Evaluation of Odors and Surface Residues in a Medical Center Research Facility

Kendra Broadwater, MPH
Scott E. Brueck, MS, CIH
Fariba Nourian, BS
Jennifer Roberts, BS
Aalok Y. Oza, MPH

HHE Report No. 2013-0117-3247
March 2016

U.S. Department of Health and Human Services
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

Contents

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The cover photo is a close-up image of sorbent tubes, which are used by the HHE Program to measure airborne exposures. This photo is an artistic representation that may not be related to this Health Hazard Evaluation. Photo by NIOSH.

Highlights of this Evaluation

The Health Hazard Evaluation Program received a request from a medical center research facility. Employees working in some laboratories were concerned about odors and a residue on shelving.

What We Did

- We collected samples of residue on shelves in three research laboratories.
- We collected air samples throughout the new research building and on the roof.
- We evaluated the building's heating, ventilation, and air-conditioning system.

What We Found

- We found very low levels of common indoor chemicals in the air and on the roof.
- We found very low levels of uncommon indoor chemicals in the air.
- Supply air intakes on the roof pulled building exhaust back into the building. This could have been one of the sources for unusual odors and uncommon indoor chemicals.
- In laboratory 3032, the imbalance of airflow exhaust to airflow supply could have caused air to come into the laboratory from gaps around pipe chases. This situation could have brought in odors from other areas.
- On the third floor, the supply airflow and exhaust airflow in many laboratories did not operate as they were designed. Air was moving from laboratories into the hallway.
- Treated humidified air was used to humidify the research facility.
- Degradation of the shelving could be causing the residue on the shelving.

We evaluated odors in a medical research building and residue on shelving in some laboratories. We found that laboratories were not pressurized as intended and building exhaust was re-entering air intakes. Degradation of the laminate may be causing the shelving residue. We recommended testing and balancing the ventilation system, properly pressurizing laboratories, reassessing the exhaust stack height, and stopping use of treated steam for building heat and humidification.

What the Employer Can Do

- Modify the roof exhaust stacks to reduce re-entry of exhaust air into the building.
- Establish and follow performance guidelines for the heating, ventilation, and air-conditioning system.
- Test and balance the heating, ventilation, and air-conditioning system. Repeat testing regularly and after any major renovation.

- Properly pressurize laboratories, offices, and restrooms.
- Identify and seal gaps around vertical and horizontal pipes that span multiple laboratories.
- Inspect the heating, ventilation, and air-conditioning refrigerant system for gas leaks.
- Stop using treated steam to humidify the building.
- Ensure that anesthetic gas containment systems in the veterinary medicine area are operating correctly and not leaking.

Abbreviations

AHU	Air handling unit
ANSI	American National Standards Institute
cfm	Cubic feet per minute
CFR	Code of Federal Regulations
GC/FPD	Gas chromatograph/flame photometric detector
GC/MS	Gas chromatography/mass spectrometry
HPLC	High performance liquid chromatography
HVAC	Heating, ventilation, and air-conditioning
ICP-AES	Inductively coupled plasma - atomic emission spectroscopy
IEQ	Indoor environmental quality
NRA	New research building A
NRB	New research building
NRC	New research building C
NIOSH	National Institute for Occupational Safety and Health
ppm	Parts per million
SVOC	Semivolatile organic compound
VOC	Volatile organic compound

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Introduction

The Health Hazard Evaluation Program received a request from a medical center research facility. Employees working in the third floor laboratories of the new research building (NRB) were concerned about indoor environmental quality (IEQ), transient odors, and a residue on shelving surfaces. They were concerned that the odors could be causing nausea, headache, sinus problems, and aggravation of asthma. We visited the facility in November 2013. We met with management representatives, health and safety staff, maintenance personnel, and employee representatives to discuss the health hazard evaluation request. We observed workplace conditions; spoke with employees; evaluated the heating, ventilation, and air-conditioning (HVAC) system; collected air samples in the building and on the roof; and took bulk samples of residue from shelves of some third floor laboratories. We provided preliminary recommendations in a letter in November 2013.

Background

The medical research complex was constructed in the 1930s. Since then, several additions and remodels have been made. The seven-story NRB was built in the 1970s. Laboratories in the NRB followed a modular design. Each laboratory module was equipped with utilities and ventilation. Modules could be combined or partitioned from adjacent modules to make laboratories of different sizes and to create office spaces. The research complex included new research building A (NRA) and new research building C (NRC), which were added between 1970 and 1990. All three research buildings were connected. The veterinary medicine research department was located on the sixth and seventh floors of the NRB and NRC. Research staff maintained small animal populations on these floors. Animal food and bedding were sanitized in an autoclave on these floors.

The employee requestors were particularly concerned about IEQ and a residue on some shelves in laboratory 3032 on the northeastern side of the NRB. This laboratory was part of the molecular biology research group originally located in the subbasement. When the lab was in the subbasement, employees often reported objectionable odors. In 2008, the laboratory personnel and analytical equipment were moved to the third floor of the NRB for reasons unrelated to the odors. After moving, noticeable odors initially subsided, but returned in 2011. Employees working in the northeast sections of the second, third, and fourth floors reported that odors became very strong during the summer of 2013.

During informal interviews conducted by National Institute for Occupational Safety and Health (NIOSH) staff in 2013, employees working on the third floor of the NRB characterized odors in several different ways. Several described a “dirty diaper-like” odor that emanated from laboratory cabinets and wall chases containing plumbing for laboratory benchtop fixtures. The odor was centralized on the third floor, predominantly in laboratory 3032. Additionally, some employees reported an “animal cage” smell that was common but intermittent throughout the NRB. It was more noticeable on the northeast side of the building. Employees working in laboratory 3032 also described “petri dish agar” and “solvent-like” odors, reportedly from the second and fourth floor laboratories. During our site visits we also spoke with employees working in the fourth floor pulmonary research

area above laboratory 3032 and with employees working in the second floor pathology laboratories below laboratory 3032. Employees working in these areas also reported an intermittent "animal cage" smell.

In response to the complaints, the health and safety department relocated employees from laboratory 3032 to another laboratory on the same floor. They also used cardboard and masking tape to cover the supply air diffusers and exhaust air grilles. However, reports of odors in laboratory 3032 continued intermittently; employees noticed the odors when they entered the laboratory to collect supplies or equipment.

Methods

The objectives of this evaluation were as follows:

1. To identify sources of the intermittent odors in the NRB
2. To identify the composition and sources of the residue on shelf surfaces in some third floor laboratories

Indoor Environmental Quality

We measured carbon dioxide concentrations, temperature, and relative humidity with a TSI Q-Trak™ Plus direct reading monitor. These IEQ measurements gave us information about whether the HVAC systems were providing adequate outdoor air and maintaining proper thermal comfort conditions according to American National Standards Institute (ANSI)/ASHRAE guidelines. We took measurements in laboratories and offices on the third floor, excluding areas that were locked or otherwise inaccessible. Although laboratories and offices had windows, the windows could not be opened.

Ventilation Assessment

We toured laboratories on several floors and the mechanical equipment rooms. We looked at the NRB rooftop supply air intakes and exhaust stacks. We also reviewed engineering diagrams of the ventilation systems with the engineering staff. We measured airflow rates in cubic feet per minute (cfm) at supply air diffusers and ducted exhaust air grilles in laboratory 3032 with a TSI AccuBalance® air capture hood with a 2-foot by 2-foot hood attachment. We positioned the air capture hood in the center of the linear slotted supply air diffusers or exhaust air grilles. If the supply air diffusers or exhaust air grilles were not fully covered by the air capture hood, we covered the peripheral portions. We measured air velocity in feet per minute across the face of the fume hoods with a TSI VelociCalc Plus® thermoanemometer. We measured face velocity of the laboratory fume hoods with the sash at the working height of approximately 8 inches. After measuring the area of the fume hood opening, we calculated the airflow rate in cfm for the fume hoods. We used ventilation smoke to visualize air movement and pressure differentials in the third floor laboratories relative to the hallways when doors were open and closed. We also used ventilation smoke to visualize airflow movements at supply air diffusers, exhaust air grilles, utility chases, and outdoor supply air intakes.

Air Sampling for Volatile Organic Compounds

On November 6, 2013, we collected area air samples in 10-liter SKC FlexFoil Plus® air sampling bags at a flow rate of 1 liter per minute to screen for reduced sulfur compounds. We collected duplicate samples in laboratory 3032, laboratory 3038, pathology laboratory 2038, and pulmonary research laboratory 4038. We collected one air sample in the sixth floor veterinary medicine area on the same side of the building as laboratory 3032. We also collected a sample from outside of the research building complex. This sample was collected outside the main entry of the NRB. All air sampling bag volumes ranged from 8 to 9 liters. For analysis, a 1 milliliter aliquot of air from each bag was removed and directly injected into a gas chromatograph equipped with a flame photometric detector (GC/FPD) to screen the samples for sulfur compounds. Reduced sulfur compounds, such as sulfides and mercaptans, can be detected by humans at very low concentrations and often are the source of offensive odors.

On November 15, 2013, we took additional area air samples using thermal desorption tubes in laboratories 3032, 3031, 3038, 4038, and 2038. We screened the area air samples for volatile organic compounds (VOCs), which could be associated with odors. We collected the thermal desorption tube samples at a flow rate of 50 cubic centimeters per minute using SKC pocket pumps. The thermal desorption tubes contained three beds of sorbent material: (1) 90 milligrams of Carbopack™ Y, (2) 115 milligrams of Carbopack™ B, and (3) 150 milligrams Carboxen™ 1003. We analyzed the samples using gas chromatography-mass spectrometry (GC/MS) according to NIOSH Method 2549 [NIOSH 2016]. Sample times ranged from 121–169 minutes, and sample volumes ranged from 6.05–8.46 liters. A summary of sample locations and analysis methods is provided in Table 1.

Table 1. Area air sampling in the NRB in November 2013

Sample location	Number of samples	Sample description	Analysis method
Laboratory 3032	2	SKC FlexFoil Plus air sampling bags	GC/FPD
	1	Thermal desorption tube	Benchtop GC/MS
Laboratory 3031	1	Thermal desorption tube	Benchtop GC/MS
Laboratory 3038	2	SKC FlexFoil Plus air sampling bags	GC/FPD
	1	Thermal desorption tube	Benchtop GC/MS
Laboratory 4038	2	SKC FlexFoil Plus air sampling bags	GC/FPD
	1	Thermal desorption tube	Benchtop GC/MS
Laboratory 2038	2	SKC FlexFoil Plus air sampling bags	GC/FPD
	1	Thermal desorption tube	Benchtop GC/MS
6th floor veterinary medicine hallway	1	SKC FlexFoil Plus air sampling bags	GC/FPD
Outdoors on ground floor	1	SKC FlexFoil Plus air sampling bags	GC/FPD

We returned on November 19, 2013, to evaluate the potential for re-entrainment and distribution of air from rooftop exhaust stacks back into the building through air handling unit (AHU) outdoor supply air intakes. We sampled the air using a Hapsite® ER portable GC/MS instrument. We also took duplicate air samples on thermal desorption tubes for comparison with the Hapsite measurement results. Sample times for the duplicate air samples were 132–206 minutes, and sample volumes were 6.6–10.3 liters. We collected and analyzed the duplicate samples using the methods described above. We took the air samples in laboratory 3032, in the animal cage washing room of the veterinary medicine floor (7204), at the intake of the rooftop NRC-AHU-5, at the intake of the rooftop NRB AHUs, and from the penthouse roof exhaust pipe where NIOSH investigators observed HVAC re-entrainment of an exhaust plume.

Residue and Laminate Sampling and Analysis

We collected bulk samples of residue from laminated particle board shelving in laboratories 3031, 3032, 3038, and 3049. The residue was present on some but not all shelving units. We scraped the residue with small spatulas and placed samples into inert glass containers with Teflon®-lined caps. We also took a bulk sample of the laminated shelving material.

NIOSH analytical chemists analyzed the residue and laminate bulks. They used inductively coupled plasma-atomic emission spectroscopy (ICP-AES) to look for metals, metalloids, phosphorous, and selenium according to NIOSH Method 7302 [NIOSH 2016]. A sample of the residue and laminate bulks was dissolved in dimethyl sulfoxide and analyzed by GC/MS and by high performance liquid chromatography (HPLC). In addition, bulk residue and laminate were analyzed using a thermal desorption system that was interfaced with a GC/MS. Bulk samples were also analyzed using a stereomicroscope, a polarized light microscope, and a scanning electron microscope. We sent samples of the residue and laminate to an external laboratory for elemental analysis via combustion. Further details of the residue and laminate analyses are provided in Appendix B.

Document Review

In April 2013, the medical research facility hired a safety and environmental engineering contractor to investigate the odors in laboratory 3032. The contractor took air samples for common air contaminants including VOCs, semivolatile organic compounds (SVOCs), as well as airborne mold and bacteria. The contractor used standardized methods for sample collection and analysis. We reviewed the consultant's report.

Results and Discussion

Indoor Environmental Quality

IEQ issues are common and have been extensively evaluated by NIOSH. Symptoms associated with IEQ concerns typically reported by building occupants are diverse and are usually not suggestive of a particular medical diagnosis or readily associated with a causative agent. The building environment is often suspected of causing symptoms, especially where occupants report symptoms lessening or resolving when the occupants are away from the workplace. Suggested causes can include HVAC system deficiencies, exposures to low concentrations of multiple chemicals, odors, microbiological contamination, psychological factors (stress), and physical factors such as temperature, lighting, and noise.

At the time of our evaluation, the outdoor temperature was 55°F, and the relative humidity was 81%. The ANSI/ASHRAE Standard 55-2013: Thermal Environmental Conditions for Human Occupancy specifies conditions in which at least 80% of the building occupants are comfortable. ASHRAE guidelines recommend temperatures remain 73°F to 79°F. The temperature range accounts for changes in building occupants' seasonal clothing selection. ASHRAE recommends keeping humidity levels below 65%. Fifty percent relative humidity is ideal. Excessive humidity can cause discomfort and promote the growth of molds, bacteria, and dust mites. Humidity levels below 30% can cause dry eyes and irritate sinus and mucous membranes. Table A1 in Appendix A shows temperature and relative humidity spot measurement results for several laboratories and offices throughout the NRB. Most temperature and all relative humidity measurements were within the ASHRAE recommended guidelines [ANSI/ASHRAE 2013a].

Ventilation Assessment

On November 15, 2013, we met with members of the health, safety, and compliance department staff along with facilities and maintenance managers and employees to discuss the NRB HVAC system. The NRB was equipped with a constant volume, forced air HVAC system. According to facilities personnel, the system supplied 100% outdoor air (no recirculation) with all air exhausting directly to the roof.

Carbon dioxide is a component of exhaled breath and is not considered a building air pollutant unless it is generated and released as a contaminant from a production process. However, indoor carbon dioxide concentrations, when compared to those outdoors, are an indicator of building ventilation system effectiveness [ANSI/ASHRAE 2013a,b]. Our measurements of outdoor carbon dioxide concentrations at approximately noon on November 6, 2013, ranged from 355–400 parts per million (ppm). Our indoor spot measurements in some of the laboratories and offices on the third floor of the NRB showed carbon dioxide concentrations ranging from 416–965 ppm (Table A1, Appendix A). These carbon dioxide concentrations are up to 610 ppm higher than outdoor carbon dioxide levels, and suggest uneven distribution of supply air in some areas on the third floor.

Figure 1 shows a rooftop view of the research building complex, locations of AHUs, and exhaust stacks from the research buildings. At the time of our evaluation, the facilities department did not have performance guidelines or standards for the HVAC system of the research building complex. They relied on institutional knowledge among facilities employees about how the system had operated in the past.

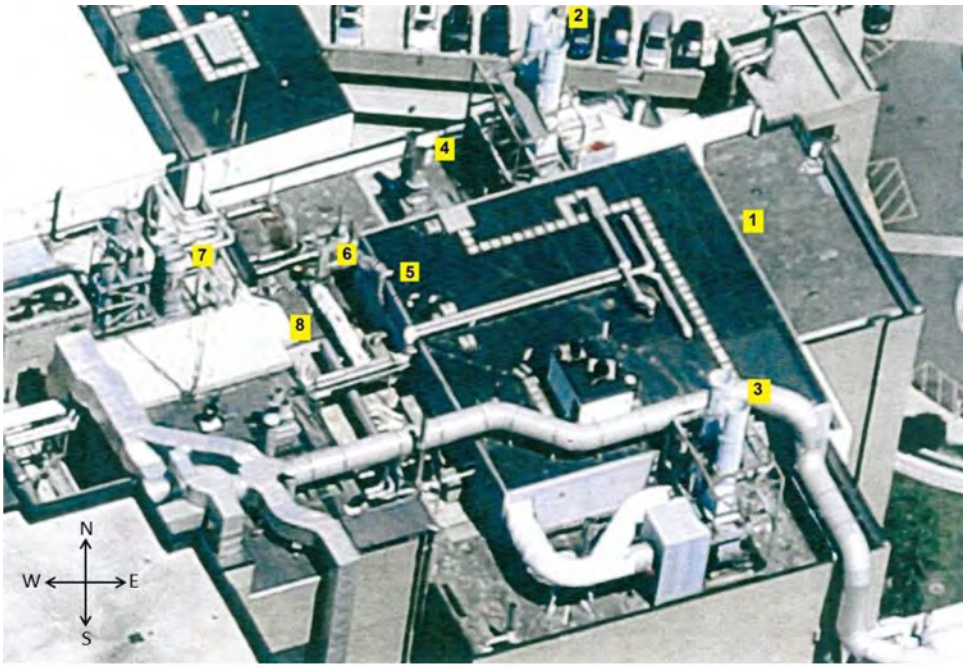

Photo key:
1. Supply air intakes for NRB air handling units 1, 2, and 3.
2. NRB exhaust – north and east
3. NRB exhaust – south and west
4. Animal cage wash wet exhaust
5. Unidentified exhaust stack
6. NRB common restroom exhaust
7. General veterinary research exhaust
8. Supply air intake for air handling unit NRC-AHU-5

Figure 1. Annotated aerial image of the NRB and NRC with supply air intakes and exhaust stacks identified. Photo by Google Earth.

Air was supplied to the NRB building from four AHUs. Three units were located on the east side of the building roof, designated NRB-AHU-1, 2, and 3. These units supplied air only to the NRB. A fourth AHU (NRC-AHU-5) located on the western side of the NRB roof and bordering the NRC was brought online during the summer of 2013. This unit was a redundant system designed to supply air to the NRB or the NRC, depending on supply air volume needs. At the time of our evaluation, NRC-AHU-5 was supplying air solely to NRB.

For all AHUs, outdoor air entered the air intakes and passed through bag-type prefilters with a minimum efficiency reporting value of 8, and subsequently passed through activated charcoal filters before mixing in a common plenum space. The prefilters were inspected each month for static pressure changes and replaced as needed. Charcoal filters were changed every month per manufacturer's recommendations. After mixing, supply air passed through two parallel main supply air ducts on the north and south sides of the building's center mechanical shaft. To ensure that adequate air reached all areas of the building, the main supply air ducts were fitted with variable frequency drive ventilation, located on the second floor of the building. The variable frequency drive system monitored static pressure within the supply trunks and varied AHU fan speeds according to the ventilation requirements. Trunk lines branched off of the main supply ducts and provided ducted air to each floor. All HVAC duct in the research building complex was unlined.

Supply air on each floor was conditioned with terminal reheating coil units that operated using a 50% ethylene glycol to water mixture. Dampers within the terminal reheating coil duct were used to control airflow for each laboratory module. Following our site visit on November 15, 2013, employees working on the third floor of the NRB noticed pink-colored stains on ceiling tiles where a number of reheating coils were located. This may have been caused by leaking fluid from these coils. Supply air was delivered to laboratory modules through linear slotted diffusers. Each laboratory was equipped with two ceiling mounted supply air diffusers: a smaller two-slot linear diffuser approximately 2 feet long and 4 inches wide and a larger four-slot diffuser approximately 10 feet long and 7 inches wide. The diffuser slots were about 1 inch wide. Air was exhausted from the laboratory modules through two slotted exhaust air grilles located toward the back of the laboratory. Laboratories equipped with fume hoods had only one exhaust air grille. All laboratory exhaust, including exhaust air from fume hoods, was ducted through common trunk lines that emptied into two main exhaust ducts located on the northeastern and southwestern sides of the NRB. These large ducts exhausted air out of the building through rooftop exhaust stacks.

During our site visit on November 15, 2013, facilities and maintenance personnel reported that the combined supply airflow through the two linear slotted supply diffusers in each laboratory module was designed to be approximately 700 cfm. Each exhaust grille was designed to exhaust approximately 350 cfm. We measured the supply and exhaust airflow rates for laboratory 3032. Results of airflow rate measurements for laboratory 3032 are shown in Table 2. Neither the HVAC air supply nor air exhaust in laboratory 3032 met reported design specifications. Because of the additional exhaust airflow from the east module fume hood, more than twice the amount of air was being exhausted from laboratory 3032 than being supplied. Therefore, the laboratory was negatively pressurized relative to the adjacent hallways, which meets standard design requirements. However, the degree of imbalance between exhaust and supply air rates we measured may lead to excessive make-up air being drawn from the hallway and other unplanned pathways.

Table 2. Laboratory 3032 airflow measurements (November 19, 2013)

Location of measurement	Airflow rate (cfm)
Supply air	
West module large diffuser	135
West module small diffuser	119
East module large diffuser	105
East module small diffuser	72
Total supply airflow	431
Exhaust air	
West module exhaust air grille (west)	204
West module exhaust air grille (east)	245
East module fume hood	605
Total exhaust airflow	961

Facilities and maintenance personnel reported to us that all laboratories and offices were assumed to be negatively pressurized relative to the adjacent hallways. However, our testing revealed that 13 of 16 laboratories and offices on the third floor were under positive pressure relative to the hallway. This positive pressure differential can lead to migration of air from laboratories into hallways and subsequently into other spaces that are under negative pressure relative to the hallway. Results for the ventilation smoke testing are shown in Table 3.

Table 3. Air pressure differential between third floor laboratories, offices, and the adjacent hallways (November 6, 2013)

Room	Air pressure relationship to adjacent hallway
3025 office	Positive
3026	Negative
3027	Positive
3029	Positive
3030 office	Positive
3031	Positive
3032	Negative
3033 office	Neutral
3038	Positive
3039 office	Positive
3040	Positive
3042	Positive
3045	Positive
3047	Positive
3049	Positive
3050 office	Positive

Ventilation smoke testing under the laboratory bench cabinets along the exterior wall in laboratory 3032 demonstrated that air flowed into the space under the laboratory bench cabinets from a gap between the floor and a utility drain pipe, which ran vertically between floors along the outside wall (Figure 2). Additionally, we observed that air from the gap around the utility drain pipe moved through the laboratory bench cabinet space into the laboratory through gaps around the laboratory bench cabinet drawers, doors, and access panels. Because of the differential between exhaust and supply rates in laboratory 3032 the gap around the utility pipe was an unanticipated supply air pathway from neighboring laboratories on other floors.

Figure 2. Photo of gap between utility drain pipe under laboratory cabinet and floor provided unplanned pathway for movement of air from floor below. Photo by NIOSH.

During our site visit on November 15, 2013, we noted an "animal cage" odor while we were taking air samples on the roof. Facilities staff also noted the odor and reported that it was similar to the "animal cage" odors previously reported on the second, third, and fourth floors of the NRB. We also saw re-entrainment of exhaust on the penthouse roof from an unidentified exhaust pipe into NRC-AHU-5. HVAC staff were unsure where the pipe exhausted from. Figure 3 shows the exhaust pipe, and Figure 4 shows NRC-AHU-5.

Figure 3. Rooftop penthouse exhaust pipe (shown in the upper right corner of the figure), which was located adjacent to NRC-AHU-5. Prevailing winds carried exhaust from the pipe toward the NRC-AHU-5 supply air intake. Photo by NIOSH.

Figure 4. Photo of a supply air intake for rooftop air handling unit, NC-AHU-5, where building exhaust air was observed being captured by the intake. Photo by NIOSH.

The NRB was humidified by the introduction of boiler house steam at the AHUs. The boiler house steam was treated with a neutralizing amine corrosion inhibitor that was added to produce a concentration of 25 ppm. The proprietary corrosion inhibitor contained diethylaminoethanol (CAS 100-37-8) and morpholine (CAS 130-91-8) in unlisted concentrations [Weas Engineering, Inc. 2005]. Diethylaminoethanol and morpholine are listed as strong eye, skin, and respiratory irritants [NIOSH 2010]. Maintenance personnel manually added corrosion inhibitor into the boiler water, as per the manufacturer's recommended instructions and schedule. The U.S. Environmental Protection Agency and NIOSH do not recommend using treated steam for building humidification because it can contain potentially harmful corrosion inhibitors [NIOSH 1991].

Air Sampling for Volatile Organic Compounds

We did not identify sulfur compounds, ammonia, or amine-containing compounds during our initial screening or analysis of the thermal desorption tubes. However, we identified a variety of other VOCs and SVOCs. Specifically, we found trace amounts of solvents (i.e., acetone, ethanol, isopropanol), aliphatic hydrocarbons (i.e., decane, hexane), aldehydes (i.e., hexanal, acetaldehyde, formaldehyde), aromatic hydrocarbons (i.e., toluene, xylene), chlorinated solvents (i.e., trichloroethane, perchloroethylene), and terpenes (i.e., limonene) in all samples we collected throughout the building. Many of these contaminants are common in indoor environments, and a wide range of building materials can be a source for these compounds [Wallace 1986, 1991; Wallace et al. 1987]. These materials include but are not limited to paint, adhesives, flooring materials, ceiling tiles, upholstered furniture, workstations, personal care products (nail polish, perfumes, deodorants, and hair spray), room deodorizers, aerosol spray products, and surface cleaning products.

Some of the compounds identified in the air could be attributed to the chemicals known to be used and stored in research laboratories across the building. According to a hazardous chemical inventory list provided by management, chemicals in the classes listed above (such as ethanol, propanol, urethane, formaldehyde, and 2,3-diaminonaphthalene) were stored and used in the research complex.

We also identified compounds in the samples taken at the penthouse exhaust area, at the face of the NRC outdoor air intake (NRC-AHU-5), at the face of main NRB AHUs, in the 7204 cage washing area, and in laboratory 3032 that are typically not found in ambient indoor air. Specifically, we found isoflurane and sevoflurane in these samples. The concentrations were very low, less than 1 part per billion. Isoflurane and sevoflurane are halogenated ether anesthetics with mild ether-like odors. Isoflurane was used as the primary anesthetic for research animals at this facility. All surgical core suites used anesthetic gas evacuation systems that are designed to capture fugitive emissions of the anesthetic waste gases during surgical procedures and exhaust them directly outside of the building. We did not evaluate the effectiveness of these anesthetic gas evacuation systems to assess whether they were operating as designed.

Anesthetic waste gases from evacuation systems can migrate to unexpected areas of the building because of leaks, unplanned ventilation pathways, or re-entrainment into building air intakes. During previous health hazard evaluations, NIOSH investigators have identified instances of overexposures to anesthetic gases (e.g., nitrous dioxide and isoflurane) in operating rooms and dental offices. Across several evaluations, we found overexposures to anesthetic waste gases were caused by loose fitting intubation tubes or face masks, leaks in the evacuation system, exhaled anesthetic gases from recovering patients, and scavenging system malfunctions [NIOSH 1986a,b; 1987a,b]. Neither the Occupational Safety and Health Administration nor NIOSH has occupational exposure limits for these anesthetic gases. American National Standards Institute standard Z79.11-1982, Anesthetic Equipment-Scavenging Systems for Excess Anesthetic Gases, provides guidance for proper protection of employees and performance guidelines for waste anesthetic gas scavenging systems [ANSI 1982]. Additionally, information about occupational anesthetic gas exposure

and exposure prevention in a hospital setting can be found in NIOSH's Waste Anesthetic Gases: Occupational Health Hazards. The document provides recommendations concerning ventilation, scavenging systems, and administrative controls, like training, and can be applied to animal research settings in NRB [NIOSH 2007].

We found trace amounts of carbon tetrachloride in the side-by-side air samples taken at the aforementioned sample locations. Despite being banned from consumer products in the United States in 1970, carbon tetrachloride persists in the environment and contributes to a background level in ambient air and drinking water to which the general population is exposed [ATSDR 2005]. Additionally, carbon tetrachloride is a common indoor and outdoor environmental contaminant found in trace levels that probably originates from building materials or household products such as cleaners or pesticides [ATSDR 2005]. The U.S. Environmental Protection Agency has classified carbon tetrachloride as a Group B2, probable human carcinogen; however, human data on the carcinogenic effects of carbon tetrachloride are limited.

We also identified trace levels of perchloroethylene in one set of side-by-side air samples taken in laboratory 3032 and at the outdoor air intakes at NRC-AHU-5 and the AHU that served the east side of the building. Perchloroethylene is commonly used as a dry-cleaning solvent and for metal degreasing. It is noted as having a sharp and sweet odor. The source of the perchloroethylene is unknown. Small amounts of perchloroethylene can be released from clothing that has been dry cleaned [ATSDR 1997].

We found trace amounts of 1,1,2-Trichloro-1,2,2-trifluoroethane (Freon® 113) and trichloromonofluoromethane (Freon 11) in the side-by-side samples taken at the penthouse roof exhaust pipe. These compounds have been commonly used as commercial refrigerants and aerosol propellants. Freon 113 has also been used as an aerosol propellant and as a chlorofluorocarbon cleaning agent. Although they were largely phased out of production in the mid-1990s, they can persist for decades in the environment.

Residue Sampling and Analysis

We found residue on some shelving in four laboratories on the third floor. However, we did not find residue on other laboratory surfaces, including benchtops or laboratory equipment. Analysis of the residue by ICP-AES did not reveal appreciable amounts of metals, metalloids, phosphorous, or selenium. Analysis of the residue by traditional GC/MS and HPLC did not identify any major compounds.

Elemental analysis identified the amount, by weight, of nitrogen, oxygen, hydrogen, and carbon in the residue and laminate samples. Comparing the ratios of these elements in the residue to the elemental ratios in the laminate provided useful information about the potential source of the residue. The carbon to hydrogen molar ratios were 0.88 in the laminate and 0.83 in the residue. The similarity in these ratios suggests that the residue was more likely a degradation product of the laminate than an environmental deposition or growth on the laminate. The carbon to oxygen molar ratios were 2.94 in the laminate and 2.04 in the residue, suggesting that the residue may be a product of oxidative degradation of the laminate.

Analysis via stereomicroscopy, scanning electron microscopy and polarized light microscopy revealed the residue is likely a synthetic polymer with plastic-like characteristics and some synthetic fiber and glass fiber contamination. The bulk samples contained colorless (cellulose) and dark (synthetic) fibers. The residue matrix was translucent brown and displayed properties associated with polymers or plastic. The sample had an uneven thickness and a stretched look which typically comes from smearing or attempting to grind or flatten a plastic or plastic-like material. Organic material is difficult to analyze by scanning electron microscopy because contrast is almost impossible to obtain while maintaining image quality and interpretability. The scanning electron microscope image (Figure 5) shows an area near the center where the sample has thinned and appears stretched. Linear features parallel to the stretching indicate that the substance is a polymer.

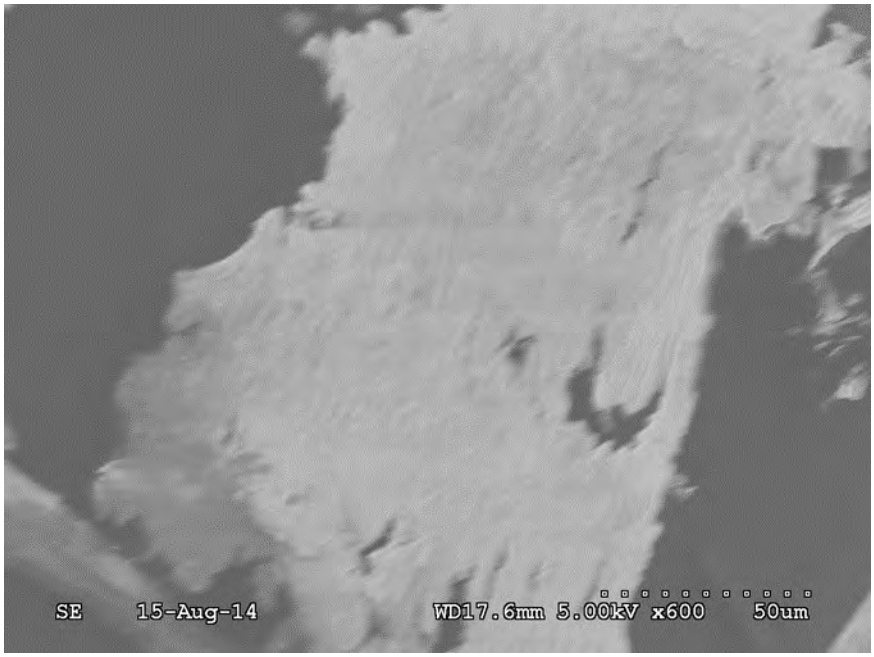

Figure 5. Scanning electron microscope image of a residue sample. Photo by NIOSH.

Analysis by thermal desorption/GC/MS of the bulk residue and laminate revealed some of the same compounds. Two of the four largest peaks in the residue chromatogram were also found in the laminate. These were for phenol and diethylaminoethanol. The other two largest peaks found in the residue analysis were for diethylamine and morpholine. Diethylamine may be generated when diethylaminoethanol, the most abundant compound in the residue analysis, degrades. In laminate manufacturing, morpholine can be used in the creation of phenolic esters to create a smooth, shiny laminate surface, but it becomes chemically cross-linked or evaporates during the curing process. The most likely source of the morpholine and diethylaminoethanol present in the samples was the additive in the boiler house steam used to humidify the lab air. These chemicals can collect on surfaces in the laboratory. Phenol, however, is likely a breakdown product of laminate material. Phenol-formaldehyde resins are commonly used for manufacturing laboratory benchtops. Its presence in the residue sample indicates that the residue is derived from the laminate material.

On the basis of GC-MS, elemental, and microscopic analyses, we concluded that the residue on shelving is more likely a product of laminate degradation rather than deposition of something from the environment. Some laboratory employees we spoke with noted that after the residue was cleaned off shelves in laboratory 3032, the residue was found on the shelves a month later, even though the ventilation supply air diffusers and exhaust air grilles were covered to prevent air flow. This finding is further support for our conclusion. However, the cause of the degradation cannot be completely determined using these results. Oxidative degradation of the laminate could be caused by age, environmental parameters (temperature and relative humidity), or other factors.

Document Review

We reviewed the safety and environmental engineering consultant reports. The analysis of air samples taken by the consultant in laboratory 3032 did not indicate the presence of VOCs, SVOCs, or metals above their laboratory limit of detection. Airborne mold spore counts were substantially less than outdoor spore counts. Occupational exposure limits for mold spores and bacteria do not exist; however, comparing indoor and outdoor mold spore concentrations is a common tool to identify whether airborne mold is being concentrated indoors.

According to a consultant report, the residue was heterogeneous, consisting of carbohydrate-based material that contained carbon, oxygen, nitrogen, and a small amount of sulfur. The residue samples inconsistently contained potassium, sulfur, sodium, magnesium, aluminum, and calcium. However, through microscopic analysis the consultant found that the residue did not differ significantly between sampling locations. The consultant did not make any conclusions about the source of the residue.

Odors

Odors result from the presence of organic or inorganic compounds that trigger the sense of smell and can be pleasant or unpleasant. The presence of odors can cause some people to suspect harmful exposures. However, odors in a building do not always mean that occupants are exposed to harmful levels of chemicals. Many chemicals or compounds have a very low odor threshold, which means people can smell them at very low levels.

It is possible that symptoms in some employees are associated with the odor. Unpleasant odors can be a warning sign or indicator of potential human health risks, even if they do not trigger health effects. Odor sensations themselves can cause health symptoms [Schiffman and Williams 2005]. It has been shown that odors can worsen chronic respiratory problems such as asthma, and it is thought that odors can affect the physiological and psychological responses of individuals with asthma [Beach et al. 1997; Jaen and Dalton 2014].

Odors may produce health symptoms by three mechanisms. First, symptoms can be induced by exposure to odorants at levels that also cause irritation. Therefore, irritation, rather than the odorant, is the cause of the symptoms. Second, health symptoms from odorants at nonirritant concentrations, such as hydrogen sulfide, can be due to innate or learned aversions. Third, symptoms may be due to a copollutant, such as endotoxin, that is part of an odorant mixture [Schiffman and Williams 2005]. It is possible that symptoms reported among

facility employees could be associated with all three mechanisms.

Conclusions

The mixtures of chemicals, including anesthetic gases, were similar across sample locations. These data, along with our observations of re-entrainment on the roof suggest that building exhaust air is being captured by a building air intake, NRC-AHU-5 and circulated throughout the NRB. On the third floor of the building we found that the supply airflow and exhaust air flow did not meet the reported design specifications. We also found that pressure differentials between third floor hallways, laboratories, and offices were not as designed. Specifically, many laboratories were under positive pressure relative to adjacent hallways and this can lead to unplanned migration of air contaminants and odors from one area to another. We found unplanned pathways of air movement into a laboratory through floor gaps around a drain pipe. All of these findings may be contributing to the occasional odor in laboratory 3032. Our analysis of residue from shelving in some third floor laboratories indicates that the residue is likely composed of a synthetic polymer produced by degradation of the shelving laminate rather than deposition of something onto the surface of the shelving.

Recommendations

On the basis of our findings, we recommend the actions listed below. We encourage the medical center to use a labor-management health and safety committee or working group to discuss our recommendations and develop an action plan. Those involved in the work can best set priorities and assess the feasibility of our recommendations for the specific situation at the research facility.

Our recommendations are based on an approach known as the hierarchy of controls. This approach groups actions by their likely effectiveness in reducing or removing hazards. In most cases, the preferred approach is to eliminate hazardous materials or processes and install engineering controls to reduce exposure or shield employees. Until such controls are in place, or if they are not effective or feasible, administrative measures and personal protective equipment may be needed.

Elimination and Substitution

Eliminating or substituting hazardous processes or materials reduces hazards and protects employees more effectively than other approaches. Prevention through design, considering elimination or substitution when designing or developing a project, reduces the need for additional controls in the future.

1. Discontinue using steam with additives to humidify the building. NIOSH does not recommend using boiler house steam that has been treated with corrosion inhibitors for building humidification [NIOSH 1991]. If additional humidification is necessary, install humidification systems such as direct steam injection into the HVAC ductwork.

Engineering Controls

Engineering controls reduce employees' exposures by removing the hazard from the process or by placing a barrier between the hazard and the employee. Engineering controls protect employees effectively without placing primary responsibility of implementation on the employee.

1. Consult with an HVAC engineer to evaluate the design, height, and location of roof exhaust stacks. Changes are needed to reduce re-entry of exhaust air into the building through the building HVAC supply air intakes, particularly NRC-AHU-5. The ASHRAE Handbook—HVAC Applications includes information on building air intake and exhaust design that may be helpful during ventilation evaluation and design [ASHRAE 2015].
2. Establish and follow performance guidelines or standards for the HVAC system. Consult with an experienced ventilation engineer to address ventilation deficiencies within the laboratory. The ventilation engineer should be familiar with relevant standards, such as ASHRAE Standard 170, ventilation of health care facilities; ASHRAE HVAC Design Manual for Hospitals and Clinics; and ANSI Z9.5, laboratory ventilation [ANSI/ASHRAE 2008; ANSI 2012; ASHRAE 2013].
3. Conduct a test and balance on the building HVAC system. Repeat testing at regularly scheduled intervals and after any major renovation.
4. Ensure that laboratories, offices, and restrooms are properly pressurized once HVAC performance standards and guidelines are established and needed renovations completed.
5. Prevent unplanned migration of laboratory chemicals through utility chases or other means of airflow between buildings and floors. Eliminate existing unplanned airflow into laboratories and offices. Specifically, inspect plumbing and pipe chases to ensure that any gaps around vertical and horizontal pipes spanning multiple laboratories are identified and sealed.
6. Inspect and repair terminal reheating coil leaks.
7. Inspect the HVAC refrigerant system for gas leaks.
8. Inspect all anesthetic gas containment systems in the surgical core suites of the veterinary medicine area of the research building complex to ensure they are operating correctly and without leaks. Consult ANSI Z79.11 American National Standard for anesthetic equipment—scavenging systems for excess anesthetic gases [ANSI 1982].
9. Review the additional guidance and recommendations for laboratory safety, design, and ventilation available in the National Research Council (NRC) 2011 edition of "Prudent Practices in the Laboratory: Handling and Management of Chemical Hazards" [NRC 2011].

Appendix A: Tables

Table A1. Third floor NRB carbon dioxide concentration, temperature, relative humidity measurements (November 6, 2013)

Laboratory/ office number	Carbon dioxide (ppm)	Temperature (degrees F)	Relative humidity (%)
3025	667	75	50
3025 office	945	75	53
3026	617	75	50
3027	617	75	49
3028	517	76	50
3029	731	75	50
3030	545	75	49
3031	790	73	48
3032	730	73	49
3033	733	72	48
3033 office	701	73	50
3037	430	70	55
3038	509	70	55
3039	545	72	51
3039 office	750	72	51
3040	590	72	57
3041	521	72	50
3042	558	73	49
3047	480	70	50
3048	465	71	50
3049	560	71	49

Appendix B: Detailed Methods for Residue and Laminate Analysis

Analytical Techniques Used for Residue and Laminate Analysis

NIOSH used multiple analytical techniques to help determine composition and potential relationship between the laminate and the residue on some laboratory shelving. This appendix details the analytical procedures used and the series of results that ultimately provided information regarding the composition and potential sources of the residue and laminate described previously.

Inductively coupled plasma-atomic emission spectroscopy

After collection, the residue was dried before sample preparation. The sample was then digested and analyzed according to NIOSH method 7302 [NIOSH 2016]. ICP-AES was used to detect metals, metalloids, phosphorous, and selenium.

Elemental analysis

A 7.42 milligram dried sample of the residue and a 12.68 milligram dried sample of the laminate were sent to an external laboratory for analysis of carbon, hydrogen, nitrogen, and oxygen. Elemental analysis included sample combustion followed by measurement of combustion products (e.g., carbon dioxide, water, carbon monoxide, nitrogen oxides).

Gas chromatography-mass spectrometry

A sample of the residue dissolved in dimethyl sulfoxide was analyzed using an Agilent 6890/5973 GC-MS with a 30 meter Rtx-1 column and operated under electron ionization conditions. A variety of analytical and temperature conditions were used. For example, an injection port temperature of 300°C was used to try to thermally breakdown the material in solution.

A one milligram sample of the bulk residue and laminate was analyzed using a Markes Unity/Ultra automatic thermal desorption system interfaced to an Agilent 7890/5977 GC-MS with a 30 meter HP-1MS column and operated under electron ionization conditions. The samples were placed inside separate glass thermal desorption tubes which were heated at 380°C for 10 minutes and the trap was desorbed at 300°C (maximum temperature for the trap) for 3 minutes.

High performance liquid chromatography with ultraviolet detection

An aliquot of the residue in dimethyl sulfoxide was analyzed using an Agilent 1100 HPLC with a diode array detector and a reversed-phase C8 column. A mobile phase gradient was used with a 50/50 acetonitrile/water initial hold for 5 minutes followed by a gradient to 95/5 acetonitrile/water over 40 minutes. A second analysis was done using an isocratic 95/5 acetonitrile/water mobile phase for 50 minutes.

Microscopy

Some residue samples were analyzed by a stereomicroscope and polarized light microscopy. One sample was also analyzed on a Hitachi S3000N scanning electron microscope, in which secondary electron images were obtained at a magnification of 600 and an accelerating voltage of 5000 kilovolts.

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Keywords: North American Industry Classification System 541711 (Research and Development in Biotechnology), Ohio, indoor environmental quality, IEQ, odor, anesthetic gas, building exhaust, laboratory, research lab, research laboratory, medical research, veterinary medicine, residue, laminate

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Acknowledgments

Analytical Support: Amos Doepke, Robert Streicher, Ronnee Andrews, Joseph Fernback, Galbraith Laboratories, Inc., Bureau Veritas North America
Desktop Publisher: Shawna Watts
Editor: Ellen Galloway
Industrial Hygiene Field Assistance: Greg Burr, Wei Gong, Amos Doepke, Ronnee Andrews
Logistics: Donnie Booher, Kevin Moore

Availability of Report

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This report is available at http://www.cdc.gov/niosh/hhe/reports/pdfs/2013-0117-3247.pdf.

Recommended citation for this report:
NIOSH [2016]. Health hazard evaluation report: evaluation of odors and surface residues in a medical research facility. By Broadwater K, Brueck SE, Nourian F, Roberts J, Oza AY. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, NIOSH HHE Report No. 2013-0117-3247.

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