA Other Methods. EPA Technology Transfer Network: Emission Measurement Center. Retrieved September 15, 2014 <http://www.epa.gov/ttn/emc/prelim.html>.

<sup>58</sup> EPA Air Monitoring Methods – Inorganic (IO) Compendium Methods. EPA Technology Transfer Network: Ambient Monitoring Technology Information Center. Retrieved September 15, 2014 <http://www.epa.gov/ttnamti1/inorg.html>.

## Mold and Mildew

In many instances, laboratory testing for mold and mildew will be unnecessary. Although there are over 200 species of mold that can cause illness from a number of sources,<sup>59</sup> mold visibility correlates to mold exposure. As the US Department of Housing and Urban Development describes it, “visual observation of active or past microbial growth, or measurement of mold in dust or a sample of source material, can be used to establish potential for mold exposure.”<sup>60</sup> Consequently, there is generally little need to test for mold in a residential setting – if the mold is visible, then abatement is generally recommended. However, should testing be requested or required, there are a number of options available, both in terms of the type of environmental sample (see Table 1) or the analytical method (see Table 2). Note that the relative costs associated with mold testing may be high or that it may require new pieces of equipment or validated methods.

Moreover, interpreting data results associated with mold testing may pose its own difficulties.<sup>61</sup> Baseline levels are difficult to establish and communicating results to the lay public may cause added confusion or uncertainty. Should mold testing be requested or preferred, refer to Guide for interpreting reports from inspections/investigations of indoor mold for examples of the forms and reports that may be needed.<sup>62</sup>

**Table 1: Selected Mold Sampling Strategies<sup>63</sup>**

Type of Environmental Sample	Sampling Technique	Advantages/Disadvantages	Relative Cost	Possible/Example Results
Bulk	Remove section of building material (e.g., wallboard)	Destructive technique	Moderate	Detection of past mold colonization or active growth
Surface	Press collection material (contact plate of adhesive tape)	Non-Destructive  Spatially and temporally variable	Low	Detection of past mold colonization or active growth
	Wipe small area with a wetted swag, cloth, or filter	Settled dust samples expected to be less temporally variable and be a better indicator of exposure over time		Identification of surfaces/ areas where airborne mold spores and fragments have settled and accumulated
	Vacuum sample of settled dust			

<sup>59</sup> US Environmental Protection Agency. An Introduction to Indoor Air (IAQ): Biological Pollutants. Retrieved from <http://www.epa.gov/iaq/biologic.html>, August 7, 2014.

<sup>60</sup> US Department of Housing and Urban Development. 2011. Healthy Homes Issue: Mold. Retrieved August 6, 2014 from: [http://www.healthyhousingsolutions.com/Portals/0/HUD\\_Mold\\_Paper\\_Final\\_11-20-12.pdf](http://www.healthyhousingsolutions.com/Portals/0/HUD_Mold_Paper_Final_11-20-12.pdf).

<sup>61</sup> Horner, W.E., Barnes, C., Codina, R., Levetin, E. J. Guide for interpreting reports from inspections/investigations of indoor mold. *Allergy Clin. Immunol.* 2008. 121(3): 592-597.

<sup>62</sup> Horner, W.E., Barnes, C., Codina, R., Levetin, E. J. Guide for interpreting reports from inspections/investigations of indoor mold. *Allergy Clin. Immunol.* 2008. 121(3): 592-597.

<sup>63</sup> Reproduced from: US Department of Housing and Urban Development. 2011. Healthy Homes Issue: Mold. Retrieved August 6, 2014 from: [http://www.healthyhousingsolutions.com/Portals/0/HUD\\_Mold\\_Paper\\_Final\\_11-20-12.pdf](http://www.healthyhousingsolutions.com/Portals/0/HUD_Mold_Paper_Final_11-20-12.pdf).

Type of Environmental Sample	Sampling Technique	Advantages/Disadvantages	Relative Cost	Possible/Example Results
Air	Static sampler Personal sampler With HVAC off and on	Useful if it is suspected that the ventilation systems are contaminated  Air levels are variable, especially with disturbance  Short-term air samples limit sensitivity  Requires calibration and careful handling	Most expensive	Detection of mold contamination where the presence of mold is suspected but cannot be identified by a visual inspection or bulk sampling
Sedimentary	Gravity Slide  Settled Plate  Electrostatic dust collector  Dust fall collector	Simple  Deposition can be affected by air turbulence; may underestimate small cells	Moderate	Determination of cumulative assessment over a given period of time
Aerosolization	Fungal Spore Source Strength Test (FSSST)	Destructive technique  Testing requires specialized equipment and a chamber	Moderate	Evaluation of potential for fungal spores to aerolize from building materials  Calculation of maximum fungal load  Source identification

**Table 2: Selected Methods for Analyzing Home Environmental Samples for Mold<sup>64</sup>**

ANALYSIS		Test Applicability	
Method (units)	Advantages/Limitations	Important Species	Data Obtained <sup>65</sup>
Allergen immunoassay, ELISA <sup>66</sup> (µg/g or pg/m <sup>3</sup> )	Not currently reliable for fungi (e.g. <i>Alternaria</i> counts must be very high or germinating, cross reactivity occurs between <i>Penicillium</i> and <i>Aspergillus</i> and between <i>Alternaria</i> and non-related fungi)	<i>Aspergillus</i> , <i>Alternaria</i> , <i>Caldosporium</i>	Allergen levels (Asp f 1 and Alt a 1)
Direct microscopy—Spore identification, (spore count)	Intact spores may not account for total allergen load	All ( <i>Aspergillus</i> , <i>Penicillium</i> , <i>Trichoderma</i> , and yeasts difficult to identify)	Concentration of spores; spore identification

<sup>64</sup> Reproduced from: US Department of Housing and Urban Development. 2011. Healthy Homes Issue: Mold. Retrieved August 6, 2014 from: [http://www.healthyhousingsolutions.com/Portals/0/HUD\\_Mold\\_Paper\\_Final\\_11-20-12.pdf](http://www.healthyhousingsolutions.com/Portals/0/HUD_Mold_Paper_Final_11-20-12.pdf).

<sup>65</sup> Allergens listed in this column are those for which monoclonal antibodies are typically commercially available for immunoassay purposes (see INDOOR Biotechnologies website, <http://www.inbio.com/index.html>).

<sup>66</sup> Quantitative differences between allergen standards are currently an important source of assay (ELISA) variability.

Culture (CFUs)	Viable fungi may not account for total allergen load	All	Species identification  Estimates of fungal concentrations as colony forming units (CFUs)
Chemical biomarkers (ergosterol, extracellular polysaccharides [EPS], $\beta$ -glucan, VOCs, mycotoxins)	Ergosterol and EPS are good indicators of total biomass (components in all fungal hyphae and spores, cannot identify species)	Not species specific  Non-fungal sources can affect $\beta$ -glucan and VOC results  Methods not well developed for fungal VOCs or mycotoxins in indoor environments	Concentration of chemical biomarker  Estimates of fungal biomass
Polymerase chain reaction (PCR) base technologies (i.e., genetic probes)	Accurate: Based on targeting species-specific sequences of DNA  Identifies both viable and nonviable fungal elements, but is prone to amplifying sample contaminants  Genetic probes available for about 36 mold species  Particulate materials in the air may inhibit the PCR reaction	Species specific, including but not limited to <i>Alternaria</i> , <i>Aspergillus</i> , <i>Cladosporium</i> , and <i>Penicillium</i>	Mold identification to the species level

## Particulate Matter

Particulate matter (PM) can be a complex mixture of extremely small particles and liquid droplets. PM or particle pollution is made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles. The size of particles is directly linked to their potential for causing health problems. EPA is concerned about particles that are 10 micrometers in diameter or smaller because those are the particles that generally pass through the throat and nose and enter the lungs. Once inhaled, these particles can affect the heart and lungs and cause serious health effects. The US EPA groups particle pollution into two categories:<sup>67</sup>

- 1) Inhalable coarse particles, such as those found near roadways, transportation sources, coal-burning power plants, steel mills, mining operations, and dusty industries which are larger than 2.5 microns and smaller than 10 microns in diameter (PM<sub>10</sub>).
- 2) Fine particles such as those found in smoke and haze and are 2.5 microns in diameter (PM<sub>2.5</sub>) and smaller. These particles can be directly emitted from sources such as forest fires or form when gases from power plants, industries and automobiles react in the air.

One commonly used method for particulate matter analysis is the use of filter collection and gravimetric analysis. Size selective impactors are used to collect PM onto a filter, which is then analyzed gravimetrically.<sup>68</sup>

The use of relatively low-cost air sensors compared to stationary outdoor monitors is now available as an emerging technology to assist citizen scientists and others in making appropriate choices for monitoring equipment. Basic information is required to calibrate sensors and determine precision of the device's response as well as other bias. EPA's Air Sensor Guidebook can assist those interested in using lower-cost air quality sensor technology for air quality measurements.<sup>69</sup> One disadvantage of the air sensor methodology is that it is in early-stage development and many sensors have yet to be evaluated to determine accuracy of measurements.

EPA offers technology developers the opportunity to send in air sensors for evaluation in a controlled laboratory setting, <http://www.epa.gov/airscience/air-sensor.htm>. The sensors listed below are from the US EPA Air Sensor Guidebook that have been evaluated to date.

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<sup>67</sup> US Environmental Protection Agency. Particulate Matter. Retrieved September 11, 2014, from <http://www.epa.gov/airquality/particulatepollution/index.html>.

<sup>68</sup> State of Alaska Department of Environmental Conservation. Standard Operating Procedure for Laboratory Gravimetric Analysis of Fine Particulate Matter (PM<sub>2.5</sub>) Air Quality Filter Samples. Retrieved October 23, 2014 from [https://dec.alaska.gov/air/doc/Lab\\_SOP-Grametric\\_Analysis-Morgan\\_Rev.pdf](https://dec.alaska.gov/air/doc/Lab_SOP-Grametric_Analysis-Morgan_Rev.pdf)

<sup>69</sup> US Environmental Protection Agency. Air Sensor Guidebook. Retrieved August 25, 2014 from <http://www.epa.gov/research/airscience/docs/air-sensor-guidebook.pdf>.

**Table 3: Performance characteristics of commercially available and emerging sensors for continuous measurements of PM mass and physical properties.<sup>70</sup>**

Reference Sampler / Sensor	Measurement Principle	Manufacturer	Accuracy	Precision	Limit of Detection ( $\mu\text{g}/\text{m}^3$ ) or Lower Particle Size Detected ( $\mu\text{m}$ )	More Information** Weight (kg) and ~Cost (\$, when available) as of May 2014
831 Aerosol Mass Monitor	Light scattering; Mass concentration	MetOne Instruments	$\pm 10\%$ to calibration aerosol	- <sup>b</sup>	0.5 $\mu\text{m}$	Range: 0-1,000 $\mu\text{g}/\text{m}^3$ ; 0.8 kg; <\$2,000
Personal DataRAM, Model pDR-1500	Light Scattering; Mass concentration	Thermo Scientific	$\pm 5\%$ of reading $\pm$ precision	$\pm 0.2\%$ of reading or $\pm 0.5 \mu\text{g}/\text{m}^3$ 60-s avg	0.1 $\mu\text{m}$	Size Range: 0.1–10 $\mu\text{m}$ ; Conc Range: 1 to $4 \times 10^6 \mu\text{g}/\text{m}^3$ Precision (2 $\sigma$ ); 10-s avg; 1.2 kg; \$5500 with PM2.5 and PM10 cyclones
DC1100 Air Quality Monitor	Light scattering; Laser particle counter	Dylos Corp.	- <sup>b</sup>	$\pm 15\%$ , collocated**	0.5 $\mu\text{m}$	Size ranges: Pro: >0.5 $\mu\text{m}$ , >2.5 $\mu\text{m}$ or Household: >1 $\mu\text{m}$ , >5 $\mu\text{m}$ , difference between size ranges equals reported counts; Linear up to $\sim 10^9$ pt/mL with <10% coincidence**; $\sim 0.4$ kg; < \$300
microAeth® Model AE51	Light absorption, 880 nm	AethLabs; Black Carbon	no standard for comparison	$\pm 0.1 \mu\text{g BC}/\text{m}^3$ 60-s avg**	<0.16 $\mu\text{g}/\text{m}^3$ , 2.5 mL/s, 60-s avg	Precision at 2.5 mL/s flow rate; Range: 1-1000 $\mu\text{g BC}/\text{m}^3$ Resolution 1 ng BC/m <sup>3</sup> ; 0.3 kg; \$6,000

<sup>a</sup>Conversion from light scattering, particle number or size distribution, requires estimates of particle density and shape factors; <sup>b</sup>No data. Performance capabilities are from manufacturers' datasheets except where noted with a \*\*. Text in bold type represents a typical fixed-site higher-cost monitor for comparison purposes only to the sensors that follow in that category. Adapted from Snyder et al.<sup>29</sup>

It is important that purchased sensors have informative user manuals for general operation, storing data, conditions of operation including sensitivity, sensor expiration, directions for calibrations, precision and bias, maintenance requirements and demonstrations from scientific articles about performance.

One type of sensor, a light scattering laser particle counter is a tool that provides information crucial to determine indoor air quality. The laser particle counters can be purchased for approximately \$200 and are capable of detecting the number and size of particles in homes from mold, smoke, bacteria, pollen, plant spore and dust mites. Once pollution levels have been determined air purifiers or air sterilizers can be used to rectify indoor quality issues. As airborne particles pass through the laser light source, the unit measures the amount of light the particles scatter when passing through the detection area. Monitors are able to detect particulate matter in two concentration thresholds; small particles (approximately 1 micron) and large particles (5 microns).<sup>71</sup>

<sup>70</sup> US Environmental Protection Agency. Air Sensor Guidebook. Retrieved August 25, 2014 from <http://www.epa.gov/research/airsience/docs/air-sensor-guidebook.pdf>.

<sup>71</sup> A.M.I. Services. Dylos DC1100 Air Quality Monitor/particle counter. Retrieved September 10, 2014 from <http://www.amiservices.us/dc1100.html>.

## Radon

Radon is a radioactive gas that appears in residences via underground infiltration.<sup>72</sup> According to EPA, radon is estimated to cause 21,000 deaths from lung cancer per year, more than drunk driving and other causes. The level of concern for radon is 4 pCi/L of air and the point at which remediation is recommended, but levels below that are still of concern.<sup>73</sup>

Testing falls into two categories. First, short term (typically 1 -3 days), is often used for real estate transactions and represents a point in time and is used as a screening technique. Second, long-term testing (in some instances up to a year but more often weeks to a month) provides an integrated exposure that is more representative of an average exposure and considered to be definitive testing.

Additionally, the types of radon air testing can be broken down into two broad categories: field<sup>74</sup> and laboratory. One common type of field sampler is a continuous radon monitor. The monitor uses a flow-through cell or detection chamber after passing through a filter that removes radon decay products and dust. The radon decays are then detected by a scintillation cell, an ionization chamber or a solid-state silicon detector. A second type of field detector is the Electret Ion Chamber radon detector. This system is composed of an electrostatically charged disk of Teflon®. They measure the average concentration of radon during the period that they are exposed. The ions generated by the radon decay are drawn to the surface of the filter and cause the voltage to decrease compared to the start of the exposure period. This measurement can take place in either the field or the laboratory. There are also grab sampling techniques that can be used to determine radon concentration in air, with detection techniques that can be either in the field or in the laboratory.<sup>75</sup>

The two most common types of laboratory analysis for radon uses activated charcoal to trap the radon. Activated charcoal devices do not require power to function, and rely on adsorption of radon by the activated charcoal. They are typically exposed for two-to-seven days, and during that time period the adsorbed radon decays. Consequently, this technique does not integrate the radon concentrations over the exposure period. Activated charcoal systems can also incorporate diffusion barriers to improve the uniformity of response to temporal variations in radon concentration. The average radon concentration is decay corrected to the midpoint of the exposure time, which can introduce error if the ambient radon concentration varies greatly during that time period. Quality Assurance elements include calibration of the activated charcoal system (including cartridges and detector), known exposure cartridges (i.e. spiked samples), duplicate cartridges, laboratory and field blanks and daily instrument performance checks.<sup>76</sup>

<sup>72</sup> US Environmental Protection Agency. Radon. Retrieved from, <http://www.epa.gov/radon/index.html>, August 7, 2014.

<sup>73</sup> US Environmental Protection Agency. Consumer's Guide to Radon Reduction. Retrieved August 19, 2014 from <http://www.epa.gov/radon/pubs/consguid.html>.

<sup>74</sup> Although field testing is beyond the scope of this document, it will be discussed at a high level for informational purposes.

<sup>75</sup> Office of Air and Radiation. US Environmental Protection Agency. Indoor Radon and Radon Decay: Product Measurement Device Protocols. Retrieved August 19, 2014 from <http://infohouse.p2ric.org/ref/17/radon/pubs/devprot1.html>.

<sup>76</sup> Office of Air and Radiation. US Environmental Protection Agency. Indoor Radon and Radon Decay: Product Measurement Device Protocols. Retrieved August 19, 2014 from <http://infohouse.p2ric.org/ref/17/radon/pubs/devprot1.html>.

One type of activated charcoal procedure uses gamma spectroscopy for analysis. There are a variety of implementations of this procedure, and a common one is a circular container (approx. 10 cm in diameter and 2.5 cm deep) filled with 25 to 100 grams of charcoal. One side of the container has a screen (to keep the charcoal in) and some devices have a diffusion barrier over the opening. Some also include a desiccant to reduce interferences from moisture adsorption. The canister is returned to the laboratory and placed on the gamma detector and analyzed for the radon decay products. The result should be corrected for any adsorbed water, as water reduces the sensitivity. Accounting for the water is done by weighing the device before and after deployment, and assuming any weight gain is due to the water. The gamma detector system must be calibrated before use, and the detector response verified before any sample analysis is performed.<sup>77,78</sup>

Another activated charcoal procedure uses liquid scintillation counting. A typical device is a 20 mm liquid scintillation vial (approx. 25 mm in diameter and 60 mm deep) containing one-to-three grams of activated charcoal. Some cartridge designs also include a diffusion barrier and desiccant. After the vial is returned to the laboratory, liquid scintillation cocktail is added and the vial is counted on a liquid scintillation counter. As with the method discussed above, cartridge results must be corrected for adsorbed moisture. Further corrections must be made for radon transfer from the activated charcoal to the scintillation fluid as well as for the counting efficiency of the system. Finally, the entire detection system should be calibrated as for the charcoal canisters.<sup>79</sup>

A final laboratory procedure for radon in air is the Alpha Track Detector. These were commonly used in the United States in the 1980's (and are still more common in Europe), but less so today because of the need for a quick turn-around time driven by the real estate market. The device is a piece of plastic or film encased in a holder with a filter covered opening. As the radon diffuses into the device, the alpha particles hit the film and create tracks in it. When the device is returned to the laboratory, the filters are chemically etched in caustic to make the tracks more visible. The tracks are then counted either with a microscope or an automated counting device. This technique provides a true integrated reading of the radon concentration because every alpha particle causes a track on the film.<sup>80</sup>

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<sup>77</sup> Office of Radiation Programs. US Environmental Protection Agency. EERF Standard Operating Procedures for Rn-222 Measurements Using Charcoal Canisters. Retrieved August 19, 2014 from <http://1.usa.gov/1AuFAAv>.

<sup>78</sup> For information of measurement uncertainty, see: Panteli, G., Savkovic, M.E., Zivanovic, M., Nikolic, J., Rajacic, M., Todorovic, D. Uncertainty evaluation in radon concentration measurement using charcoal canister. *Applied Radiation and Isotopes*, 87 (2014) 452–455. Retrieved August 19, 2014 from [http://www.academia.edu/7319700/Uncertainty\\_evaluation\\_in\\_radon\\_concentration\\_measurement\\_using\\_charcoal\\_canister](http://www.academia.edu/7319700/Uncertainty_evaluation_in_radon_concentration_measurement_using_charcoal_canister).

<sup>79</sup> George, A.C., Esposito, J.Z., Bredhoff, N. Determination of Environmental 222Rn by Adsorption in a Diffusion Barrier Activated Carbon Collector Using Liquid Scintillation Counting. Radon Testing Corporation of America. Retrieved August 19, 2014 from <http://bit.ly/1p9Hi6M>.

<sup>80</sup> Office of Air and Radiation. US Environmental Protection Agency. Indoor Radon and Radon Decay: Product Measurement Device Protocols. Retrieved August 19, 2014 from <http://infohouse.p2ric.org/ref/17/radon/pubs/devprot1.html>.

## Volatile Organic Compounds

Volatile Organic Compounds (VOCs) and semi-volatile organic compounds (sVOCs) are emitted from materials such as paints, cleaning supplies, building materials and adhesives.<sup>81</sup> In addition, petroleum combustion, from powered garden tools or other outside sources that can enter the house may also be a source of VOCs. Soil vapor intrusion occurs when the organic compounds from a contaminated water and/or soil site enters the interstitial air space in soil. Some organic compounds may not be toxic but may be irritants.

There are several well-established EPA methods to test indoor and outdoor air for VOCs. EPA methods TO-15<sup>82</sup> and TO-17<sup>83</sup> are widely used for fence line, soil gas, stack, outdoor and indoor air monitoring. These are quantitative and qualitative methods using mass spectrometry (MS) detection. The system is calibrated using a standard of known concentration. When the unknown sample is investigated, it is referenced to this known standard which determines the concentration of the sample. The sample volume collected is applied to the calculation. The greater the sample volume the better the detection limits will be.

EPA TO-15 uses a summa canister to collect the sample. After sampling, the canister is sent to a laboratory that has the analytical capability to perform the analysis. A canister introductory system is connected to a gas chromatograph/mass spectrometer (GC/MS). The canister is attached to this sample introductory system. The laboratory analyzes a known volume from the canister and the compounds are focused on a trap. Then the effluent passes to the GC analytical column for separation and then detection by the MS detector. TO-15 has a fixed sample volume and can measure only VOCs in the boiling point range from C2 to C12.

EPA TO-17 uses sorbent tube sampling which can sample larger volumes; therefore, the detection limits are lower with TO-17 making it a more sensitive technique than TO-15. There are two sampling techniques: active (pumped) and passive (long-term). During active sampling, a known volume of air is pumped through the tube via time and flow. The tubes are shipped to a laboratory for analysis by inserting them into an automated thermal desorber (sample introductory system) that desorbs the sample onto a concentrator trap. The trap is then heated to releases the compounds bringing the effluent into the GC column for separation and then analysis by GC/MS. Thermal desorption has more flexibility in that it can be used for a broader sampling range of components both VOCs and sVOCs.<sup>84</sup> Depending on the sorbent tube, the boiling point range of compounds is from C2 to C40. TO-17 is more cost effective because tubes are smaller and lighter than other sampling media; therefore, shipping costs are less.

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<sup>81</sup> US Environmental Protection Agency. An Introduction to Indoor Air (IAQ): Volatile Organic Compounds (VOCs). Retrieved August 7, 2014, from <http://www.epa.gov/iaq/voc.html>.

<sup>82</sup> US Environmental Protection Agency. Compendium Method TO-15: Determination Of Volatile Organic Compounds (VOCs) In Air Collected In Specially-Prepared Canisters And Analyzed By Gas Chromatography/Mass Spectrometry (GC/MS).

<sup>83</sup> US Environmental Protection Agency. Compendium Method TO-17: Determination of Volatile Organic Compounds in Ambient Air Using Active Sampling Onto Sorbent Tubes Center for Environmental Research Information.

<sup>84</sup> Provost, R., Marotta, L., Thomas, R. A Single-Method Approach for the Analysis of Volatile and Semivolatile Organic Compounds in Air Using Thermal Desorption Coupled with GC-MS. 2014. Chromatography Online. Retrieved October 24, 2014, from <http://www.chromatographyonline.com/lcgc/article/articleDetail.jsp?id=856296>.

Passive sampling is used for long-term average sampling. The uptake rate for passive sampling is significantly slower than what can be achieved in pumped sampling. Consequently, to attain the needed sensitivity, passive samples are usually taken for weeks to a month in addition to gathering long-term sampling information. The media for passive sampling are either sorbent tubes or badges used in industrial hygiene for instance Radielle tubes.

The EPA recently released a Method 325.<sup>85</sup> This method uses sorbent tube and thermal desorption (method TO-17) and focuses on petroleum sources of contamination. While primarily a method for outdoor use, these passive tubes can be used for indoor air and the uptake rates will be the same.

Air samples may also be collected in tedlar bags called grab samples. The sample volume is limited. After collection and shipment, TO-15 or TO-17 methodologies may be employed.

Finally, VOCs may also be analyzed by sensor technology. These technologies positively identify only a few compounds but provide a total organic compound analysis and can be used for screening purposes (Table 4).

**Table 4: Comparison of Sensor Technology**

	Product			
	PerkinElmer ELM	Aeroqual Series 930	Aeroqual SM70	Libelium waspmote
Target				
VOC	Yes	Yes	Yes	Yes
Specification on VOC in ppm (humidity)	50 - 2,000	1 - 500	1 - 500	40 - 400
Ozone	Yes	Yes	Yes	Yes
PM	Yes (PM10)*	Yes	Yes	Yes
Noise	Yes	No	No	Yes
Humidity	Yes	No	No	Yes
Temperature	Yes	No	No	Yes
NO2	Yes	Yes	No	Yes
Other gases	Yes	Yes	Yes	Yes
Support	Yes	Unknown	Unknown	Unknown
Price	\$	\$\$\$	Unknown	Unknown
Network	Standard	Optional	No	Standard

\*Will have PM2.5 in next version of product

<sup>85</sup> See 79 FR 36880, 37046, retrieved October 21, 2014 from <http://www.gpo.gov/fdsys/pkg/FR-2014-06-30/pdf/2014-12167.pdf>.

# Appendix I: Summary of Sampling and Analysis Procedures Used in Recent Studies of Affordable Housing Renovation Conducted by the National Center for Healthy Housing<sup>86</sup>

## STUDY 1

The study will compare resident health parameters and environmental quality within affordable multifamily properties before and after substantial rehabilitations that meet the Enterprise Green Communities criteria. Our overall goal is to gather concrete evidence that integrating healthy building practices in the development and rehabilitation of affordable housing improves respiratory and other health outcomes for low-income people and also reduces health care costs.

The primary hypothesis is that green housing renovations complying with the Enterprise Green Communities criteria will reduce asthma-related health care utilization of resident children with asthma from baseline to one year after intervention, and this reduction will be greater for study group children than for control group children. Health care utilization will be measured principally by caregiver reports of the number of emergency department visits and unscheduled clinical care visits for asthma in the prior 12 months. The change in the number of hospitalizations for asthma in the prior 12 months will also be analyzed. The secondary hypothesis is that green housing renovations will improve the self-reported general physical (including asthma control, quality of life, and other metrics) and mental health of adult and child residents one year after intervention, and study group improvement will be greater than control group improvement.

Samples are collected for a 4-day period at pre-renovation, immediate post-renovation, and 1-year post-renovation.

### 1.2.1 Air Sampling Methods

#### 1.2.1.1 Passive Sampling for Formaldehyde (UMEX 100)

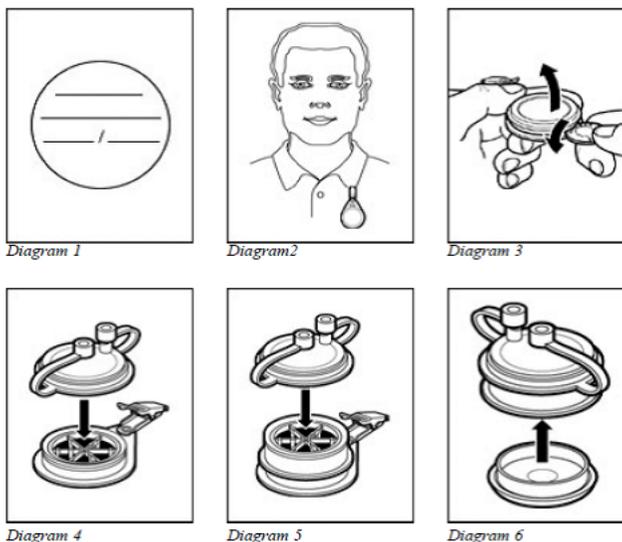
The UMEX 100 Passive Samplers for formaldehyde contain a tape treated with 2,4-dinitrophenylhydrazine (DNPH) for reliable collection of formaldehyde. Samplers are provided in individual aluminized pouches that can be used to transport the sampler to a laboratory after sampling. The shelf-life date is printed on a label on the outside of each pouch. Samplers outside the shelf life shall not be used (nominal 12-month period). The UMEX 100 Sampler includes a clip for attachment to an appropriate location or ring stand for area sampling.

Remove the sampler from the pouch, record sampling information using the environmental sampling form (see Appendix), including sampler serial number, Study ID, and start and stop dates and times to the nearest second, and slide the cover to the “on” position. Place the sampler using the clip so that the screen is open to the air (do not lay it flat on a shelf).

<sup>86</sup> For specific questions on this Sampling and Analysis Procedure, or for more information on the National Center for Health Housing, see [www.nchh.org](http://www.nchh.org) or call (410) 992-0712.

When sampling is complete, slide the cover to the “off” position, place the sampler back in the pouch immediately, and seal. Analysis is completed with high-performance liquid chromatography. The UMEX 100 sampler is designed for single use only and cannot be reused. See Table 4 for refrigeration and sample shipping requirements.

Laboratory analysis is completed in accordance with International Standard for Determination of Formaldehyde—Diffusive Sampling Method (ISO/FDIS 16000-2004) or equivalent. With this method, formaldehyde vapor diffuses into the sampler and is collected on silica gel filter paper that has been treated with 2,4-Dinitrophenylhydrazine (DNPH) with a phosphoric acid stabilizer. A stable hydrazone is formed, which is desorbed with acetonitrile and analyzed by HPLC with ultraviolet (UV) detector. Refrigeration requirements for all sampling devices are provided below in the Quality Assurance section. Accuracy is 5 ppb to 5 ppm ± 25 percent, which exceeds OSHA requirements.



### 1.2.1.2 Passive Sampling for Total VOCs (3M 3520 Badge)

1. Remove the badge from the sealed can (Diagram 1).
2. Record the following information on the environmental sampling form (see Appendix): badge serial number, study sampler number, sampling start and stop times should be recorded on both the badge label and field form. DO NOT REMOVE WHITE FILM AND PLASTIC RING.
3. Hang badge away from walls, corners, tabletops, or other regions where the air movement in the room may be limited. (Note: Diagram 2 is not used for this study.)
4. After sampling period is ended, remove plastic ring and white film from the badge (Diagram 3).
5. Separate the primary body and secondary body sections. Snap the bottom cup (no plugs) into the bottom of the primary section (diagrams 4, 5, and 6). Snap elution cap on the secondary body. Monitor is now ready for shipment. (Note: Check to make sure the primary and secondary sections have the same identification numbers.)
6. Return badge to can and close with plastic lid provided.

View this video to understand how to use the VOC sampler: <http://www.youtube.com/watch?v=MrmPiCVZPBQ>

Laboratory analysis is completed using EPA Method TO-15, with total VOCs reported as hexane equivalents. Refrigeration and shipping requirements are provided in the Quality Assurance Section.

### Passive Sampling for NO<sub>2</sub> (UMEX 200)

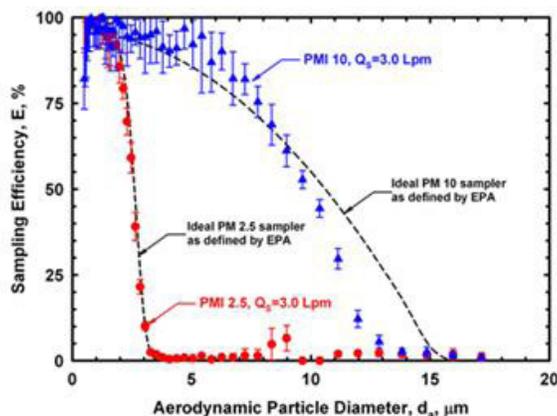
The single-use SKC UMEX 200 Passive Sampler collects NO<sub>2</sub> using a sample medium with a tape treated with triethanolamine (TEA). Samplers are provided in individual aluminized pouches that can be used to transport the sampler to a laboratory. The label on the outside of each pouch contains the shelf-life date and has an 18-month shelf life and shall not be used if outside the shelf life. Refrigeration requirements are provided in the QC section below.



Remove the sampler from the pouch, record sampling information (including sampler serial number) on the environmental sampling form (see Appendix), Study ID, and start and stop dates and times to the nearest minute, and slide the cover to the "on" or sampling position. When sampling is complete, slide the cover to the "off" position, place the sampler back in the pouch immediately, and seal. Send the sampler and the completed chain of custody to the laboratory for analysis by solvent extraction ion chromatography (IC) with conductivity detection.

### 1.2.1.3 Active Sampling for PM<sub>2.5</sub> (Personal Modular Impactor (PMI))

The patented (U.S. Patent No. 7,334,453) SKC Single-stage Personal Modular Impactors (PMIs) are designed for the highly efficient collection of PM<sub>10</sub>, PM<sub>2.5</sub>, or PM Coarse (10-2.5). For this study, only PM<sub>2.5</sub> will be measured. The samplers have a removable filter cassette and pre-oiled impaction disc. The PMI media changes are done by removing the filter cassette and replacing it with one already loaded with a 37-mm final filter; for this study, filter loading will be done in the laboratory. The 25-mm pre-oiled impaction disc mounts directly on top of the filter cassette and reduces particle bounce for high collection efficiency.



Collection Efficiency of PMI 2.5 and PMI 10 Samplers

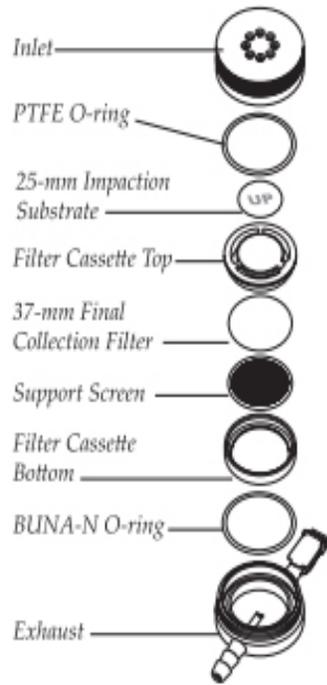


Figure 1. PMI 2.5 exploded

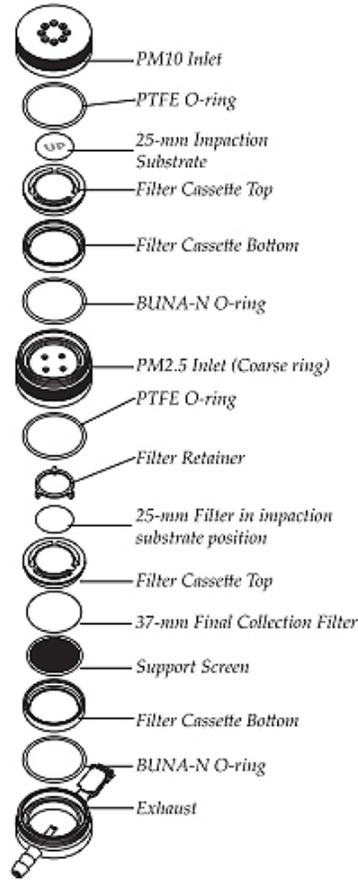


Figure 2. PMI Coarse exploded

### Performance Profile

<b>Flow Rate</b>	3 L/min for all models
<b>50% Cut-point</b>	10 µm or 2.5 µm (model dependant)
<b>Material</b>	<b>Inlet:</b> Precision-tooled aluminum
	<b>Exhaust:</b> PVC
	<b>Filter Cassette:</b> Delrin® with stainless steel support screen
	<b>O-ring:</b> Inlet – PTFE <b>O-ring:</b> Exhaust – BUNA-N
<b>Final Collection Filter</b>	37-mm filter, select filter material based on application
<b>Impaction Substrate</b>	25-mm pre-oiled, disposable porous plastic disc to reduce particle bounce or 25-mm filter for optional chemical analysis
<b>Analyses</b>	Gravimetric and chemical
<b>Dimensions (without clip)</b>	<b>Diameter:</b> 2 in (5.1 cm)
	<b>Height:</b> 1 in (2.6 cm)
	<b>Weight:</b> 2.5 oz (70.9 gm)
<b>Tubing</b>	1/4-inch ID

For this study, all PMIs will be prepared and pre-weighed in the laboratory, not the field. Field personnel will attach the PMI to an air-sampling pump supplied by the lab using Tygon tubing. Pumps will be operated at a nominal flow rate of 3.0 liters/minute. Pump flow rate will be measured prior to sampling using a laboratory-supplied rotameter (which has been calibrated against a primary standard) recorded to the nearest 0.1 liters/minute. At the end of the sampling period but before turning off the pump, record the flow rate using the rotameter on the pump. Use the top of the ball to read the flowrate. The laboratory will calculate the average flow rate in reporting its analytical results. Sampling personnel shall enter the start and stop times to the nearest minute and designate AM or PM. Place the PMI sampler into a ziplock plastic baggie and label with the study ID as specified above. Record the pump number, PMI serial number and other data specified on the electronic environmental sampling form.

### **1.2.2 Allergens in Settled Dust**

Five allergens will be measured in settled dust using 5-Plex Multiplex Array for Indoor Allergens (MARIA®) methodology: dust mite allergens Der p 1 and Der f1; cat allergen Fel d 1; cockroach allergen Bla g 2; mouse allergen Mus m 1. Two separate allergen samples will be collected from the floors of each of two rooms: one from the youngest index child's bedroom and the second from the living room floor (n=2 total samples).

The Eureka Mighty Mite (EMM) (model 3670, Electrolux Home Care Products, Inc., Peoria, IL) or equivalent catches dust in a Whatman cellulose extraction thimble (Whatman International Ltd., Maidstone, UK), part of the DUSTREAM™ Collector (Indoor Biotechnologies, Inc., Charlottesville, VA). After collection, the extraction thimble is immediately placed in a 76x20 mm tube with cap (Sarstedt Aktiengesellschaft and Co.). Record the Study ID and sample number on the shipment tube and on the field sampling form. The allergen sampling protocol is based on HUD's Office of Healthy Homes and Lead Hazard Control "Vacuum Dust Sample Collection Protocol for Allergens," Version 2.0 (May 2008), available at this link: [http://portal.hud.gov/hudportal/documents/huddoc?id=DOC\\_12539.pdf](http://portal.hud.gov/hudportal/documents/huddoc?id=DOC_12539.pdf).

Laboratory sample preparation and analysis details are at these links, respectively:  
[http://inbio.com/US/images/pdfs/Sample\\_Extraction\\_Procedure.pdf](http://inbio.com/US/images/pdfs/Sample_Extraction_Procedure.pdf)  
[http://inbio.com/US/images/pdfs/MRA-P8\\_CoA.pdf](http://inbio.com/US/images/pdfs/MRA-P8_CoA.pdf)

## **STUDY 2**

The study will determine the resident health and environmental impacts of two randomly assigned residential ventilation protocols, the more typically used standard, ASHRAE 62-1989, and the more recent standard, ASHRAE 62.2. Under ASHRAE 62-1989, a Building Tightness Limit (BTL) is determined from characteristics of the house and occupancy, and air-tightening efforts are directed towards not tightening below the BTL. Under ASHRAE 62.2, air-tightening efforts are directed to continue as far as technically feasible, and mechanical ventilation is provided to meet the requirements of the standard. The ventilation modifications will be included as part of weatherization work performed in low-income housing. The air exchange standards of ASHRAE 62-1989 are more typically used in

standard weatherization assistance interventions and will be performed in Control Group dwellings, while dwellings randomly assigned to the ASHRAE 62.2 group (Study Group) will have alternative ventilation interventions performed in accordance with the newer standard.

### 1.1.1 IAQ Sampling

Air sampling for formaldehyde and Volatile Organic Compounds (VOCs) as well as placement of radon charcoal canisters will be done for one-week periods both before and after installation of weatherization measures. The sampling instruments and analytical methods are described in Table 5, below:

**Table 5. Sampling and Analytical Methods**

	Output	Number	Instrument	Source
VOC	Average value	180	VOC Passive Ultra I	<a href="http://www.skcinc.com/passive.asp">http://www.skcinc.com/passive.asp</a>
HCHO	Average value	180	UMEX-100	<a href="http://gasdetectors.conceptcontrols.com/">http://gasdetectors.conceptcontrols.com/</a>
CO	Time series	12	LASCAR-EL-USB-CO	<a href="http://www.lascarelectronics.com/temperatedatalogger.php?datalogger=104">http://www.lascarelectronics.com/temperatedatalogger.php?datalogger=104</a>
CO2	Time series	12	Telaire 7001 + U12	<a href="http://www.onsetcomp.com/products/sensors/tel-7001">http://www.onsetcomp.com/products/sensors/tel-7001</a>
T/RH	Time series	48	LASCAR-EL-USB-2	<a href="http://www.lascarelectronics.com/temperatedatalogger.php?datalogger=102">http://www.lascarelectronics.com/temperatedatalogger.php?datalogger=102</a>
Rn-charcoal	Average Value	180	EPA charcoal canister	US EPA lab, Las Vegas NV
Rn-cont	Time series	12	Radstar RS300	<a href="http://www.4radon.com/rarscoragasm.html">http://www.4radon.com/rarscoragasm.html</a>

Sampling for VOCs and formaldehyde (HCHO) is done using badges (passive air samplers). Following exposure, the badges are sent to an AIHA accredited laboratory for analysis using method EPA TO-17. Radon canisters will be analyzed by the EPA lab in Las Vegas.

### Sample Locations

- Continuous radon monitors and charcoal canisters will be located on the lowest living level. In any zone that may be occupied (including basements) the instruments will be located at breathing zone height and away from exterior walls and doors, and away from vents. Test kits will be placed to minimize the risk of occupant interference, and will be identified to residents with instructions to avoid disruption.
- Formaldehyde and VOC Badges will be exposed in the living room.

### IAQ Sampling Materials and Supplies

- Sampling Equipment listed in Table 5
- Lab chain-of-custody form
- IAQ Sampling Form
- Non-sterilized non-powdered disposable gloves (vinyl or latex)
- Permanent ink pen
- Trash bags
- Ziploc bags

## **1.1 ANALYTICAL METHODS**

### **1.1.1 Single-Use IAQ Samplers**

Single-use IAQ VOC and formaldehyde samplers will be analyzed by laboratories accredited by the American Industrial Hygiene Association.

The per-house results of single-use IAQ (VOC and HCHO) samplers will be analyzed as simple differences between pre- and post-weatherization with adjustments for indoor-outdoor temperature difference as appropriate. Because an individual house may have changes in sources that cannot be controlled, such as new furnishings that contain formaldehyde, the distribution of these results will be compared between control and treatment group homes using standard statistical methods.

For charcoal canister radon measurements, additional adjustments will be made to reflect temporal and seasonal variations as measured with the continuous radon monitors, and the difference between pre- and post-weatherization results will be analyzed for statistical significance relative to these differences.

These differences will all be analyzed for correlation to weatherization measures, including ventilation, overall air sealing, and air sealing at certain building boundaries such as between the house and a crawl space.

## **STUDY 3**

The general study hypothesis is that green healthy housing rehabilitation of public housing occupied by elders improves their health status. The goal of this study is to characterize those occupant health factors that can be related to housing undergoing green rehabilitation over a one-year time period in multifamily housing.

Hypothesis: Pre-renovation levels of CO, CO<sub>2</sub>, allergens, TVOC, and formaldehyde in a subset of enrolled units are significantly higher than post-renovation levels.

### **2.1.1 Environmental Sample Collection**

In a convenience sample of 21 non-smoking units from the first set of units enrolled in the study, CSBR will collect environmental samples for the following analytes using the methods listed below:

- Temperature, Humidity, CO<sub>2</sub> (a marker of fresh air) and CO (a marker of inadequate venting of combustion appliances): HOBO dataloggers. The purpose of this monitoring is to determine if adequate ventilation is occurring within the units. CSBR will begin tracking temperature, relative humidity, CO<sub>2</sub>, and CO by placing dataloggers in 21 enrolled, nonsmoking units for an approximate one month period before renovation begins in their part of the building. CSBR will remove the dataloggers prior to renovation and reinstall them immediately after renovation is complete. The re-installed dataloggers will remain in place for approximately one year, with data downloaded electronically on a quarterly basis.

- Total Volatile Organic Chemicals (TVOCs): 3M 3500 Organic Vapor Monitors (passive diffusion monitors). CSBR will collect a 3-day sample from each of the 21 units once at pre-renovation, once immediately post-renovation, and once at one-year post-renovation.
- Formaldehyde: 3M 3720 Formaldehyde passive monitoring badge with accuracy  $\pm 10\%$  and detection limit of 0.000242 ppm. CSBR will collect a 3-day sample from each of the 21 units once at pre-renovation, once immediately post-renovation, and once at one-year post-renovation.
- Allergens: Settled dust vacuum sampling on floors using guidance provided in HUD's Office of Healthy Homes and Lead Hazard Control "Vacuum Dust Sample Collection Protocol for Allergens," Version 1.0 (April 2004). CSBR will collect one dust vacuum sample from each of the 21 units, once at pre-renovation and once at one-year post-renovation.

### **2.1.2 TVOCs**

CSBR will collect total volatile organic compound (TVOC) data using 3M 3500 Organic Vapor Monitors (a passive diffusion monitor) with an exposure time of three days or approximately 72 hours, with data collection done at pre-renovation, immediate post-intervention and one-year post-intervention to evaluate changes in these gases over time. CSBR will place one TVOC monitor in the kitchen in a location open to the room but out of the way of cooking and other resident disturbances. When the three-day sample period is complete, CSBR will remove the badge from the sampling location and place it in Ziploc bag labeled with the Unit ID and Sample ID.

### **2.1.3 Formaldehyde**

CSBR will collect formaldehyde data using a passive diffusion monitor with an exposure time of three days or approximately 72 hours, with data collection done at pre-renovation, immediate post-intervention and one-year post-intervention to evaluate changes in these gases over time. CSBR will place one formaldehyde monitor in the kitchen in a location open to the room but out of the way of cooking and other resident disturbances. When the three-day sample period is complete, CSBR will remove the badge from the sampling location and place it in Ziploc bag labeled with the Unit ID and Sample ID.

### **2.1.4 Allergens**

This protocol provides for measurement of settled allergens on floor surfaces where children may play. It is not intended to determine compliance with any existing regulations or to determine if allergen cleanup is needed. These methods were developed in accordance with the guidance provided in HUD's Office of Healthy Homes and Lead Hazard Control "Vacuum Dust Sample Collection Protocol for Allergens," Version 1.0 (April, 2004).

### **Allergen Sample Collection Materials**

- Powderless vinyl gloves (appropriate size for technician)
- Wet wipes to be used for decontaminating equipment and wiping hands when necessary
- Tape measure showing units in inches
- Trash bags

- Masking tape-must be painter's tape
- Pen/clipboard
- Permanent marker
- Timing device/watch
- Extension cord (25 feet) with 2-prong adapter and plug strip
- Temperature/relative humidity gauge
- Allergen Dust Sampling Form
- Sketch
- Chain of custody form
- Cooler containing blue ice or equivalent to keep samples cold while in field (no ice cubes)
- Clean Dustream™ collectors (nozzles) stored in resealable Ziploc bag (three per dwelling). Filter collection device (Dustream™ filters), each packaged in screw top centrifuge tubes with pre-marked sample label. Write the sample ID on the dust filter and on outside of the centrifuge tube. Label each sample with an "A" (for "allergen") followed by the sample number. Label the kitchen floor sample "A1," and the bedroom as "A2."
- Vacuum and vacuum supplies:
  - Plug-in, portable vacuum cleaner (2) fitted with new clean vacuum bag.
  - Vacuum bags

## General Rules

- Do not begin to collect allergen samples until potential participant has signed an informed consent.
- Do not sample under large furniture or refrigerators.
- Move small throw rugs if needed.
- Sample only one surface type (i.e., bare floor or carpet) in each room, preferably carpet.
- Avoid vacuuming wet or damp areas or collecting moist materials.
- Attempt to remove all dust in the sampling area.
- Hold the collector pointing upwards before turning off the vacuum to avoid dust dropping out of filter. Do not shake the hose or sample may be lost.
- Bulky debris in the sampling area will quickly fill the dust filters; therefore, in locations having a large quantity of visible debris (e.g., paint chips, trash, etc.), remove debris by gloved hand before vacuuming. Do not remove bulky debris by vacuuming.

## Identification of Rooms and Floor Areas to be Sampled

**Room Identification.** One sample will be collected from the kitchen (K) and one from the bedroom (BR). Record these rooms on the Sketch. During the baseline and one-year post-renovation visits, collect one vacuum sample each from the floor of the kitchen and bedroom, sampling non-carpeted rooms prior to carpeted rooms.

**Floor Surface Type and Condition.** Identify the predominant surface type in each room and record it on the Allergen Dust Sampling Form. "Predominant" is defined as follows: if more of the floor is bare, then consider the surface type to be "bare" and sample the non-carpeted area. If more than 50% of the floor is carpeted or covered with an area rug, then consider the surface type to be carpeted and sample the carpeted area. For each room, record on

Allergen Dust Sampling Form the surface type and the condition of the floor surface to be sampled. For carpets, “not cleanable” is defined as very matted, soiled, old, worn carpet, while “cleanable” is defined as unsoiled, new carpet, with few if any worn or matted spots.

**Outline of Floor Area to be Sampled in Each Room.** At the baseline visit, choose the following floor area to be sampled in each room:

- **Kitchen:** You will not need to mark a taped outline of the kitchen sampling area because you will vacuum the entire perimeter of the kitchen (i.e., along the base of walls, appliances cabinets, etc.).
- **Bedroom:**
  - *Carpeted Floor:* On the carpeted floor below the bed, use painter’s tape to outline a roughly rectangular section, approximately 12 inches by 36 inches (1 foot by 3 feet, or a total of 3 ft<sup>2</sup>) along the long side of the bed, making sure that about one quarter of the outline is underneath the bed.
  - *Bare Floor:* Because bare floors are expected to have less dust, sample a larger area to ensure you collect enough dust to be analyzed. On the bare floor below the bed, outline a roughly rectangular section, approximately 2 by 5, with the longest length following the length of the bed, and with about one quarter of the outline is underneath the bed. If needed to get enough dust, mark another sample location along a second length of the same bed, and collect dust into the same Dustream collector used for the first side of the bed.

Place masking tape to mark each rectangular area to be sampled. Avoid walking inside the area while marking it off and once you finished marking it.

On the one-year post-renovation visit, to the extent possible, collect the sample from the same floor location sampled at the baseline visit, collecting dust from approximately the same surface area (i.e., same length and width).

### **Vacuum Sampling Procedures**

Collect single surface allergen dust vacuum samples systematically to allow results from different visits to be compared. At the one-year post-renovation visit, collect the sample from the same rooms that were sampled at the baseline visit and from the same general floor location, collecting the sample from approximately the same surface area that was sampled at baseline.

**Initial Set-Up of the Vacuum Sampler.** Plug in vacuum and make sure the cord will reach the vacuum area. Use an extension cord if necessary. If you must unplug an existing electrical cord in order to plug in the vacuum, avoid unplugging clocks, computers, etc., and plug items back in once you finish sampling. Obtain the resident’s permission. Insert the nylon filter into the Dustream collector and attach the collector to the vacuum cleaner tube. If the collector does not fit the vacuum cleaner tube, attach the adaptor piece to the collector. Use the side of the adaptor that best fits the vacuum cleaner. Use blue painter’s tape if needed to ensure that the nozzle will not come off during sampling.

## **Vacuum Procedure for Floor**

1. With the hose in a vertical position pointing up and the Dustream collector pointed upwards, turn the vacuum on and check that the filter is tightly fitted.
2. Placing the Dustream collector in the upper corner of the marked area, press down firmly, but not excessively, holding the long tip of the collector in firm contact with the surface to be vacuumed. On bare floors, do not place the whole face of the collector onto the floor surface because you will not be able to collect dust into the filter.

### **Bedroom:**

- *Carpeted Floors:* Proceed to vacuum the marked area using a side-to-side motion along the width (short side) of the outline area. Collect the sample for approximately 2 minutes for 3 ft<sup>2</sup>. If the carpeted floor is dusty, you may need to periodically turn off the vacuum and let the vacuum cool off before collecting more sample into the same filter. If the filter becomes full before you are done sampling the entire outlined area, remove and cap the used filter and place it into a centrifuge tube that has been labeled with the Unit ID, Room ID, and the Sample ID. Place another clean filter into the collector and finish sampling the outlined area. Place the second filter into the SAME centrifuge tube with the first filter. If the centrifuge tube is too small to hold two filters place the second filter in another centrifuge tube with the same labeling as the first. Place all centrifuge tubes with dust samples from the same location in a marked Ziploc bag. Make sure that the lab knows to extract both filters as a SINGLE SAMPLE.
- *Bare Floors:* Dust from this marked area will be collected into a single dust filter. Collect the sample for approximately 6 minutes for 9 ft<sup>2</sup>. If the floor is dusty, you may need to periodically turn off the vacuum and let the vacuum cool off before collecting more sample into the same filter. Do not make a special effort to sample the crevices between floorboards.

**Kitchen:** In the kitchen, sample the entire perimeter of the kitchen (i.e., along the base of walls, appliances, and cabinets) where pests are more likely to walk. Do not move appliances to vacuum behind or between them. Press one edge of the nozzle against the wall/appliance. Do not sample inside cabinets or underneath refrigerators and other appliances. Perform sampling for a minimum of 5 minutes. You will need to measure the perimeter of the floor area sampled (including all turns) to the nearest inch. This measurement will constitute the length sampled. The width of the nozzle constitutes the width of the area sampled-this should always be recorded as **7/8 inch (0.875 inch)**.

3. Once the sample collection is complete, hold the collector in an upright position and turn off the vacuum. Remove the filter containing the dust sample, put a cap on it, and place it in a centrifuge tube that has been labeled with the Unit ID, Room ID, and Sample ID. Place the used Dustream collector into a plastic bag labeled “dirty” (not with the clean collectors) until you can clean it. Estimate the approximate length and width sampled in feet to the nearest inch and record these measurements on the Allergen Dust Sampling Form.
4. Repeat steps 1 through 3 in the next room to be sampled, using a new, clean Dustream collector and new filter.
5. Once both rooms have been sampled in a dwelling, place the two sample collections with all, labeled centrifuge tubes into one large Ziploc bag and label the large bag with the Participant ID. Place large bag into cooler until you return to the office.

## **2.2 ANALYTICAL METHODS**

### **2.2.1 TVOCs and Formaldehyde**

For TVOCs, Braun Intertec will analyze the samples by gas chromatography according to 3M methods. Results will be reported as total hydrocarbons as hexane with an accuracy of +/- 15% and a detection limit of 0.029 ppm.

For formaldehyde, Braun Intertec will analyze the samples by gas chromatography according to 3M methods. Accuracy is +/- 10% with a detection limit of 0.00242 ppm.

Braun Intertec is an AIHA Industrial Hygiene accredited laboratory (AIHA #101103).

### **2.2.2 Allergens**

Indoor Biotechnologies will conduct analysis of the dust vacuum samples by Multiplex Array for Indoor Allergens (MARIA) for five allergens: der f1, der p1, bla g2, mus m1, and rat n1.

No federal or state laboratory accreditation is required for the measurement of indoor allergens since it is an environmental measurement that is not regulated by CDC.

Turnaround time for laboratory analysis will depend on the number of specimens received in a given batch but will generally be 2 weeks from the date of receipt if the sample does not need to be analyzed repeatedly because its concentration exceeds the working range of the assay. The MARIA analytical method combines allergen-specific monoclonal antibodies with Luminex xMAPR technology.

## **STUDY 4**

This study will determine if low-cost, simple retrofit activities reduce radon exposures in different types of housing in two different climate zones in areas with high radon levels, as well as quantify any benefit regarding moisture.

Radon measurement methods and protocols will comply with Illinois regulation as defined in 32 Illinois Administrative Code. Measurements made in New Hampshire, where radon is not regulated, will follow the same methods and protocols as in Illinois. Radon samples are collected at 3 phases: pre-weatherization, immediate post-weatherization, and 1-year post-weatherization.

The instruments to be used in this study for measurement of average radon concentration are Electret ion chamber instruments from Radelec, Inc. (radelec.com). These consist of a Teflon plate initially charged to approximately 750V. The plate is placed in a chamber which is closed except during the time of exposure. Ionization due to radon decay leads to a reduction in the electret charge. The instrumentation units selected for this research are short-term (ST) electrets in small (L-00, 53 ml) chambers.

UIUC will purchase electrets and chambers from Radelec, to be sent directly to UIUC. Illinois Licensed Measurement Professionals at UIUC will conduct voltage readings using a SPER-1E electret voltage reader, to be purchased from Radelec, Inc. Voltage readings from the voltage

reader will be converted to average radon concentrations using the software provided by Radelec, or the appropriate functions.

In each home at each sampling phase, one instrument set will be placed in the primary living space and another in the basements of homes with basements, in compliance with instrumentation placement protocols from IAC Section 422.130. The instruments will be left in place from 14 to 21 days.

The instruments will be deployed and retrieved either by the researchers or by agency personnel trained in placement and retrieval. The time and date of exposure and closure will be recorded. Samplers will be shipped to UIUC within one week of retrieval. The Chain of Custody form (Appendix C) will be used in all sample shipments; paper forms will be maintained at NCHH and electronic scans of those forms will be posted to the secure UIUC Box.com site. A shipping account will be established with an appropriate carrier. Pre-addressed labels will be used for all shipments.

## Appendix II: Selected Contacts for Technical Assistance

- 1) **American Industrial Hygiene Association (AIHA)**  
3141 Fairview Park Dr.  
Suite 777  
Falls Church, VA 22042  
703-849-8888  
<https://www.aiha.org/>  
Directory of Certified Indoor Air Testing Laboratories: <https://www.aiha.org/publications-and-resources/buyers-guide/Pages/Indoor-Air-Quality.aspx>
  
- 2) **Underwriters Laboratories, Air Quality Sciences (UL AQS)**  
847-664-2040  
<http://newscience.ul.com/indoorairquality>  
  
**Marilyn S. Black, Ph.D., and LEED AP**  
President and Founder, UL AQS  
[Marilyn.Black@ul.com](mailto:Marilyn.Black@ul.com)  
  
**Elliott Horner, Ph.D., LEED AP and FAAAAI**  
Principal Scientist  
[Elliott.Horner@ul.com](mailto:Elliott.Horner@ul.com)
  
- 3) **The American Academy of Allergy, Asthma & Immunology**  
555 East Wells Street  
Suite 1100  
Milwaukee, WI 53202-3823  
414-272-6071  
<http://www.aaaai.org/conditions-and-treatments/library/at-a-glance/indoor-allergens.aspx>  
<http://www.aaaai.org/conditions-and-treatments/allergies/mold-allergy.aspx>

## Appendix III: Selected Contacts for Local Governments and Community Organizations

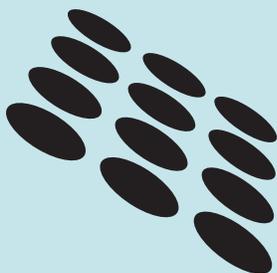
- 1) **National Center for Healthy Housing**  
10320 Little Patuxent Parkway  
Suite 500  
Columbia, MD 21044  
410-992-0712 or 877-312-3046  
<http://nchh.org/Home.aspx>
- 2) **National Association of Clean Air Agencies**  
444 N. Capitol Street, NW  
Suite 307  
Washington, DC 20001  
202-624-7864  
[4cleanair@4cleanair.org](mailto:4cleanair@4cleanair.org)  
<http://www.4cleanair.org/>  
Listing of State and Local Air Agencies: <http://www.4cleanair.org/agencies>
- 3) **Alameda County Health Homes** (Alameda County, CA)  
2000 Embarcadero  
Suite 300  
Oakland, CA 94606  
510-567-8280  
<http://www.achhd.org/>
- 4) **Ashland-Boyd County Health Department** (Kentucky)  
P.O. Box 4069  
Ashland, KY 41105  
606-329-9444
- 5) **Building Performance Center** (Washington, Alaska, Oregon, Idaho)  
3406 Redwood Ave.  
Bellingham, WA 98225  
360-734-5121 ext. 114  
<http://www.buildingperformancecenter.org/services-2/environmental-investigation/>
- 6) **Children's Mercy Hospitals and Clinics** (Missouri)  
2401 Gillham Road  
Kansas City, MO 64108  
816-960-8919  
[http://www.childrensmercy.org/Patients\\_and\\_Families/Support\\_and\\_Services/Environmental\\_Health/Healthy\\_Home\\_Program/](http://www.childrensmercy.org/Patients_and_Families/Support_and_Services/Environmental_Health/Healthy_Home_Program/)

- 7) **City of Houston Department of Health and Human Services** (Texas)  
8000 North Stadium Drive  
2nd Floor  
Houston, TX 77054  
832-393-5141  
[http://www.houstontx.gov/health/Environmental/healthy\\_homes.html](http://www.houstontx.gov/health/Environmental/healthy_homes.html)
- 8) **City of San Diego Environmental Services Dept/Energy, Sustainability & Environmental Protection Division**  
9601 Ridgehaven Court  
Suite 310  
San Diego, CA 92123  
858-694-7000  
<http://www.sandiego.gov/environmental-services/ep/leadsafety/sdhhc.shtml>
- 9) **Florida Department of Health**  
4052 Bald Cypress Way, Bin #A08  
Tallahassee, FL 32399  
850-245-4444 ext. 2204  
<http://www.floridahealth.gov/environmental-health/lead-poisoning/>
- 10) **Michigan Department of Community Health**  
Healthy Homes Section  
P.O. Box 30195  
Lansing, MI 48909  
517-335-9390  
Toll-free (866) 691-LEAD (5323)  
[http://www.michigan.gov/mdch/0,1607,7-132-2940\\_2955\\_2983-19366--,00.html#HHS](http://www.michigan.gov/mdch/0,1607,7-132-2940_2955_2983-19366--,00.html#HHS)
- 11) **Georgia Department of Public Health**  
2 Peachtree St. N.W., Ste. 13-464  
Atlanta, GA 30303  
404-463-2619  
<http://dph.georgia.gov/lead-and-healthy-homes>
- 12) **Kansas City, MO Health Department**  
2400 Troost Ave.  
Suite 3300  
Kansas City, MO 64108  
816-513-6008  
<http://kcmo.gov/health/childhood-lead-poisoning-prevention-and-healthy-homes-program/>

- 13) **Kansas Department of Health and the Environment, Healthy Homes & Lead Hazard Prevention Program**  
1000 SW Jackson Street  
Suite 330  
Topeka, KS 66612  
866-865-3233  
<http://www.kshealthyhomes.org/>
- 14) **Kenosha County Division of Health** (Wisconsin)  
8600 Sheridan Road  
Suite 600  
Kenosha, WI 53143  
262-605-6741  
<http://www.healthyhomespartnership.com/>
- 15) **Los Angeles County Department of Public Health**  
5555 Ferguson Drive  
Ste 210-02  
Commerce, CA 90022  
800-LA-4-LEAD (5323)  
[http://www.publichealth.lacounty.gov/eh/TEA/Lead\\_Programs/lead\\_main.htm](http://www.publichealth.lacounty.gov/eh/TEA/Lead_Programs/lead_main.htm)
- 16) **Marion County Health Department - Lead Safe and Healthy Homes Department** (Indiana)  
3838 N. Rural St.  
Indianapolis, IN 46205  
317-221-2266  
<http://www.mchd.com/ia.htm>
- 17) **New Jersey Department of Health and Senior Services**  
PO Box 360  
369 South Warren Street  
Trenton, NJ 08608  
609-826-4950  
<http://www.state.nj.us/health/iep/index.shtml>

## **Association of Public Health Laboratories**

The Association of Public Health Laboratories (APHL) is a national nonprofit dedicated to working with members to strengthen laboratories with a public health mandate. By promoting effective programs and public policy, APHL strives to provide public health laboratories with the resources and infrastructure needed to protect the health of US residents and to prevent and control disease globally.



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