HealthHazard Evaluation Program

Evaluation of Exposures and Health Concerns in a Dental Clinic

HHE Report No. 2019-0232-3394

March 2024

Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

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Keywords: North American Industry Classification System (NAICS) 621210 (Healthcare and Social Assistance), Connecticut, Dental Clinics, Exposure Assessment, Volatile Organic Compounds, Respirable Dust, Ventilation

Disclaimer

The Health Hazard Evaluation Program investigates possible health hazards in the workplace under the authority of the Occupational Safety and Health Act of 1970 (29 U.S.C. § 669(a)(6)). The Health Hazard Evaluation Program also provides, upon request, technical assistance to federal, state, and local agencies to investigate occupational health hazards and to prevent occupational disease or injury. Regulations guiding the Program can be found in Title 42, Code of Federal Regulations, Part 85; Requests for Health Hazard Evaluations (42 CFR Part 85).

Availability of Report

Copies of this report have been sent to the employer and employees at the dental clinic. The state and local health department and the Occupational Safety and Health Administration Regional Office have also received a copy.

Recommended Citation

NIOSH [2024]. Evaluation of exposures and health concerns in a dental clinic. By Blackley BH, Fechter-Leggett ED, Burns DA, Fortner AR, Martin SB. Morgantown, WV: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Health Hazard Evaluation Report 2019-0232-3394, http://www.cdc.gov/niosh/hhe/reports/pdfs/2019-0232-3394.pdf

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Introduction

Request

We received a management request for a health hazard evaluation at a dental clinic. The request stated concerns about idiopathic pulmonary fibrosis (IPF). IPF is a serious long term lung disease that can cause permanent scarring in the lungs. IPF was first identified in a cluster of dentists reported in 2018. In response to the request, we performed an air sampling survey in August 2022 to evaluate potential exposures to respirable dust, respirable crystalline silica, respirable metals, and volatile organic compounds (VOCs). We also assessed the existing ventilation systems in the dental clinic.

Workplace

The dental clinic provides dental care services to patients. General dentistry services and procedures are performed at the clinic and clinic laboratory. The dental clinic is housed on the second floor of a two-story medical clinic on an academic campus. At the time of our survey, eight staff were onsite, including two dentists, two dental hygienists, three dental assistants, and one administrative staff.

To learn more about the workplace, go to [Section A in the Supporting Technical Information]

Our Approach

We conducted a site visit in August 2022 to assess possible exposures during routine dental care, assess the ventilation systems in use, and informally interview clinic staff. We conducted opening and closing meetings with employees and management to share background information about NIOSH and this health hazard evaluation. We also described the purpose of our survey, activities that would be performed while onsite, and actions that would be taken after we concluded our survey. During our onsite survey, we:

- Collected full-shift personal air samples on dental clinic employees for respirable dust and respirable crystalline silica.
- Collected full-shift area air samples in multiple locations in the dental clinic for respirable dust, respirable crystalline silica, respirable metals, and volatile organic compounds (VOCs).
- Collected instantaneous air samples for VOCs during various tasks and procedures.
- Collected real-time measurements of respirable aerosols in and just outside of the laboratory.
- Assessed the heating, ventilation, and air-conditioning (HVAC) systems in use.
- Informally interviewed clinic staff to learn about any health concerns potentially related to exposures at work.

To learn more about our methods, go to [Section B in the Supporting Technical Information]

Our Key Findings

All personal air samples were below the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) and the American Conference of Governmental Industrial Hygienists (ACGIH®) threshold limit value (TLV®) for respirable dust.

- Personal full-shift, time-weighted average (TWA) air samples for respirable dust were all below the limit of detection (LOD) and ranged from less than 41.9 micrograms per cubic meter of air (μg/m^3) to less than 71.9 μg/m^3.
- The OSHA PEL for respirable dust is 5,000 μg/m^3, and the ACGIH recommended level for respirable dust is 3000 μg/m^3.

All personal air samples for respirable crystalline silica were below the NIOSH recommended exposure limit (REL) and OSHA PEL.

- Personal full-shift, TWA air samples for respirable crystalline silica (cristobalite, quartz, and tridymite) were all below their respective LODs and ranged from:
  - Less than 5.2 μg/m^3 to less than 9.0 μg/m^3 for cristobalite.
  - Less and 5.2 μg/m^3 to less than 9.0 μg/m^3 for quartz.
  - Less than 10.5 μg/m^3 to less than 18.0 μg/m^3 for tridymite.
- The NIOSH REL and OSHA PEL for respirable crystalline silica is 50 μg/m^3.

All area air samples for respirable dust, respirable crystalline silica, and respirable metals were low; some metals were measured in all or most areas of the clinic.

- Because area air samples are not collected directly on employees (known as personal air samples), exposure limits are not directly applicable to area air sampling results for exposure monitoring purposes. However, area air samples can highlight areas with higher exposure risk, and the RELs can be used as points of reference.
- Three of the 36 area air samples had measurable respirable dust but were below the OSHA PEL (5,000 μg/m^3) and ACGIH's recommended level (3,000 μg/m^3).
  - Two air samples (22.0 μg/m^3 and 41.8 μg/m^3) were collected in treatment room 232A.
  - One air sample (21.7 μg/m^3) was collected by the grinder in the laboratory area.
  - The other 33 area air samples were below the LOD which ranged from 18.0 μg/m^3 to 41.8 μg/m^3. Note that air sampling LODs vary due to differing air sample durations and sampled air volumes.
- All area samples for respirable crystalline silica (cristobalite, quartz, and tridymite) were below their respective LODs except for one sample collected in treatment room 223 which measured 6.2 μg/m^3 respirable quartz. NIOSH considers respirable crystalline silica a potential occupational carcinogen, and exposures should be reduced to the greatest extent feasible.
- All 36 area samples analyzed for respirable metals were below their respective NIOSH RELs.

- Iron (49.0 µg/m³) had the highest measurement of any metal analyzed. This air sample was collected in the hallway outside the laboratory and was below the NIOSH REL of 5,000 µg/m³ (5 mg/m³) for iron oxide dust and fume.
- Zinc (8.5 µg/m³) had the second highest measurement of any metal analyzed. This air sample was also collected in the hallway outside the laboratory and was below the NIOSH REL of 5,000 µg/m³ (5 mg/m³) for zinc.
- Chromium and copper were detected in all or most of the area air samples collected on all days of sampling at the clinic.
    - Chromium was measured in all area samples collected in the clinic (n=36) on all days of sampling, at low concentrations (0.05–0.22 µg/m³). All samples were below the NIOSH REL for chromium metal of 500 µg/m³.
    - Copper was measured in 69% of samples (n=25/36 total samples collected in the clinic), also at low concentrations (<0.03–0.11 µg/m³). All samples were below the NIOSH REL for copper of 1,000 µg/m³.
- Nickel was detected in one sample (0.13 µg/m³) in treatment room 221 and was below the NIOSH REL of 15 µg/m³ for nickel. NIOSH considers nickel metal dust to be a potential occupational carcinogen, and exposures should be reduced to the greatest extent feasible. Exposure to nickel can also cause sensitization dermatitis/allergic contact dermatitis, allergic asthma, and pneumonitis.

Some VOCs were higher in some locations or during specific tasks and procedures. Ethanol and isopropyl alcohol were the highest measurements collected during full-shift area sampling and during task or source sampling and were likely due to cleaning and disinfecting tasks.

- All area air samples for full-shift area air measurements of VOCs were relatively low.
    - The highest full-shift area measurements among any VOCs analyzed were measurements for ethanol, isopropyl alcohol, and acetone.
        - Ethanol ranged from 110 parts per billions (ppb) to 1,200 ppb. All samples were below the NIOSH REL of 1,000,000 ppb ethanol.
        - Isopropyl alcohol ranged from 110 ppb to 5,300 ppb. All samples were below the NIOSH REL of 400,000 ppb isopropyl alcohol.
        - Acetone ranged from 6.8 ppb to 44 ppb. All samples were below the NIOSH REL of 250,000 ppb acetone.
    - Other notable VOCs measured included toluene and methylene chloride.
        - Toluene ranged from <0.9 ppb to 2.8 ppb. All samples were below the NIOSH REL of 100 ppm (100,000 ppb) for toluene.
        - Methylene chloride ranged from <0.9 ppb to 2.1 ppb. All samples were below the OSHA PEL of 25 ppm (25,000 ppb) for methylene chloride. Methylene chloride is considered an occupational carcinogen by NIOSH, and exposures should be reduced to the greatest extent feasible.

- Instantaneous task-based canister air samples collected near the breathing zone of employees while they performed tasks in the laboratory measured multiple VOCs. Notable measurements collected near the breathing zone of employees included:
    - The highest instantaneous measurements were ethanol (570 ppb) and isopropyl alcohol (570 ppb). These were collected in the laboratory while grinding a mouthguard without LEV.
    - Other notable VOCs included benzene and methylene chloride. Benzene (1.3 ppb) was measured while trimming a retainer with a soldering iron while using LEV. Methylene chloride was measured while (1) grinding a mouthguard with a handheld grinder without LEV (0.35 ppb) and (2) molding a mouthguard while using the round heater without LEV (0.41 ppb).
    - Although measurements for benzene and methylene chloride were low, their detection is notable because both benzene and methylene chloride are considered potential occupational carcinogens by NIOSH and exposures should be reduced to the lowest feasible concentrations greatest extent feasible.
- Instantaneous canister samples collected near sources while employees performed various tasks in the laboratory also measured multiple VOCs. Notable measurements collected near sources included:
    - The highest instantaneous measurements collected near sources were also measurements of isopropyl alcohol (1,500 ppb), ethanol (790 ppb), and acetone (460 ppb).
        - The highest measurement of 1,500 ppb isopropyl alcohol was collected near an Essix retainer while it was being trimmed with the soft tray trimmer without LEV. When the same task was performed while LEV was used, the source measurements for isopropyl alcohol were reduced to 600 ppb.
        - The elevated ethanol (790 ppb) and acetone (460 ppb) measurements were collected near an acrylic mouth guard while it was being trimmed using a soldering iron while using LEV.
    - Other elevated instantaneous measurements collected near sources were measurements of benzene (120 ppb) and *m,p*-xylene (140 ppb) which were measured near a retainer while it was trimmed with a soft tray trimmer without LEV. Toluene (60 ppb) and methylene chloride (0.37 ppb) were also measured near the retainer while it was trimmed without LEV.
        - When the same task was performed with LEV, benzene was reduced to 3.3. ppb, *m,p*-xylene to 2 ppb; toluene to 1.7 ppb, and methylene chloride was reduced to levels below the LOD.
        - Benzene and methylene chloride are considered potential occupational carcinogens by NIOSH, and exposures should be reduced to the greatest extent feasible.

Treatment rooms (dental operatories) and staff offices did not receive adequate outdoor air from existing mechanical ventilation systems, and the clinic was unable to maintain temperatures in the clinic recommended by ASHRAE.

- The dental reception/waiting area, panoramic room, dental laboratory, sterilization area, and dental supply room were served by a central air handling unit in the attic of the building. These spaces generally received adequate outdoor air according to the ASHRAE standards.
- The dental treatment rooms and staff offices were heated and cooled with packaged terminal air conditioning units through the walls. Additional cooling was provided with supplemental window air conditioning units in some spaces. These systems brought in little to no outdoor air into the spaces, and these spaces did not meet ASHRAE requirements for outdoor air.
- Temperatures in the clinic that exceeded 75°F during our visit indicated that the existing ventilation system serving these areas was not able to maintain recommended temperatures by ASHRAE.

LEV controls in the laboratory were not consistently used. When no LEV was used, higher levels of air contaminants were measured in the laboratory and adjacent hallway.

- Two forms of LEV were available in the laboratory:
    - A LEV tray located below the soldering iron and soft tray trimmer that could be turned on manually by employees, and
    - A downdraft table that operated automatically whenever the benchtop grinder was used.
- We observed that the LEV tray located below the soldering iron and soft tray trimmer was not used every time either of these tools were used.
- Measurements collected in the laboratory area by direct-reading instruments indicated that respirable aerosol reached peaks almost two- to six-fold higher when a retainer grinding task was performed without LEV versus when performed with the LEV turned on.
- Peak respirable aerosol measured by direct-reading instruments in the laboratory were observed immediately afterward (minutes afterward) by direct-reading instruments in the hallway just outside the laboratory, indicating that (1) respirable aerosol generated in the laboratory migrated into the adjacent hallway and (2) the laboratory was not maintained under negative pressure relative to adjacent spaces. Measurements were higher for tasks performed without LEV when compared to measurements collected during the same tasks performed while using LEV.
- As noted above, the highest measurements of benzene, *m,p*-xylene, toluene, and methylene chloride were measured near an Essix retainer while it was trimmed without LEV. These VOCs were greatly reduced when the same task was performed while using the LEV tray located beneath the soft tray trimmer in the laboratory.

Respirable aerosol generated in the laboratory migrated to adjacent areas.

- Real-time measurements of respirable aerosol in the laboratory area and adjacent hallway outside the laboratory indicated that respirable aerosol generated in the laboratory migrated into adjacent spaces.
- As described above, peak respirable aerosol measured by direct-reading instruments in the laboratory area were observed immediately afterward in the hallway just outside the laboratory, indicating that respirable aerosol generated in the laboratory migrated into adjacent areas.
- Although no air sampling results exceeded any occupational exposure limits, migration of respirable aerosol from the laboratory to the hallway indicates that contaminants generated in the laboratory area could migrate into adjacent areas in the future.

Employees reported no work-related symptoms.

- Of seven clinic staff who were informally interviewed, all reported working five days and 40 hours per week, and none reported any work-related health symptoms.

To learn more about our results, go to Section B in the Supporting Technical Information

Our Recommendations

The Occupational Safety and Health Act requires employers to provide a safe workplace.

Potential Benefits of Improving Workplace Health and Safety:	
↑ Improved worker health and well-being	↑ Enhanced image and reputation
↑ Better workplace morale	↑ Superior products, processes, and services
↑ Easier employee recruiting and retention	↑ May increase overall cost savings

The recommendations below are based on the findings of our evaluation. For each recommendation, we list a series of actions you can take to address the issue at your workplace. The actions at the beginning of each list are preferable to the ones listed later. The list order is based on a well-accepted approach called the "hierarchy of controls." The hierarchy of controls 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 (PPE) might be needed. Read more about the hierarchy of controls here: https://www.cdc.gov/niosh/topics/hierarchy/

We encourage the company to use a health and safety committee to discuss our recommendations and develop an action plan. Both employee representatives and management representatives should be included on the committee. Helpful guidance can be found in "Recommended Practices for Safety and Health Programs": https://www.osha.gov/shpguidelines/index.html

Recommendation 1: Reduce risk of entrainment of air from the laboratory into adjacent spaces

Why? The relationship between supply air and exhaust air flow rates can be used to help maintain appropriate pressure relationships. If more air is supplied than exhausted, the space will generally be under positive pressure, which allows contaminants to migrate from the space to adjacent areas under lower pressures. Conversely, exhausting more air than is supplied, maintains the space under negative pressure which helps contain the contaminants in the area where they are generated. The laboratory space was under positive pressure relative to adjacent spaces and can serve as a source of contaminants that are spread beyond the laboratory. We observed aerosols generated in the laboratory were entrained into adjacent spaces.

How? At your workplace, we recommend these specific actions:

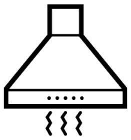
Ensure the laboratory area is maintained under negative pressure relative to adjacent areas.

- Ensure the downdraft table by the benchtop grinder is on when using the benchtop grinder.
- Close the door to the laboratory on days when the laboratory is used.
- Consult with a ventilation engineer to rebalance the air flow rates into and from the laboratory space to ensure the laboratory is maintained under negative pressure relative to the adjacent spaces. Possible options to increase air return to the HVAC system or exhaust from the laboratory area include utilizing a capture hood in the laboratory area to capture and remove contaminants before they can be entrained into the laboratory air and neighboring spaces. If installed, the capture hood should be operated continuously during clinic hours to increase the air exhausted from the laboratory space.
- Review *ANSI/ASHRAE/ASHE Standard 170-2021, Ventilation of Health Care Facilities* which has ventilation design parameters for healthcare facilities, including dental spaces. General laboratory work areas, like those in dental clinics, should be ventilated at a minimum of six total air changes per hour with at least two of those air changes being filtered outdoor air. Laboratory areas should also be maintained under negative pressure relative to adjacent spaces and be maintained between 70°F and 75°F.

Recommendation 2: Encourage employees to utilize local exhaust ventilation (LEV) controls in the laboratory area during grinding, trimming, or soldering tasks

Why? Respirable aerosol generated during grinding or soldering tasks in the laboratory area was much higher when the LEV tray below the soldering iron and soft tray trimmer was not used. Further, peaks of respirable aerosol generated in the laboratory were detected in the hallway outside the laboratory, indicating that uncontrolled respirable aerosol migrated into adjacent spaces.

How? At your workplace, we recommend these specific actions:



Utilize LEV controls in the laboratory when grinding, trimming, or soldering tasks are performed.

- Turn on LEV controls whenever performing grinding, trimming, or soldering tasks. For example, employees should turn on the LEV tray located beneath the table equipped with the soldering iron and soft tray trimmer when performing grinding, trimming, or soldering tasks.
- Ensure the downdraft table by the benchtop grinder is on every time the benchtop grinder is used.
- Additionally, if a capture hood is installed in the laboratory, ensure that at minimum, it is turned on while employees perform grinding, trimming, or soldering tasks. Ideally, the capture hood should be operated continuously during clinic hours to increase air exhausted from the laboratory space.

Recommendation 3: Consider using LEV controls such as high-volume evacuation (HVE) and voluntarily using N95®[1] filtering facepiece respirators (or other air-purifying particulate respirators) when performing dental procedures with nickel or silica (e.g., restorative procedures)

Why? Exposure to nickel can cause sensitization dermatitis/allergic contact dermatitis, allergic asthma, pneumonitis, and lung cancer. Additionally, exposure to crystalline silica can cause cough, difficulty breathing, wheezing, decreased pulmonary function, progressive respiratory symptoms (silicosis), eye irritation, and lung cancer. We observed one area sample that contained respirable nickel and one area sample that contained respirable crystalline silica in a dental treatment room. Although these were area samples and cannot be directly compared to occupational exposure limits, area samples can indicate areas or processes with higher potential exposure. Levels of nickel and crystalline silica were below their respective occupational exposure limits and additional respiratory protection is not required by OSHA. However, because nickel and crystalline silica are designated as potential occupational carcinogens by NIOSH, exposures should be reduced to the greatest extent feasible. Exposures can be reduced by utilizing LEV controls (e.g., HVE) and PPE (e.g., N95 filtering facepiece or other air-purifying particulate respirators) when performing dental procedures with nickel or crystalline silica.

How? At your workplace, we recommend these specific actions:

Make HVE and NIOSH-approved N95 filtering facepiece respirators available to employees when performing dental procedures with nickel or crystalline silica (e.g., restorative procedures). Nickel is found in some

[1] N95 is a certification mark of the U.S. Department of Health and Human Services (HHS) registered in the United States and several international jurisdictions.

metal alloys, and crystalline silica is found in some composite, glass ionomer, or porcelain restoratives.

- Ensure restorative procedures with nickel or crystalline silica are performed in treatment rooms equipped with HVE.
- Consider the use of HVE during restorative procedures performed with nickel and crystalline silica to capture and remove respirable dusts containing nickel and crystalline silica.
- Support employees who choose to voluntarily use N95 filtering facepiece or other air-purifying particulate respirators during restorative procedures with nickel and crystalline silica with training on proper use of respiratory protection (additional details on voluntary use and respiratory protection training shared in recommendation 5, further below).

Recommendation 4: Improve ventilation so that all areas receive adequate outdoor air and maintain appropriate temperatures and comfortable humidity levels

Why? The existing air handling unit (AHU) in the dental clinic provided outdoor air to all areas except the treatment rooms (dental operatories) and offices. The dental treatment rooms and offices did not receive adequate outdoor air. An adequate supply of outdoor air, typically delivered through the HVAC system, is necessary in any indoor environment to dilute pollutants that are released by equipment, building materials, furnishings, products, and people.

How? At your workplace, we recommend these specific actions:

Improve ventilation to the dental treatment rooms and staff offices.

- Consult with a ventilation engineer to implement a ventilation system that supplies outdoor air to the dental treatment rooms, laboratory, and staff offices in accordance with the ventilation design parameters specified in *ANSI/ASHRAE/ASHE Standard 170-2021, Ventilation of Health Care Facilities* and *Ventilation for Acceptable Indoor Air Quality*.
  - Tables 7.1, 8.1 and 9.1 in the ANSI/ASHRAE/ASHE Standard 170-2021, *Ventilation of Health Care Facilities*, provide minimum air exchange rate, temperature, and relative humidity guidelines for health care settings, including dental treatment rooms. For instance,
    - Treatment rooms should be ventilated with at least three total ACH and at least two of those air changes should be from filtered outdoor air (Table 9-1).
    - Refer to Tables 7-1, 8-1, 8-2 and 9-1 in Standard 170-2021 for ventilation design parameters for other applicable spaces, including support and service areas.

- Guidelines for areas that are not specified in ANSI/ASHRAE/ASHE 170-2021, *Ventilation of Health Care Facilities,* should be obtained from *ANSI/ASHRAE Standard 62.1-2022, Ventilation for Acceptable Indoor Air Quality*. ANSI/ASHRAE Standard 62.1-2022 recommends outdoor air supply rates that take into account people-related sources as well as building-related sources of contaminants.
    - For office spaces and conference rooms, five cubic feet per minute of outdoor air per person (cfm/person) is recommended for people-related sources, and an additional 0.06 cfm for every square foot (cfm/ft^2) of occupied space is recommended to account for building-related sources.
- When areas of the facility have recommended rates in both Standard 170-2021 and Standard 62.1, the higher of the two air exchange rates should be used.

Recommendation 5: Make NIOSH-approved N95 filtering facepiece respirators (or other air-purifying particulate respirators) available for voluntary use and train employees on proper use of respiratory protection

Why? We observed some employees using surgical masks. Surgical masks are not respirators and do not protect the wearer from inhaling small particles, gases, or vapors. Surgical masks are designed for potential exposures to blood and body fluids but do not offer protection against particle, gas, or vapor exposures in the air. Additionally, they are not designed to eliminate air leakage around the edges. Because all measurements for dusts and particles were below established exposure limits, respiratory protection is not required by OSHA. However, we do not currently know what exposures could be contributing to IPF among dentists, and this is an ongoing area of research at NIOSH. Few studies have identified specific exposures relevant to dental settings that are associated with IPF. One previous study observed an association between respirable dust exposure and IPF (described further in the discussion section of this report). If employees desire to voluntarily use respiratory protection that also provide protection against particles (including potential occupational carcinogens like nickel or crystalline silica) during particle generating procedures (e.g., drilling, grinding, and polishing), they should use N95 disposable filtering facepiece or other air-purifying particulate respirators.

How? At your workplace, we recommend these specific actions:

Make NIOSH-approved N95 disposable filtering facepiece respirators available for voluntary use when performing tasks that can generate particles such as drilling, grinding, or polishing, including restorative procedures.

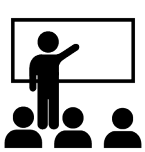
- Provide training to these employees on how to wear N95 respirators correctly.
- Inform employees that N95 respirators do not protect against exposures to gases or vapors.

- Review and share this respirator training tool on how to properly put on and take off a disposable respirator at: http://www.cdc.gov/niosh/docs/2010-133/pdfs/2010-133.pdf.
- Ensure NIOSH-approved N95 respirators are available in various sizes, and each voluntary N95 user receives a copy of Appendix D of the OSHA Respiratory Protection Standard which provides information for employees about using respirators when not required under the standard. Information about Appendix D and voluntary use of respirators can be found on the OSHA website at: https://www.osha.gov/video/respiratory-protection/voluntary-use/transcript.
- Review the NIOSH website on respiratory protection information at https://www.cdc.gov/niosh/npptl/topics/respirators/disp_part/respsource.html.
- Please note that we observed some employees voluntarily using powered air purifying respirators (PAPRs) during some dental procedures. The voluntary use of PAPRs (or elastomeric facepiece respirators) requires a written respiratory protection program in compliance with OSHA 29 CFR 1910.134 to ensure that employees voluntarily using such respirators are medically fit to do so, and the respirators are cleaned, stored, and maintained properly. For more information, please see the following:
    - OSHA interpretation letter dated April 26, 2018 https://www.osha.gov/laws-regs/standardinterpretations/2018-04-26
    - OSHA Small Entity Compliance Guide for the Respiratory Protection Standard https://www.osha.gov/sites/default/files/publications/3384small-entity-for-respiratory-protection-standard-rev.pdf
    - NISOH/OSHA Hospital Respiratory Program Toolkit – Resources for Program Administrators https://www.cdc.gov/niosh/docs/2015-117/pdfs/2015-117revised042022.pdf?id=10.26616/NIOSHPUB2015117

Recommendation 6: Ensure employees understand the hazards associated with working in a dental clinic and how to protect themselves

Why? OSHA's Hazard Communication Standard, also known as the "Right to Know Law" (29 CFR 19.10.1200), requires that employees are informed and trained on potential work hazards and associated safe practices, procedures, and protective measures.

How? At your workplace, we recommend these specific actions:



Train employees and volunteers on potential workplace hazards, what precautions they should take to protect themselves, and workplace policies for reporting their concerns.

Recommendation 7: Encourage employees to report any new, persistent, or worsening respiratory symptoms, particularly those with a work-related pattern, to their healthcare providers and, as instructed by their employer, to a designated individual at their workplace.

> Why? Early recognition of work-related respiratory symptoms can help identify potential occupational exposures and risk factors for disease and help prioritize interventions to prevent work-related lung disease in employees. Work-related symptoms are symptoms that typically improve on days away from work or on vacation. An individualized management plan (such as assigning an affected employee to a different work location, perhaps at home or a remote site) is sometimes required, depending upon medical findings and recommendations of the individual's healthcare provider.

Supporting Technical Information

Evaluation of Exposures and Health Concerns in a Dental Clinic

HHE Report No. 2019-0232-3394

March 2024

Section A: Workplace Information

Workplace

Request basis: Assessment of air quality in clinic and exposures potentially contributing to idiopathic pulmonary fibrosis (IPF). Concern for exposures potentially contributing to IPF arose after reading a Morbidity and Mortality Weekly Report (MMWR) first reporting IPF in a cluster of dentists in 2018 [Nett et al. 2018].

Previous issues: None.

Employee Information

At the time of our survey, eight staff were onsite, including two dentists, two dental hygienists, three dental assistants, and one administrative staff.

Process Description

At the time of the survey, the dental clinic provided general dentistry care services to patients. The clinic had seven treatment rooms, a sterilization area, laboratory space, four offices, a panoramic room (x-ray), break room, administrative area, patient waiting area, and storage area for supplies. Dental staff performed various procedures to include dental exams, dental cleanings, taking impressions, restorative procedures, and laboratory tasks.

Section B: Methods, Results, and Discussion

We focused on these objectives:

- Observe work practices and personal protective equipment (PPE) use.
- Assess potential for exposure to respirable dust and respirable crystalline silica among dental personnel in the clinic.
- Evaluate air concentrations of respirable dust, respirable crystalline silica, respirable metals, and volatile organic compounds (VOCs) in clinic workspaces.
- Evaluate VOC exposures during laboratory tasks.
- Assess general exhaust ventilation in the clinic.
- Informally interview employees about their work history, personal protective equipment use, and any work-related symptoms.

Methods: Observations of Workplace and PPE

We observed the workplace while employees performed their job duties and noted use of PPE.

Results: Observation of Work Practices and PPE

Facility Layout

The dental clinic was operating in a two-story building at the time of our survey. The first story of the building was a medical clinic. The dental clinic was located on the second floor and included seven treatment rooms, a sterilization area, laboratory space, four offices, break room, administrative area, patient waiting area, and panoramic room used to take x-rays. The treatment rooms were open to a main hallway that connected to other spaces including the laboratory space, sterilization area, panoramic room, administrative area, patient waiting area, and offices. The administrative area was confluent with the patient waiting area. The employee break room was accessible just off the administrative area.

Personal Protective Equipment

We observed employees using surgical masks and gloves. Some employees used powered air-purifying respirators during some dental procedures.

Methods: Exposure Assessment

Dental personnel can be exposed to various agents such as chemicals, dusts, bio-aerosols, silica, and metals as part of their normal work duties. During this health hazard evaluation, we focused our exposure assessment on respirable dust, respirable crystalline silica, respirable metals, and VOCs.

During August 9–11, 2022, we conducted an exposure assessment survey which consisted of

(1) collecting personal air samples for respirable dust and respirable crystalline silica;

(2) collecting area air samples for respirable dust, respirable crystalline silica, respirable metals, and VOCs in areas throughout the clinic;

(3) collecting instantaneous air samples for VOCs near employees, sources, or in the laboratory area while employees performed routine tasks; and

(4) collecting real-time measurements of respirable aerosol in the areas in and just outside of the laboratory.

We collected full-shift time-weighted average (TWA) personal air samples for respirable dust and respirable silica on each day of our survey.

- We positioned the sampling respirable cyclone (SKC Aluminum Cyclone, SKC Inc., Eighty Four, PA) and attached filter cassette in the employee's breathing zone. A tube was connected to the cyclone and a sampling pump pulled air at a flow rate of 2.5 liters per minute (L/min).
- We collected and analyzed samples in accordance with NIOSH method 0600 for dust [NIOSH 1998] and NIOSH method 7500 for crystalline silica [NIOSH 2003a].

We also collected area air samples in 12 locations to include treatment rooms, the laboratory area, the hallway outside the laboratory, equipment sterilization area, offices, and the break room on each day of our survey. Area air samples were collected using multiple sampling devices to sample for respirable dust, respirable crystalline silica, respirable metals, and VOCs.

- We collected full-shift TWA area samples for respirable dust and respirable crystalline silica using a BGI respirable cyclone GK2.69, in all areas except the laboratory. The samples were analyzed in accordance with NIOSH method 0600 for dust [NIOSH 1998] and NIOSH method 7500 for crystalline silica [NIOSH 2003a].
- We collected full-shift TWA area samples for respirable dust and respirable crystalline silica in the laboratory and hallways just outside the laboratory with personal DataRams (pDR 1500, Thermo Scientific, Franklin, MA). The pDR 1500s were equipped with a cyclone that allowed respirable dust to be sampled and measured when operated at 2.65 L/min. The pDRs were also equipped with a filter that was used to assess full-shift TWA area concentrations of respirable dust and respirable crystalline silica in accordance with NIOSH method 0600 for dust [NIOSH 1998] and NIOSH method 7500 for crystalline silica [NIOSH 2003a].
- We used direct-reading instruments (pDR 1500s) to measure and record respirable aerosol measurements every 10 seconds in the laboratory area and the hallway just outside the laboratory. We graphed the respirable aerosol measurements recorded by the pDR 1500s with time as the x-axis and concentrations of respirable aerosol in $\mu g/m^3$ as the y-axis; this was used to note when peaks of respirable aerosol exposures occurred. We also noted when tasks were performed in the laboratory, and these notes were used to identify sources or tasks associated with peak respirable aerosol exposures in the laboratory and hallway outside the laboratory.

- We collected full-shift TWA area samples for respirable metals using a BGI respirable cyclone GK2.69. The samples were analyzed in accordance with NIOSH method 7303 [NIOSH 2003b]. Each respirable cyclone GK2.69 was connected to a sampling pump that pulled air through the cyclone at 4.2 liters per minute.
- We collected full-shift TWA area samples for VOCs in all 12 locations using evacuated canisters. The evacuated canister sampling setup consisted of a 450-milliliter (mL) evacuated canister equipped with a restricted flow controller set at an 8-hour sampling duration. The full-shift TWAs area samples were analyzed in accordance with NIOSH method 3900 using a gas chromatograph-mass spectrometer equipped with a pre-concentrator [NIOSH 2018].
- We also used evacuated canisters to collect instantaneous task-based, source, or area air samples for VOCs in the laboratory. We used 450-mL evacuated canisters equipped with an instantaneous flow controllers designed for a short sampling duration (less than 30 seconds) to collect instantaneous samples near the breathing zone of employees during a specific task (instantaneous task-based), at the source of an exposure during a specific task (instantaneous source), or in the general laboratory area (instantaneous area). The instantaneous samples collected using the evacuated canisters were analyzed in accordance with NIOSH method 3900 [NIOSH 2018].

Results: Exposure Assessment

Personal Air Samples

Personal air sampling for respirable dust

A summary of personal air sampling results for respirable dust can be seen in Table C1a. All personal full-shift samples were below the LOD, which was well below the OSHA PEL of 5,000 μg/m³ and the ACGIH recommended level of 3,000 μg/m³ for respirable dust [OSHA 2021, 2023; ACGIH 2023]. Concentrations ranged from less than 41.9 μg/m³ to less than 71.9 μg/m³. One personal sample had a pump failure at 68 minutes, and it was also below the LOD (<235.5 μg/m³). This sample was not considered a full-shift sample due to its shorter sampling period.

Personal air sampling for respirable crystalline silica

A summary of personal air sampling results for respirable crystalline silica (cristobalite, quartz, and tridymite) can be seen in Table C1b. All samples were below the LOD and below the NIOSH recommended exposure limit (REL) of 50 μg/m³ for respirable crystalline silica [NIOSH 2019a]. Concentrations ranged from less than 5.2 μg/m³ to <9.0 μg/m³ cristobalite, <5.2 μg/m³ to <9.0 μg/m³ quartz, and <10.5 μg/m³ to <18.0 μg/m³ tridymite. One personal sample had a pump failure at 68 minutes, and it was also below the LODs for each silica analyte (<29.4 μg/m³ cristobalite, <29.4 μg/m³ quartz, and <58.9 μg/m³ tridymite). We note that this sample was not considered a full-shift sample due to its shorter sampling period.

Area Air Samples

We note that because area air samples are not personal air samples collected directly on an employee, the NIOSH RELs are not directly applicable to the results for exposure monitoring purposes. However, area air samples can highlight areas with higher exposure risk, and the occupational exposure limits (OELs) can be used as points of reference. Below, we provide comparisons with NIOSH RELs or other OELs as a point of reference when sharing area air sampling results.

Area air sampling for respirable dust and respirable silica

A summary of area air sampling results for respirable dust and respirable crystalline silica can be seen in Tables C2a and C2b. Three area air samples had measurable respirable dust: two air samples (22.0 $\mu g/m^3$ and 41.8 $\mu g/m^3$) collected in treatment room 232A and one air sample (21.7 $\mu g/m^3$) collected in the laboratory area by the grinder. All other area samples were below the LOD (the LODs for samples ranged from 18.0 $\mu g/m^3$ to 41.8 $\mu g/m^3$). Please note that air sampling LODs can vary due to differing air sample durations and sampled air volumes. All three measurable samples were well below the OSHA PEL of 5,000 $\mu g/m^3$ and the ACGIH recommended level of 3,000 $\mu g/m^3$ for respirable dust [OSHA 2021, 2023a; ACGIH 2023]. The two detectable respirable dust samples were collected in treatment room 232A where dental cleaning (hygiene) procedures were performed. Multiple procedures were performed in the laboratory while the one detectable respirable dust sample was collected, including retainer trimming with the soldering iron, molding retainers with the square heater, using the handheld grinder to grind a mouthguard, molding mouthguards with the round heater, and using the handheld grinder to grind a retainer.

All samples for respirable crystalline silica (cristobalite, quartz, and tridymite) were below their respective LODs, except for one sample collected in treatment room 223, which measured 6.2 $\mu g/m^3$ respirable quartz (Table C2b). Procedures performed in treatment room 223 while the sample was collected included restorative procedures (one filling procedure was performed). The one measurable sample was well below the OSHA PEL and NIOSH REL for respirable crystalline silica of 50 $\mu g/m^3$ [OSHA 2021; NIOSH 2019a]. We note that NIOSH considers respirable crystalline silica a potential occupational carcinogen and exposures should be reduced to the lowest feasible concentration whenever possible [NIOSH 2019a].

Area air sampling for respirable metals

A summary of area air sampling results for respirable metals can be seen in Table C3. All samples analyzed for respirable metals were below their respective NIOSH RELs. The highest measurement of any metal analyzed was for iron (49.0 $\mu g/m^3$). Zinc (8.5 $\mu g/m^3$) had the second highest measurement of any metal analyzed (Table C3). The air sample containing these measurements of iron and zinc was collected in the hallway outside the laboratory and was below the NIOSH REL of 5,000 $\mu g/m^3$ for iron oxide dust and fume and the NIOSH REL of 5,000 $\mu g/m^3$ for zinc oxide [NIOSH 2019b]. We note that measurements of iron and zinc in the adjacent spaces (in the laboratory and panoramic office) were lower (all were below the LOD for iron and zinc), precluding our ability to identify procedures or processes that could have contributed to highest measurements for iron and zinc measurements in the hallway outside the laboratory.

Chromium and copper were detected in a majority of air samples collected at the clinic (Table C3). Chromium was measured at low concentrations (0.05–0.22 μg/m^3) in all 36 samples collected in the clinic. All samples were well below the NIOSH REL of 500 μg/m^3 for chromium metal [NIOSH 2019c]. Copper was measured in 69% of samples collected (n=25/36 samples), also at low concentrations (<0.03–0.11 μg/m^3). All samples were below the NIOSH REL of 1,000 μg/m^3 for copper [NIOSH 2019d].

Nickel was detected in one air sample (0.13 μg/m^3) collected in treatment room 221. This sample was well below the NIOSH REL for nickel of 15 μg/m^3 [NIOSH 2019e]. However, nickel is considered a potential occupational carcinogen by NIOSH and exposures should be limited to the lowest feasible concentration [NIOSH 2019e]. Exposure to nickel can also cause sensitization dermatitis/allergic contact dermatitis, allergic asthma, and pneumonitis [NIOSH 2019e].

Area air sampling for volatile organic compounds (VOCs)

A summary of full-shift area air sampling results for VOCs can be seen in Table C4. All samples for full-shift area measurements of VOCs were relatively low (Table C4). The highest measurements for the VOCs analyzed were measurements for ethanol, isopropyl alcohol, and acetone. Full-shift results for ethanol from all areas sampled ranged from 110 parts per billion (ppb) to 1,200 ppb ethanol and were all well below the NIOSH REL of 1,000,000 ppb ethanol [NIOSH 2019f]. Full-shift results for isopropyl alcohol samples from all areas sampled ranged from 110 ppb to 5,300 ppb isopropyl alcohol and were all well below the NIOSH REL of 400,000 ppb isopropyl alcohol [NIOSH 2019g]. Full-shift results for acetone from all areas sampled ranged from 6.8 ppb to 44 ppb acetone and were all well below the NIOSH REL of 250,000 ppb acetone [NIOSH 2019h].

Toluene and methylene chloride were other notable VOCs measured in the full-shift canisters (Table C4). Full-shift results from all areas sampled measured toluene levels ranging from <0.9 ppb to 2.8 ppb and methylene chloride levels ranging from <0.9 ppb to 2.1 ppb. As a point of reference, the NIOSH REL is 100 ppm (100,000 ppb) for toluene, and the OSHA PEL is 25 ppm (25,000 ppb) for methylene chloride; all samples were well below their respective NIOSH REL or OSHA PEL [NIOSH 2019i; OSHA 2021]. We note that methylene chloride is considered a potential occupational carcinogen by NIOSH and exposures should be limited to the lowest feasible concentration [NIOSH 2019j, OSHA 2023b].

A summary of instantaneous task-based air sampling results for VOCs can be seen in Table C5. We collected six instantaneous canister samples near the breathing zone of an employee while they performed tasks in the laboratory. The tasks included (1) mouthguard grinding with no LEV, (2) retainer grinding while using LEV, (3) retainer molding on the square heater without LEV, (4) retainer trimming with the soldering iron while using LEV, (5) mouthguard grinding with the handheld grinder without LEV, and (6) mouthguard molding using the round heater without LEV. Ethanol (570 ppb) and isopropyl alcohol (570 ppb) were the highest instantaneous measurements collected during a task. These were collected in the laboratory while an employee ground a mouthguard without LEV. We note that although these task measurements for ethanol and isopropyl alcohol were the highest instantaneous measurements collected during a task, they were lower than many of the full-shift measurements of ethanol and isopropyl alcohol collected in treatment rooms and the sterilization area in the clinic on the same day the task samples were collected. This suggests that levels of ethanol and isopropyl alcohol elsewhere in the clinic (likely generated from cleaning and disinfecting tasks) were likely contributing to ethanol and isopropyl alcohol levels observed during laboratory tasks, including grinding a mouth guard. Other notable VOCs measured during tasks included benzene and methylene chloride. Benzene was measured at 1.3 ppb while an employee trimmed a retainer with a soldering iron while using LEV. Methylene chloride was measured while an employee (1) ground a mouthguard with a handheld grinder without LEV (0.35 ppb) and (2) molded a mouthguard while using the round heater without LEV (0.41 ppb). Although measurements of benzene and methylene chloride were low, their detection is notable because benzene and methylene chloride are considered potential occupational carcinogens by NIOSH and should be reduced to lowest feasible concentrations [NIOSH 2019k; OSHA 2021b].

A summary of instantaneous source air sampling results for VOCs can be seen in Table C6. We collected three instantaneous canister samples near sources while an employee performed the following tasks: (1) Essix retainer trimming with the soft tray trimmer without LEV, (2) Essix retainer trimming with the soft tray trimmer while using LEV, and (3) acrylic mouthguard trimming with the soldering iron while using LEV (Table C6). The highest instantaneous measurements collected near sources were also measurements of isopropyl alcohol (1,500 ppb), ethanol (790 ppb), and acetone (460 ppb). The highest measurement of isopropyl alcohol (1,500 ppb) was collected while an employee trimmed an Essix retainer with the soft tray trimmer without LEV. When the same task was performed with LEV, the isopropyl alcohol measurements were reduced to 600 ppb. The elevated ethanol (790 ppb) and acetone (460 ppb) measurements were collected while an employee trimmed an acrylic mouth guard using a soldering iron and LEV. We note that no samples were collected when the same task was performed without LEV for comparison. We also note again that although these task measurements for ethanol and isopropyl alcohol were the highest instantaneous measurements collected at a source, they were lower than many of the full-shift measurements of ethanol and isopropyl alcohol collected in treatment rooms and the sterilization area in the clinic on the same day the task samples were collected. This suggests that levels of ethanol and isopropyl alcohol elsewhere in the clinic (likely generated from cleaning and disinfecting tasks) were likely contributing to ethanol and isopropyl alcohol levels observed during laboratory tasks, including tasks such as trimming a retainer or trimming a mouth guard.

Other elevated measurements of VOCs collected near sources included benzene (120 ppb) and *m,p*-xylene (140 ppb) which were measured near an Essix retainer while it was trimmed with a soft tray trimmer without LEV. Toluene (60 ppb) and methylene chloride (0.37 ppb) were also measured near the retainer while it was trimmed with a soft tray trimmer and no LEV was used. Levels of these four VOCs were greatly reduced when the same task was performed while using LEV. Benzene was measured at 3.3 ppb; *m,p*-xylene was measured at 2.0 ppb; toluene was measured at 1.7 ppb, and methylene chloride was below the LOD when the same retainer trimming task was performed with LEV (Table C6).

One instantaneous canister sample was collected in the middle of the laboratory area after a mouthguard was molded, trimmed, and ground (Table C7). Some notable VOCs measured in the laboratory area shortly after completion of this task included isopropyl alcohol (390 ppb), ethanol (710 ppb), acetone (18 ppb), benzene (0.54 ppb), toluene (1.4 ppb), n-hexane (1.1 ppb), *m,p*-xylene (0.63 ppb), and *o*-xylene (0.56 ppb).

Direct-reading instrument measurements of respirable aerosol in the laboratory and hallway outside the laboratory.

Measurements of respirable aerosol in the laboratory and in the hallway outside the laboratory on each day of the survey can be seen in Figures 1a–3b. On August 9, 2022, we observed multiple peaks of respirable aerosol in the laboratory that coincided with when an employee (1) trimmed a retainer with a soldering iron and no LEV, (2) used the stone grinder to trim a mouthguard without LEV, (3) used a handheld grinder to trim a mouthguard without LEV, and (4) trimmed and ground a retainer while using LEV (Figure 1a). These same four peaks of respirable aerosol were noted in the hallway outside the laboratory (Figure 1b), albeit at lower levels. We observed the highest peak while an employee trimmed a retainer with a soldering iron without LEV (Figure 1a). A similar peak was observed in the hallway outside the laboratory and approached almost one-quarter of the respirable aerosol peak concentration observed in the laboratory (Figures 1a and 1b). Peak respirable aerosol concentrations measured in the laboratory were six-fold lower when LEV was used while trimming and grinding a retainer when compared to when the same task was performed without LEV (Figure 1a).

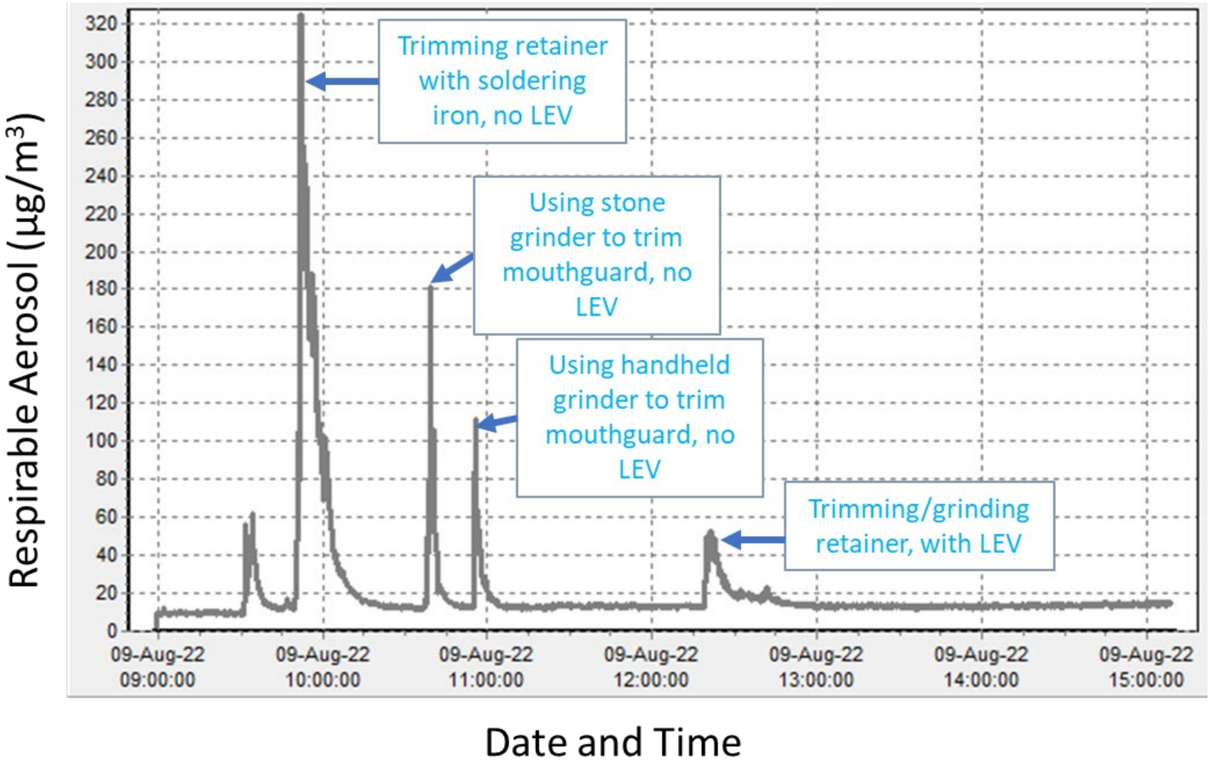


Figure 1a. Respirable aerosol measured in micrograms per cubic meter (μg/m³) near the stone grinder in the laboratory on August 9, 2022. LEV=local exhaust ventilation.

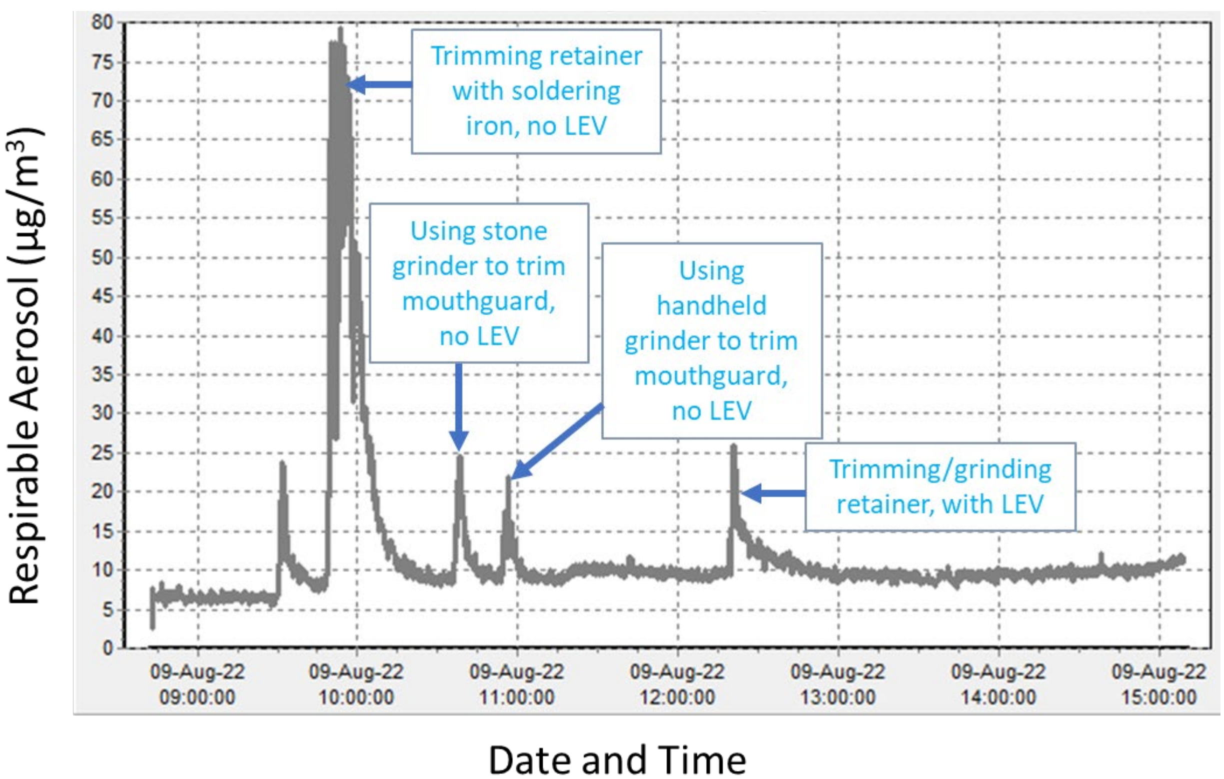


Figure 1b. Respirable aerosol measured in micrograms per cubic meter (μg/m³) in the hallway outside the laboratory on August 9, 2022. LEV=local exhaust ventilation.

On August 10, 2022, we observed multiple peaks of respirable aerosol in the laboratory that coincided with when an employee (1) trimmed and ground a mouthguard with LEV, (2) used a handheld grinder to trim a mouthguard without LEV, (3) molded a mouthguard without LEV, and (4) trimmed a mouthguard with a soldering iron while using LEV (Figure 2a). These same four peaks of respirable aerosol were noted in the hallway outside the laboratory (Figure 2b), albeit at lower levels. The highest peak measurement for respirable aerosol occurred when using a handheld grinder to trim a mouthguard without LEV (Figure 2a). We observed a similar peak in the hallway outside the laboratory that was approximately one-third of the peak observed in the laboratory (Figures 2a and 2b). Peak respirable aerosol concentrations measured in the laboratory were three- to 10-fold lower when trimming mouthguard tasks were performed with LEV compared to when the same task was performed without LEV (Figure 2a).

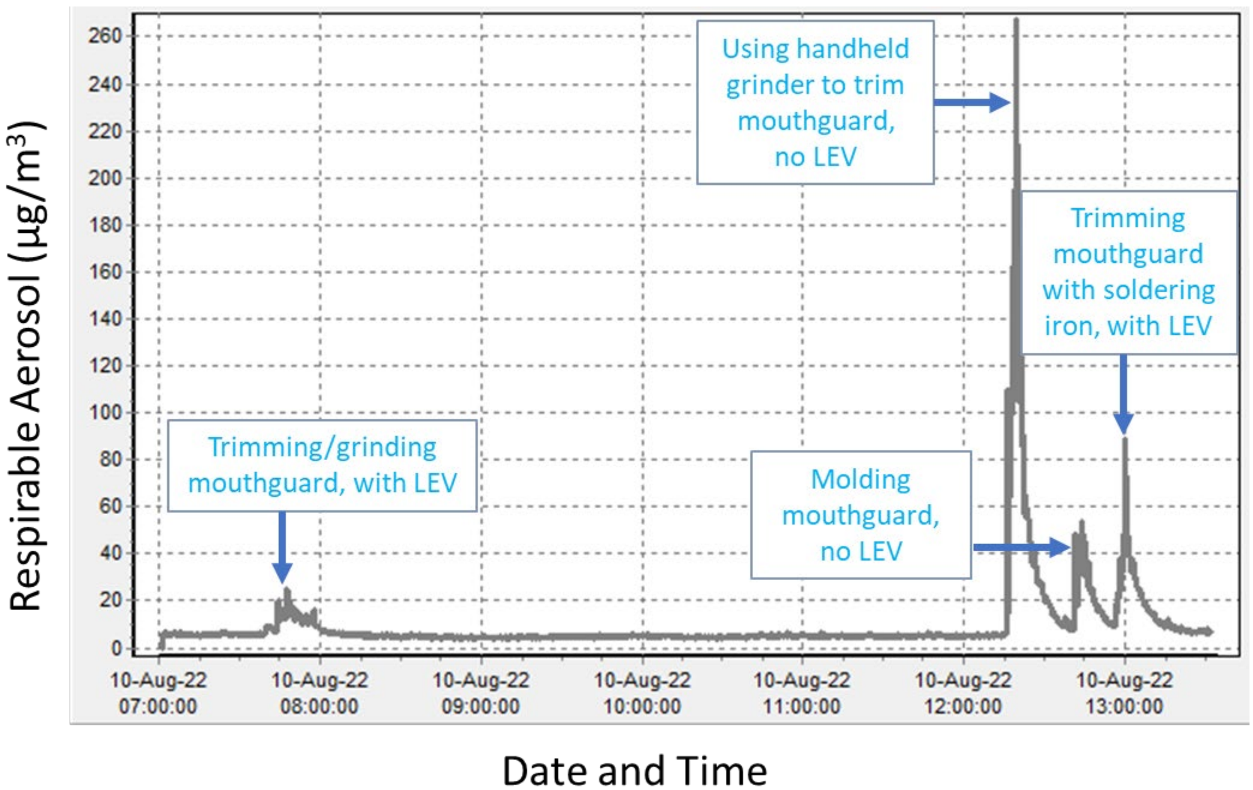


Figure 2a. Respirable aerosol measured in micrograms per cubic meter (µg/m³) near the stone grinder in the laboratory on August 10, 2022. LEV=local exhaust ventilation.

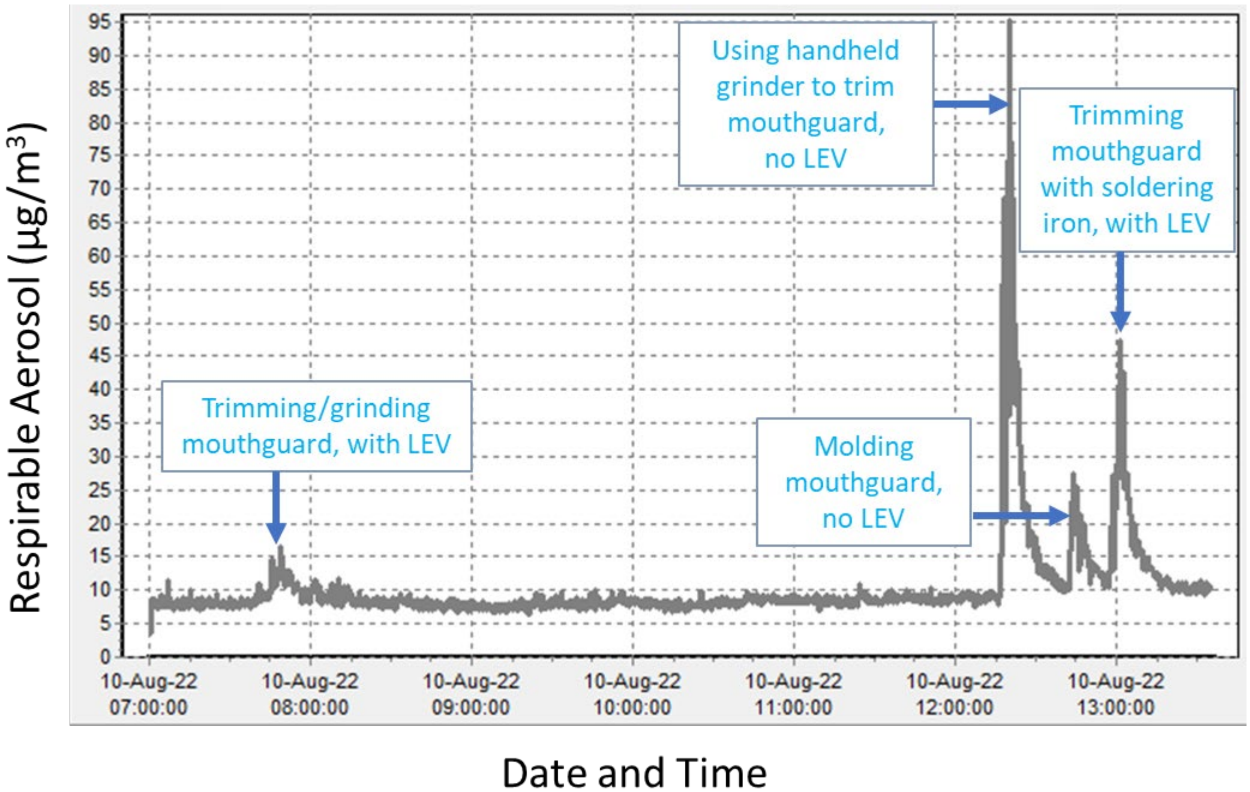


Figure 2b. Respirable aerosol measured in micrograms per cubic meter (µg/m³) in the hallway outside the laboratory on August 10, 2022. LEV=local exhaust ventilation.

On August 11, 2022, we observed multiple peaks of respirable aerosol in the laboratory that coincided with when an employee (1) used a handheld grinder to trim a mouthguard without LEV, (2) used a soldering iron to trim a mouthguard without LEV, (3) used a handheld grinder to trim a mouthguard with LEV, and (4) and ground a mouthguard (LEV use status was undocumented for this task) (Figure 3a). These same four peaks of respirable aerosol were noted in the hallway outside the laboratory (Figure 3b), albeit at lower levels. The highest peak measurement for respirable aerosol occurred when using a handheld grinder and no LEV to trim a mouthguard (Figure 3a). This same highest peak was observed in the hallway outside the laboratory and approached one-third of the peak observed in the laboratory (Figures C3a and C3b). Peak respirable aerosol concentrations measured in the laboratory were 10-fold lower when trimming mouthguard tasks were performed with LEV when compared to when no LEV was used (Figure C3a).

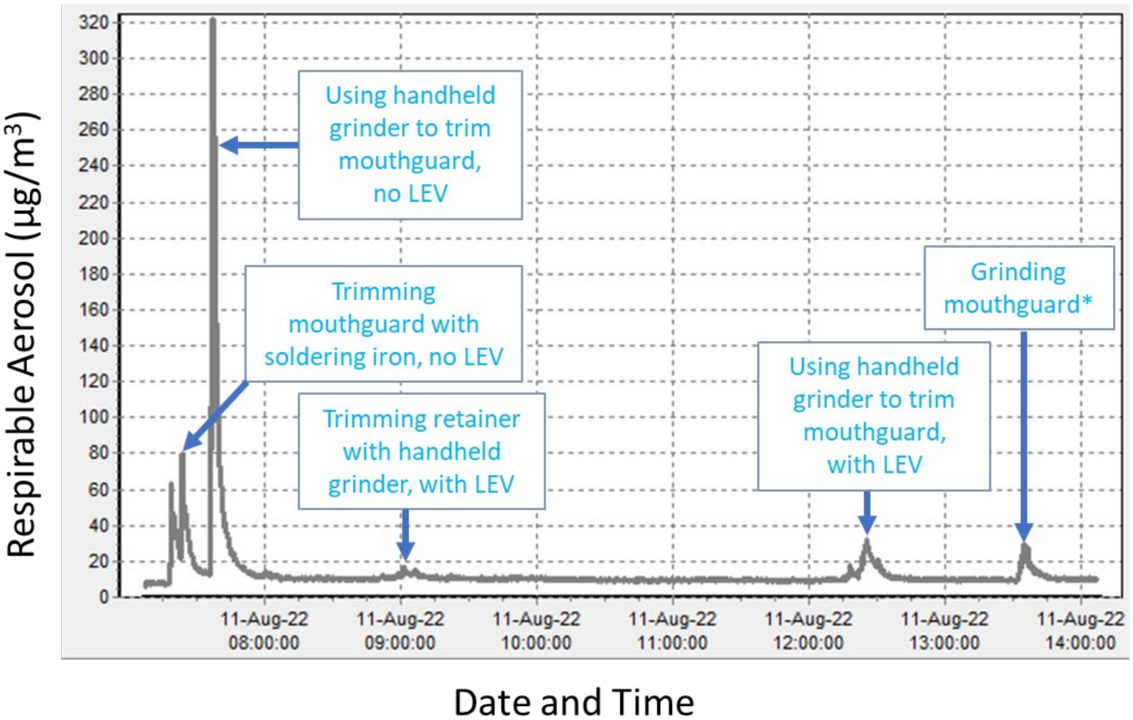


Figure 3a. Respirable aerosol measured in micrograms per cubic meter (μg/m³) near the stone grinder in the laboratory on August 11, 2022. *Indicates where local exhaust ventilation (LEV) was unknown.

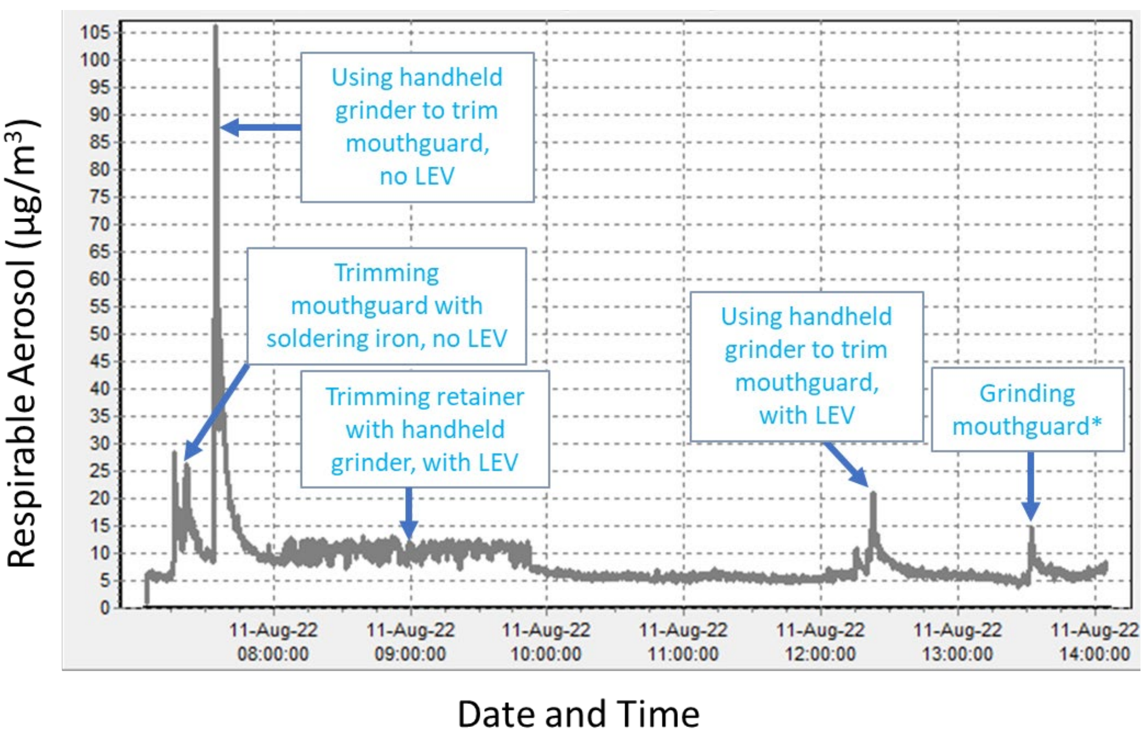


Figure 3b. Respirable aerosol measured in micrograms per cubic meter (μg/m³) in the hallway outside the laboratory on August 11, 2022. *Indicates where local exhaust ventilation (LEV) was unknown.

Methods: Ventilation

We assessed the ventilation systems in place. We conducted visual and physical assessments of all ventilation components at the facility. Physical dimensions of the facility were measured with a Model DISTO E7100i laser-tape measure (Leica Geosystems AG, Heerbrugg, Switzerland). Air flow measurements of supply vents and exhaust outlets were taken using an Accubalance Plus Model 8373 Air Capture Hood (TSI Incorporated, Shoreview, MN).

Results: Ventilation

Ventilation

The dental clinic was served by a central air handling unit (AHU) in the attic of the building. The AHU supplies outdoor air and provides heating only. However, only the dental reception/waiting area (234), panoramic room, dental laboratory (238), sterilization area (229), and dental supply room (240) were served by the system. These spaces generally received adequate outdoor air according to the ASHRAE standards. However, we observed temperatures in the clinic that exceeded 75°F during our visit which indicated that the existing ventilation system serving these areas was not able to maintain recommended temperatures by ASHRAE.

Exhaust from those spaces served by the central AHU was through a dedicated exhaust system that discharged directly outdoors. The exhaust fan was also located in the attic space. This configuration ensured no air recirculation through the AHU, only outdoor air supply and dedicated exhaust.

The dental treatment rooms and staff offices were not served by the central AHU. Instead, they were heated and cooled with packaged terminal air conditioning units (PTAC) units through the walls. Additional cooling was provided with supplemental window air conditioning units in some spaces. These systems brought in little to no outdoor air into the spaces, and these spaces did not meet ASHRAE requirements for outdoor air. Similar to the spaces served by the AHU, the existing ventilation equipment serving these areas was unable to maintain recommended temperatures.

The lack of outdoor air, and the dilution of contaminants it provides, is a potential concern. However, the most important finding from the ventilation assessment was that the laboratory area (238) was under positive pressure relative to adjacent areas. This was because it received more supply air (360 cubic feet per minute, cfm) than air exhausted from the space (190 cfm). Thus, the laboratory could serve as a source of air contaminants to surrounding areas. The positive pressure in the laboratory area could lead to entrainment of air and contaminants from the laboratory area in adjacent areas such as the hallway and adjacent panoramic room and office. The positive pressure differential between the laboratory area and adjacent spaces could cause air and hazardous contaminants from the laboratory to migrate into adjacent spaces in the future.

Methods: Informal Employee Interviews

During August 9–11, 2022, we conducted individual informal interviews in a private setting with seven staff to discuss work history, personal protective equipment worn, and health concerns. We also discussed tasks performed and products used. Most interviews lasted approximately 5–15 minutes.

Results: Informal Employee Interviews

Work History

Seven employees participated in informal employee interviews. All seven employees worked five days and 40 hours per week. Among the seven employees interviewed, six (86%) reported ever working as a dental professional at another facility.

Laboratory Tasks

Employees working in the dental laboratory reported performing three main activities: dental stone casting, molding and trimming/grinding retainers, and molding and trimming/grinding sports mouth guards.

Personal Protective Equipment Worn by Employees

All seven employees interviewed reported wearing scrubs and using eye protection, gloves, and surgical masks. Four employees reported sometimes wearing powered air-purifying respirators (PAPRs) while working with patients; remaining employees reported sometimes wearing N95 or KN95 respirators. Employees working in the laboratory reported wearing surgical masks and eye protection while working in the laboratory.

Work-related Health Symptoms

Interviewed employees reported no work-related symptoms. One employee reported seasonal allergies not associated with work products or tasks, and one employee reported a latex allergy but had not used latex gloves in years. None of the interviewed employees reported respiratory symptoms, and all denied that products caused or worsened any symptoms.

Discussion

Dental personnel can be exposed to various agents such as chemicals, dusts, bio-aerosols, silica, and metals as part of their normal work duties. We focused our exposure assessment on respirable dust, respirable silica, respirable metals, and VOCs. We also observed work practices and assessed the ventilation systems in place as well as the use of PPE. Our observations and results from the exposure assessment are further discussed below.

Work Practices, Processes, and Conditions

We observed employees using surgical masks, eye protection, and gloves. Some employees also wore PAPRs during some dental procedures. We note that surgical masks are designed for potential exposures to blood and body fluids and are not considered respiratory protection because they do not protect against particle, gas, or vapor exposures in the air. Although all measurements for dusts and particles were below established exposure limits, employees may want to voluntarily use respiratory protection, such as NIOSH-approved N95 respirators or PAPRs, that provides protection against particles (including potential occupational carcinogens like nickel or crystalline silica) during particle generating procedures (e.g., drilling, grinding, and polishing).

Exposure Assessment

Personal Air sampling

All full-shift personal air sampling measurements for respirable dust were below their respective LODs, and all LODs were well below their respective NIOSH RELs, OSHA PELs, or ACGIH TLVs. The highest LOD for respirable dust was 71.9 μg/m^3 which is 42-fold lower than the ACGIH recommended level of 3,000 μg/m^3 and 69-fold lower than the OSHA PEL of 5,000 μg/m^3 for respirable dust [ACGIH 2023; OSHA 2023a]. Respirable dust can be suspended in air during workplace operations, especially when performing grinding, cutting, or polishing tasks. Exposure to respirable dust can occur when respirable dust is inhaled. Respirable dust is made up of particles less than 4 μm in size, and when this size of particles is breathed in, they can reach the deepest area and gas exchange region of the lungs, the alveoli. Respirable dust exposure has previously been associated with IPF [Abramson et al. 2018].

All full-shift personal air sampling measurements for respirable crystalline silica were below their respective LODs, and all LODs were well below their respective NIOSH RELs. The highest LOD (and highest theoretical value for a personal exposure) for respirable silica was 36 μg/m^3 crystalline silica which was below the NIOSH REL and OSHA PEL of 50 μg/m^3 for crystalline silica [NIOSH 2019a]. Exposure to respirable crystalline silica can occur when respirable crystalline silica is inhaled. Respirable crystalline silica can sometimes be found in the air in dental settings during procedures when compounds containing crystalline silica are used such as when mixing powders; grinding and polishing castings, porcelain, or composites containing silica; removing castings from molds; and during abrasive blasting. Respirable crystalline silica refers to the crystalline silica that can reach the deepest area of the lungs. Exposure to respirable crystalline silica can lead to the development of disabling and sometimes fatal lung diseases, including silicosis and lung cancer [NIOSH 2019a; NIOSH 2023]. Respirable crystalline silica is considered a potential occupational carcinogen by NIOSH, and exposures should be reduced to lowest feasible concentrations whenever possible [NIOSH 2019a].

Area Air Sampling

Because area air samples are not personal air samples collected directly on an employee, the NIOSH RELs are not directly applicable to the results for exposure monitoring purposes. However, area air samples can highlight areas with higher exposure risk, and the NIOSH RELs can be used as points of reference.

All area samples for respirable dust, respirable silica, and respirable metals were below their respective RELs. Additional key findings from the area samples are discussed below.

All area samples for respirable dust were below the LOD (the LODs for samples ranged from 18.0 $\mu g/m^3$ to 41.8 $\mu g/m^3$), with the exception of (1) two air samples collected in treatment room 232A, which measured 22.0 $\mu g/m^3$ and 41.8 $\mu g/m^3$ of respirable dust, and (2) one air sample collected in the laboratory by the grinder stone which measured 21.7 $\mu g/m^3$ of respirable dust. Procedures performed in treatment room 232A while the two detectable respirable dust samples were collected (22.0 $\mu g/m^3$ and 41.8 $\mu g/m^3$ respirable dust) were dental cleaning procedures. Procedures performed in the laboratory while the one detectable respirable dust sample was collected (21.7 $\mu g/m^3$ respirable dust) were retainer trimming with the soldering iron, molding retainers with a square heater, molding mouthguards with a round heater, and using a handheld grinder to grind a mouthguard and a retainer. All three measurable samples were well below the OSHA PEL of 5,000 $\mu g/m^3$ (5 milligrams per cubic meter of air [mg/m^3]) and the ACGIH recommended level of 3,000 $\mu g/m^3$ (3 mg/m^3) for respirable dust.

All area samples for respirable crystalline silica (cristobalite, tridymite, and quartz) were below their respective LODs, with the exception of one sample collected in treatment room 223, which measured 6.2 $\mu g/m^3$ for respirable quartz. Procedures performed in treatment room 221 while the sample was collected included restorative procedures (one filling procedure was performed). The one measurable sample was well below the OSHA PEL and NIOSH REL for respirable crystalline silica of 50 $\mu g/m^3$ [NIOSH 2019a]. We note here and above that respirable crystalline silica is considered a potential occupational carcinogen by NIOSH and exposures should be reduced to the lowest feasible concentration whenever possible [NIOSH 2019a].

We detected chromium in every area air sample collected during the survey (n=36), albeit at levels below the NIOSH REL for chromium of 500 $\mu g/m^3$. Chromium is commonly used as a base metal in restorative procedures as a dental filling material. Exposure to elevated levels of chromium can cause irritation of the eyes and skin and lung fibrosis [NIOSH 2019c]. Exposure to chromium can also cause skin sensitization dermatitis and allergic contact dermatitis [Iyer et al. 2002; Forte et al. 2008; Lansdown 1995; Bregnbak et al. 2015; ATSDR 2023].

Chromium measurements were notably higher on the second day of our survey. The average chromium concentration for all samples collected on day 2 of our survey was almost two-fold higher than average chromium concentrations on the other days of our survey. This observation correlates with a higher number of restorative procedures (n=2) performed on day 2 of the survey than on other days of the survey. Additionally, we measured elevated levels of chromium throughout the clinic on day 2 compared to day 1 of our survey (including in offices and the breakroom), indicating that respirable chromium generated during dental procedures and tasks is potentially migrating throughout the clinic. Further, chromium was detected in every sample even on the first day of the survey when no restorative procedures were performed, albeit at lower levels. It is possible that either (A) laboratory tasks contributed to chromium being detected in air samples on day 1 of our survey or (B) respirable chromium was still present from procedures performed in the preceding days. We note that particles in the respirable size range can remain suspended in the air for hours to days, owing to their small size and slow settling velocities. If respirable chromium measured on day 1 of our survey was chromium present from procedures performed in the preceding days, it indicates a need for additional general exhaust ventilation to lower background air concentrations of residual contaminants such as chromium, and for additional LEV, such as high-volume evacuation (HVE), to be used during restorative procedures, to capture metal contaminants such as chromium before they can potentially circulate more broadly throughout the clinic. Additionally, although all samples were below the NIOSH REL for chromium, it's possible that on busier days with additional procedures performed with chromium, higher concentrations could be reached and potentially exceed the NIOSH REL. Additional general exhaust ventilation and LEV would help mitigate these exposures.

We detected copper in 69% of samples (n=25/36) collected during the survey, albeit at levels below the NIOSH REL for copper of 1,000 $\mu g/m^3$. Exposure to elevated levels of copper can cause irritation of the eyes, nose, throat; nasal septum perforation; metallic taste, and dermatitis [NIOSH 2019d]. Similar to chromium, copper is also utilized in restorative materials, and we observed similar correlations of increased copper concentrations on days when restorative procedures were performed. For example, copper was detected in 42% of samples (n=5/12) on the first day of the survey, when no restorative procedures were performed. Conversely, copper was detected in 83% (n=20/24) of samples collected on days 2 and 3 of the survey, when restorative procedures were performed. Similar to what's discussed above for chromium, our measurements of copper in samples collected on the first day of sampling, when only dental cleanings and laboratory tasks were performed, suggests that either laboratory tasks could be contributing to copper measurements, or respirable copper generated in preceding days is contributing to residual copper in the air of the clinic. If the latter is true, additional general exhaust ventilation to lower background concentrations of residual contaminants, and LEV (such as HVE) used during restorative procedures, would be necessary to capture contaminants such as copper before they can circulate more broadly throughout the clinic.

One sample for nickel was measured at 0.13 $\mu g/m^3$ in treatment room 221 and was below the NIOSH REL of 15 $\mu g/m^3$ for nickel. Nickel is often used as a restorative material or in orthodontic appliances. Although this measurement was low, nickel is designated as a carcinogen by NIOSH and should be reduced to the lowest feasible concentration whenever possible [NIOSH 2019d]. Additionally, exposure to nickel can cause sensitization dermatitis, allergic contact dermatitis, allergic asthma, and pneumonitis [NIOSH 2019e].

All samples for full-shift area measurements of VOCs were relatively low with the exception of measurements for ethanol, isopropyl alcohol, and acetone. Ethanol and isopropyl alcohol are chemicals commonly used for cleaning and disinfection which frequently occurs during routine dental care. Cleaning and disinfection in treatment rooms is routinely performed between patients as part of routine infection control procedures. Acetone is a solvent used in some dental restorative primer materials. Ethanol and acetone are sometimes used with dental bonding agents as well. Symptoms of exposure to isopropyl alcohol, ethanol, or acetone can include irritation of the eyes, nose, throat, and skin; dizziness; headache; and dry cracking skin [NIOSH 2019e,f,g]. All full-shift area measurements for ethanol, isopropyl alcohol, and acetone were below the NIOSH RELs for ethanol, isopropyl alcohol, and acetone of 1000 ppm (1,000,000 ppb), 400 ppm (400,000 ppb), and 250 ppm (250,000 ppb), respectively [NIOSH 2019e,f,g].

We measured some other VOCs, such as methylene chloride, that were below their respective exposure limits but are also notable because they are associated with symptoms or potential health effects at low levels of exposure. Full-shift TWA results from all areas sampled measured methylene chloride at levels ranging from <0.9 ppb to 2.1 ppb. All samples were well below the OSHA PEL of 25 ppm (25,000 ppb) for methylene chloride [OSHA 2022]. However, methylene chloride designated as a carcinogen by NIOSH, and it's recommended that exposures be reduced to the lowest level feasible.

Similarly, other VOCs noted as carcinogens were also observed in instantaneous canister samples. Benzene was measured at 1.3 ppb near the breathing zone of an employee while they trimmed a retainer with a soldering iron. Methylene chloride was also measured near the breathing zone of an employee at 0.35 ppb and 0.41 ppb while the employee (1) ground a mouthguard with a handheld grinder (0.35 ppb methylene chloride) and (2) molded a mouthguard while using the round heater (0.41 ppb). To try and identify a source of these VOCs, we asked management for safety data sheets (SDSs) for all materials used in the laboratory during our survey. We carefully reviewed the SDSs for laboratory materials used during our survey and found no mention of benzene or methylene chloride; thus, we were unable to identify the most probable source of benzene and methylene chloride during these laboratory tasks. However, we note that SDSs might not disclose specific chemicals when they may be part of a proprietary mixture deemed a trade secret, or in the case of carcinogens like benzene or methylene chloride, they are not required to be listed on SDSs if they are present at less than 0.1% composition [OSHA 2016]. It is possible that benzene and methylene chloride are present in laboratory materials that were used during these tasks or were generated when these materials were heated during grinding, trimming, or molding tasks. Although measurements of benzene and methylene chloride were low, their detection is notable because both benzene and methylene chloride are considered carcinogens by NIOSH and should be reduced to the lowest feasible concentrations whenever possible.

Source measurements collected near sources of VOCs in the laboratory highlight the effectiveness of the LEV tray in the laboratory. Measurements of benzene, *m,p*-xylene, toluene, and methylene chloride from samples collected near an Essix retainer while it was trimmed with a soft tray trimmer without LEV were 120 ppb, 140 ppb, 60 ppb, and 0.37 ppb, respectively. When the same task was performed while using LEV, measurements for were reduced to 3.3 ppb benzene, 2 ppb *m,p*-xylene, 1.7 ppb toluene, and to less than the LOD for methylene chloride. Our results indicate that levels of all four of these VOCs were greatly reduced when the same task was performed while using the LEV tray located beneath the soft tray trimmer in the laboratory.

Direct-reading measurements for respirable aerosol collected every 10 seconds highlighted multiple peak measurements of respirable aerosol that occurred in the laboratory on all three days of the survey. The highest peak respirable aerosol measurements occurred when employees performed tasks without LEV when compared to performing the same task with LEV. Use of the LEV tray located under the table with the soldering iron and soft tray trimmer was at the discretion of the employee. The three- to 10-fold reductions in respirable aerosol concentrations observed while employees performed tasks in the laboratory with LEV versus without LEV indicate that LEV should be used whenever possible to reduce respirable aerosol exposures in the laboratory.

Additionally, direct-reading measurements in the hallway outside the laboratory had peak respirable aerosol measurements that mirrored the same peak respirable aerosol measurements measured in the laboratory. The highest peak measurements of respirable aerosol in the laboratory were approximately one-quarter to one-third as high as the highest peaks of respirable aerosol in the laboratory and indicated that air with contaminants from the laboratory is being entrained into adjacent spaces.

Ventilation Assessment

Design standards for air exchange rates, temperature, and relative humidity for healthcare facilities differ from standards for other buildings [ASHRAE 2013; ANSI/ASHRAE/ASHE 2021]. An adequate supply of outdoor air, typically delivered through the HVAC system, is necessary in any indoor environment to dilute pollutants that are released by equipment, building materials, furnishings, products, and people. Sections 7, 8, and 9 in the ANSI/ASHRAE/ASHE Standard 170-2021, *Ventilation of Health Care Facilities*, provide air exchange rate, temperature, and relative humidity guidelines for areas of in-patient spaces, outpatient spaces, and residential health spaces, respectively [ANSI/ASHRAE/ASHE 2021]. For instance, dental treatment areas and prosthetics/orthodontics rooms should be ventilated with at least three total air changes per hour (ACH) and at least two of those air changes should be from filtered outdoor air. There is no recommendation for the pressure relationship between those areas and adjacent spaces. Similarly, there is no recommendation for indoor humidity levels in those spaces, but the temperature should be maintained in the range of 70°F -75°F. General laboratory work areas, like those in dental clinics, should be ventilated at 6 total ACH with at least two of those air changes from filtered outdoor air. Laboratory areas should also be maintained under negative pressure relative to adjacent spaces and be maintained between 70°F and 75°F, with no recommendation for humidity levels. Clean supply storage rooms should receive two ACH of outdoor air (and two ACH total) with no recommendations for pressure relationship, temperature, or relative humidity. Refer to Tables 7-1, 8-1, 8-2 and 9-1 in Standard 170-2021 for ventilation design parameters for other applicable spaces, including support and service areas [ANSI/ASHRAE/ASHE 2021].

Guidelines for areas that are not specified in ANSI/ASHRAE/ASHE 170-2021, *Ventilation of Health Care Facilities*, should be obtained from ANSI/ASHRAE Standard 62.1-2022, *Ventilation for Acceptable Indoor Air Quality* [ANSI/ASHRAE 2022]. When areas of the facility have recommended rates in both Standard 170-2021 and Standard 62.1, the higher of the two air exchange rates should be used [ANSI/ASHRAE/ASHE 2021]. ANSI/ASHRAE 62.1-2022 makes ventilation recommendations in a slightly different way. Standard 62.1-2022 recommends outdoor air supply rates that take into account people-related sources as well as building-related sources. For office spaces and conference rooms, five cubic feet per minute of outdoor air per person (cfm/person) is recommended for people-related sources, and an additional 0.06 cfm for every square foot (cfm/ft^2) of occupied space is recommended to account for building-related sources. To find rates for other indoor spaces, refer to Table 6-1 which is found in ANSI/ASHRAE 62.1-2022 [ANSI/ASHRAE 2022]. ASHRAE provides solid guidance on outdoor air requirements, and their standards are generally incorporated into legally-enforceable building codes. However, there are occasions when ASHRAE guidance may differ from state and/or local mechanical codes. Therefore, care should be taken to meet the ventilation requirements most appropriate for your locality and building type.

For spaces not included in Standard 170-2021, ANSI/ASHRAE Standard 55-2020, *Thermal Environmental Conditions for Human Occupancy* specifies the combinations of indoor environmental and personal factors that produce acceptable thermal conditions to a majority of occupants within a space [ANSI/ASHRAE 2020]. Assuming slow air movement (less than 40 feet per minute) and 50% indoor relative humidity, the operative temperatures recommended by ASHRAE range from 68.5°F to 75°F in the winter, and from 75°F to 80.5°F in the summer. The difference in temperature ranges between the seasons is largely due to clothing selection. ASHRAE Standard 62.1-2022 also recommends that indoor humidity be maintained to provide a maximum indoor-air dew-point temperature of 60°F in buildings that are mechanically cooled, during occupied and unoccupied periods [ANSI/ASHRAE 2022]. Using indoor-air dew-point temperature to limit humidity limits the total mass of water vapor available for condensation and adsorption on surfaces indoors. Condensation and adsorption of water on surfaces is largely responsible for indoor microbial growth. For other mechanical system types or where spaces are not served by mechanical systems, Standard 62.1 has no humidity limitations. The EPA recommends maintaining indoor relative humidity between 30% and 50% to reduce mold growth [EPA 2023].

The spaces served by the attic AHU generally meet the requirements for outdoor air delivery, but none of the dental operatories or office areas received any measurable outdoor air. During our visit, the dental clinic areas were not maintained at recommended temperatures. Improving the overall ventilation systems serving the clinic to meet outdoor air, temperature, and humidity requirements would provide a safer, more productive, and more comfortable place to clinic staff and visitors.

Work-related Symptoms or Conditions

Work-related asthma refers to asthma that is brought on by ("occupational asthma") or made worse by ("work-exacerbated asthma" or "work-aggravated asthma") workplace exposures [Tarlo 2016; Tarlo and Lemiere 2014; OSHA 2014; Henneberger et al. 2011; Venables and Chan-Yeung 1997]. It includes asthma due to sensitizers, which cause disease through immune (allergic) mechanisms, and asthma due to irritants, which cause disease through non-immune mechanisms. Symptoms of work-related asthma include episodic shortness of breath, cough, wheeze, and chest tightness. The symptoms may begin early in a work shift, towards the end of a shift, or hours after a shift. They generally, but do not always, improve or remit during periods away from work, such as on weekends or holidays.

Chromium and nickel are associated with occupational asthma [Park et al. 1994; Olaguibe and Basomba 1989, Fernández-Nieto et al. 2006, AOEC 2012]. It is unknown what concentrations of chromium or nickel air can lead to sensitization or asthma. Persons who become sensitized (develop an immune reaction) to chromium or nickel can subsequently react to relatively low concentrations in the air. Additionally, chromium and nickel can cause occupational contact dermatitis in exposed skin [Bregnbak et al. 2015; Ahlström et al. 2019]. Dermal exposure can be mitigated with protective barriers such as gloves when handling products that contain chromium or nickel.

Other potential exposures include potential exposure to ethanol, isopropyl alcohol, and acetone. Symptoms of high exposure to ethanol or isopropyl alcohol include irritation of the eyes, skin, and nose; headache; drowsiness; weakness or dizziness; exhaustion; cough; liver damage; anemia; and reproductive effects [NIOSH 2019f; NIOSH 2019g]. Symptoms of high exposure to acetone include irritation of the eyes, skin, nose, throat; headache, dizziness, and central nervous system depression [NIOSH 2019h].

No employees reported any work-related symptoms. However, should employees develop symptoms consistent with any of the exposures described above, they should report new, persistent, or worsening symptoms to their personal healthcare providers, and, as instructed, to a designated individual at their workplace.

Limitations

Our evaluation has several limitations. First, the request stated concerns about IPF; however, few studies to date have identified specific exposures associated with IPF, limiting our ability to address concerns about exposures that could contribute to the development of IPF. One previous study has observed an association between respirable dust exposure and IPF [Abramson et al. 2018]; however additional studies are needed to assess potential exposures in dental settings that could be contributing to pulmonary fibrosis and IPF. Second, our sampling was limited to three days of sampling at the clinic and might not represent all working conditions and potential exposures. For example, the exposure assessment was conducted during a week during an academic break and thus, there were fewer appointments during our survey than during other times of year such as when the academic campus is at full capacity; potential exposures on days when the clinic is operating at full capacity are likely higher than the measured exposures reported here. Additionally, we were only able to document concerns and symptoms that were reported to us during our evaluations by current employees who chose to participate. We were not able to include information from employees who had transferred to other locations or were not present at the facility at the time of the evaluation. Further, interviews could have been affected by recall biases.

Conclusions

All personal exposure measurements to respirable dust and respirable silica were below their respective NIOSH RELs, and all area air samples for respirable dust, respirable silica, and respirable metals were low. Most area VOC samples were also low. We noted positive pressure in the laboratory area that could lead to entrainment of air and contaminants from the laboratory area into adjacent areas. Additional exhaust such as LEV can be utilized in the laboratory to convert it to negative pressure and prevent contaminants from the laboratory from being entrained into adjacent spaces. The spaces served by the attic AHU generally met the requirements for outdoor air delivery, but none of the dental treatment rooms or office areas received any measurable outdoor air. During our visit, the dental clinic areas were not maintained at recommended temperatures. Improving the overall ventilation systems serving the clinic to meet outdoor air, temperature, and humidity requirements would provide a safer, more productive, and more comfortable place to clinic staff and visitors. No work-related symptoms were reported by employees. Should employees develop symptoms consistent with exposure to any of the contaminants measured, they should report new, persistent, or worsening symptoms to their personal healthcare providers, and, as instructed, to a designated individual at their workplace.

Section C: Tables

Table C1a. Full-shift personal exposures to respirable dust, August 2022.

Job Title	N	Above LOD N (%)	Minimum Concentration (µg/m³)	Maximum Concentration (µg/m³)	Above REL N (%)
Dental Assistant	3	0 (0%)	<46.7	<71.9	0 (0%)
Dental Hygienist	5*	0 (0%)	<41.9	<70.4	0 (0%)
Dentist	3	0 (0%)	<42.8	<68.6	0 (0%)

NIOSH=National Institute for Occupational Safety and Health; N=number of samples; LOD=limit of detection; REL=NIOSH Recommended Exposure Limit; *indicates where one sample was excluded (maximum LOD<235.5) due to a shortened sampling duration (68 minutes) due to a pump failure early in sampling period.

Table C1b. Full-shift personal exposures to respirable crystalline silica forms (crystobalite, quartz, and tridymite), August 2022.

Job Title	Analyte	N	Above LOD N (%)	Minimum Concentration (µg/m³)	Maximum Concentration (µg/m³)	Above REL N (%)
Dental Assistant	Cristobalite	3	0 (0%)	<5.8	<9.0	0 (0%)
	Quartz	3	0 (0%)	<5.8	<9.0	0 (0%)
	Tridymite	3	0 (0%)	<11.7	<18.0	0 (0%)
Dental Hygienist	Cristobalite	5*	0 (0%)	<5.2	<8.8	0 (0%)
	Quartz	5*	0 (0%)	<5.2	<8.8	0 (0%)
	Tridymite	5*	0 (0%)	<10.5	<17.6	0 (0%)
Dentist	Cristobalite	3	0 (0%)	<5.4	<8.6	0 (0%)
	Quartz	3	0 (0%)	<5.4	<8.6	0 (0%)
	Tridymite	3	0 (0%)	<10.7	<17.1	0 (0%)

NIOSH=National Institute for Occupational Safety and Health; N=number of samples; LOD=limit of detection; REL=NIOSH Recommended Exposure Limit; *indicates where one sample was excluded due to a shortened sampling duration (68 minutes) caused by a pump failure early in the sampling period.

Table C2a. Full-shift area air measurements of respirable dust, August 2022.

Work Area	**N**	**Above LOD N (%)**	**Minimum Concentration ($\mu g/m^3$)**	**Maximum Concentration ($\mu g/m^3$)**
Treatment Room 221	3	0 (0%)	<22.3	<40.3
Treatment Room 223	3	0 (0%)	<22.0	<40.7
Treatment Room 232A	3	2 (67%)	<=22.0	41.8
Treatment Room 232B	3	0 (0%)	<22.1	<41.8
Lab Area 238 (by grinder stone and by impressions area)	6	1 (17%)	<18.1	21.7
Hallway Outside Laboratory	3	0 (0%)	<18.0	<19.5
Office 222	3	0 (0%)	<22.1	<41.1
Office 228	3	0 (0%)	<22.3	<40.8
Pano Office	3	0 (0%)	<21.8	<34.6
Sterilization 229	3	0 (0%)	<22.4	<41.6
Breakroom 231	3	0 (0%)	<22.5	<41.6

N=number of samples; LOD=limit of detection; $\mu g/m^3$= micrograms cubic meter of air.

Table C2b. Full-shift area air measurements of respirable crystalline silica forms (cristobalite, quartz, and tridymite), August 2022.

Work Area	Analyte	N	Above LOD N (%)	Minimum Concentration (µg/m³)	Maximum Concentration (µg/m³)
Treatment Room 221	Cristobalite	3	0 (0%)	<2.8	<5.0
	Quartz	3	0 (0%)	<2.8	<5.0
	Tridymite	3	0 (0%)	<5.6	<10.1
Treatment Room 223	Cristobalite	3	0 (0%)	<2.8	<5.1
	Quartz	3	1 (33%)	<2.8	6.2
	Tridymite	3	0 (0%)	<5.5	<10.2
Treatment Room 232A	Cristobalite	3	0 (0%)	<2.8	<5.2
	Quartz	3	0 (0%)	<2.8	<5.2
	Tridymite	3	0 (0%)	<5.5	<10.5
Treatment Room 232B	Cristobalite	3	0 (0%)	<2.8	<5.2
	Quartz	3	0 (0%)	<2.8	<5.2
	Tridymite	3	0 (0%)	<5.5	<10.5
Lab Area 238 (by grinder stone and by impressions area)	Cristobalite	6	0 (0%)	<4.5	<5.1
	Quartz	6	0 (0%)	<4.5	<5.1
	Tridymite	6	0 (0%)	<9.0	<10.3
Hallway Outside Lab	Cristobalite	3	0 (0%)	<4.5	<4.9
	Quartz	3	0 (0%)	<4.5	<4.9
	Tridymite	3	0 (0%)	<9.0	<9.7
Office 222	Cristobalite	3	0 (0%)	<2.8	<5.1
	Quartz	3	0 (0%)	<2.8	<5.1
	Tridymite	3	0 (0%)	<5.5	<10.3
Office 228	Cristobalite	3	0 (0%)	<2.8	<5.1
	Quartz	3	0 (0%)	<2.8	<5.1
	Tridymite	3	0 (0%)	<5.6	<10.2
Pano Office	Cristobalite	3	0 (0%)	<2.7	<4.3
	Quartz	3	0 (0%)	<2.7	<4.3
	Tridymite	3	0 (0%)	<5.4	<8.6
Sterilization 229	Cristobalite	3	0 (0%)	<2.8	<5.2
	Quartz	3	0 (0%)	<2.8	<5.2
	Tridymite	3	0 (0%)	<5.6	<10.4
Breakroom 231	Cristobalite	3	0 (0%)	<2.8	<5.2
	Quartz	3	0 (0%)	<2.8	<5.2
	Tridymite	3	0 (0%)	<5.6	<10.4

N=number of samples; LOD=limit of detection; µg/m³= micrograms cubic meter of air.

Table C3. Full-shift area measurements for respirable metals, August 2022.

Work Area	Analyte	N	Above LOD N (%)	Minimum Concentration (µg/m³)	Maximum Concentration (µg/m³)
	Aluminum	3	1 (33%)	<0.280	0.530
	Antimony	3	0 (0%)	<0.112	<0.201
	Arsenic	3	0 (0%)	<0.056	<0.101
	Barium	3	1 (33%)	<0.003	0.006
	Beryllium	3	0 (0%)	<0.002	<0.004
	Cadmium	3	0 (0%)	<0.006	<0.010
	Calcium	3	0 (0%)	<0.224	<0.402
	Chromium	3	3 (100%)	0.100	0.150
	Cobalt	3	0 (0%)	<0.011	<0.020
	Copper	3	3 (100%)	0.056	0.120
	Iron	3	1 (33%)	<0.336	0.760
	Lanthanum	3	0 (0%)	<0.056	<0.101
Treatment Room 221	Lead	3	0 (0%)	<0.056	<0.101
	Lithium	3	0 (0%)	<0.224	<0.402
	Magnesium	3	0 (0%)	<0.224	<0.402
	Manganese	3	0 (0%)	<0.011	<0.020
	Molybdenum	3	0 (0%)	<0.017	<0.030
	Nickel	3	1 (33%)	<0.056	0.101
	Phosphorus	3	1 (33%)	<0.168	0.302
	Potassium	3	0 (0%)	<0.556	<1.006
	Selenium	3	0 (0%)	<0.112	<0.201
	Silver	3	0 (0%)	<0.017	<0.030
	Strontium	3	0 (0%)	<0.006	<0.010
	Tellurium	3	0 (0%)	<0.112	<0.201
	Thallium	3	0 (0%)	<0.280	<0.503
	Tin	3	0 (0%)	<0.056	<0.101
	Titanium	3	0 (0%)	<0.003	<0.006

Table C3. Full-shift area measurements for respirable metals, August 2022.

Work Area	**Analyte**	**N**	**Above LOD N (%)**	**Minimum Concentration (µg/m³)**	**Maximum Concentration (µg/m³)**
Treatment Room 221	Vanadium	3	0 (0%)	<0.168	<0.302
	Yttrium	3	2 (67%)	<0.006	0.010
	Zinc	3	1 (33%)	<0.045	0.180
	Zirconium	3	0 (0%)	<0.011	<0.020
Treatment Room 223	Aluminum	3	0 (0%)	<0.276	<0.510
	Antimony	3	0 (0%)	<0.111	<0.204
	Arsenic	3	0 (0%)	<0.055	<0.102
	Barium	3	1 (33%)	<0.003	0.006
	Beryllium	3	0 (0%)	<0.002	<0.004
	Cadmium	3	0 (0%)	<0.006	<0.010
	Calcium	3	0 (0%)	<0.221	<0.408
	Chromium	3	3 (100%)	0.110	0.160
	Cobalt	3	0 (0%)	<0.011	<0.020
	Copper	3	3 (100%)	0.081	0.087
	Iron	3	0 (0%)	<0.332	<0.612
	Lanthanum	3	0 (0%)	<0.055	<0.102
	Lead	3	0 (0%)	<0.055	<0.102
	Lithium	3	0 (0%)	<0.221	<0.408
	Magnesium	3	0 (0%)	<0.221	<0.408
	Manganese	3	0 (0%)	<0.011	<0.020
	Molybdenum	3	0 (0%)	<0.012	<0.031
	Nickel	3	0 (0%)	<0.055	<0.102
	Phosphorus	3	0 (0%)	<0.166	<0.306
	Potassium	3	0 (0%)	<0.552	<1.02
	Selenium	3	0 (0%)	<0.111	<0.204
	Silver	3	0 (0%)	<0.017	<0.031
	Strontium	3	0 (0%)	<0.006	<0.010

Table C3. Full-shift area measurements for respirable metals, August 2022.

Work Area	Analyte	N	Above LOD N (%)	Minimum Concentration (µg/m³)	Maximum Concentration (µg/m³)
Treatment Room 223 .	Tellurium	3	0 (0%)	<0.111	<0.204
	Thallium	3	0 (0%)	<0.276	<0.510
	Tin	3	0 (0%)	<0.055	<0.102
	Titanium	3	0 (0%)	<0.003	<0.006
	Vanadium	3	0 (0%)	<0.166	<0.306
	Yttrium	3	0 (0%)	<0.006	<0.010
	Zinc	3	0 (0%)	<0.044	<0.082
	Zirconium	3	0 (0%)	<0.011	<0.020
Treatment Room 232A	Aluminum	3	0 (0%)	<0.277	<0.522
	Antimony	3	0 (0%)	<0.111	<0.209
	Arsenic	3	0 (0%)	<0.055	<0.105
	Barium	3	0 (0%)	<0.003	<0.005
	Beryllium	3	0 (0%)	<0.002	<0.004
	Cadmium	3	0 (0%)	<0.006	<0.010
	Calcium	3	0 (0%)	<0.222	<0.418
	Chromium	3	3 (100%)	0.110	0.170
	Cobalt	3	0 (0%)	<0.011	<0.021
	Copper	3	2 (67%)	<0.028	0.071
	Iron	3	0 (0%)	<0.332	<0.627
	Lanthanum	3	0 (0%)	<0.055	<0.105
	Lead	3	0 (0%)	<0.055	<0.105
	Lithium	3	0 (0%)	<0.222	<0.418
	Magnesium	3	0 (0%)	<0.222	<0.418
	Manganese	3	0 (0%)	<0.011	<0.021
	Molybdenum	3	0 (0%)	<0.017	<0.031
	Nickel	3	0 (0%)	<0.055	<0.105
	Phosphorus	3	0 (0%)	<0.166	<0.313

Table C3. Full-shift area measurements for respirable metals, August 2022.

Work Area	Analyte	N	Above LOD N (%)	Minimum Concentration (µg/m³)	Maximum Concentration (µg/m³)
Treatment Room 232A	Potassium	3	0 (0%)	<0.554	<1.045
	Selenium	3	0 (0%)	<0.111	<0.209
	Silver	3	0 (0%)	<0.017	<0.031
	Strontium	3	0 (0%)	<0.006	<0.010
	Tellurium	3	0 (0%)	<0.111	<0.209
	Thallium	3	0 (0%)	<0.277	<0.522
	Tin	3	0 (0%)	<0.055	<0.105
	Titanium	3	0 (0%)	<0.003	<0.006
	Vanadium	3	0 (0%)	<0.166	<0.313
	Yttrium	3	1 (33%)	<0.006	0.010
	Zinc	3	0 (0%)	<0.044	<0.084
	Zirconium	3	0 (0%)	<0.011	<0.021
Treatment Room 232B	Aluminum	3	0 (0%)	<0.277	<0.521
	Antimony	3	0 (0%)	<0.111	<0.209
	Arsenic	3	0 (0%)	<0.055	<0.104
	Barium	3	0 (0%)	<0.003	<0.005
	Beryllium	3	0 (0%)	<0.002	<0.004
	Cadmium	3	0 (0%)	<0.006	<0.010
	Calcium	3	0 (0%)	<0.222	<0.417
	Chromium	3	3 (100%)	0.120	0.150
	Cobalt	3	0 (0%)	<0.011	<0.021
	Copper	3	3 (100%)	0.028	0.052
	Iron	3	1 (33%)	<0.332	0.800
	Lanthanum	3	0 (0%)	<0.055	<0.104
	Lead	3	0 (0%)	<0.055	<0.104
	Lithium	3	0 (0%)	<0.222	<0.417
	Magnesium	3	0 (0%)	<0.222	<0.417

Table C3. Full-shift area measurements for respirable metals, August 2022.

Work Area	Analyte	N	Above LOD N (%)	Minimum Concentration (µg/m³)	Maximum Concentration (µg/m³)
Treatment Room 232B	Manganese	3	0 (0%)	<0.011	<0.021
	Molybdenum	3	0 (0%)	<0.017	<0.031
	Nickel	3	0 (0%)	<0.055	<0.104
	Phosphorus	3	0 (0%)	<0.166	<0.313
	Potassium	3	0 (0%)	<0.554	<1.042
	Selenium	3	0 (0%)	<0.111	<0.209
	Silver	3	0 (0%)	<0.017	<0.031
	Strontium	3	0 (0%)	<0.006	<0.010
	Tellurium	3	0 (0%)	<0.111	<0.209
	Thallium	3	0 (0%)	<0.277	<0.521
	Tin	3	0 (0%)	<0.055	<0.104
	Titanium	3	0 (0%)	<0.003	<0.006
	Vanadium	3	0 (0%)	<0.166	<0.313
	Yttrium	3	0 (0%)	<0.006	<0.010
	Zinc	3	0 (0%)	<0.044	<0.083
	Zirconium	3	0 (0%)	<0.011	<0.021
Lab Area 238 (by grinder stone and by impressions area)	Aluminum	6	0 (0%)	<0.282	<0.320
	Antimony	6	0 (0%)	<0.113	<0.128
	Arsenic	6	0 (0%)	<0.056	<0.064
	Barium	6	1 (17%)	<0.003	0.009
	Beryllium	6	0 (0%)	<0.002	<0.003
	Cadmium	6	0 (0%)	<0.006	<0.006
	Calcium	6	2 (33%)	<0.225	0.76
	Chromium	6	6 (100%)	0.095	0.220
	Cobalt	6	1 (17%)	<0.011	0.013
	Copper	6	4 (67%)	<0.028	0.097
	Iron	6	0 (0%)	<0.338	<0.384

Table C3. Full-shift area measurements for respirable metals, August 2022.

Work Area	**Analyte**	**N**	**Above LOD N (%)**	**Minimum Concentration (µg/m³)**	**Maximum Concentration (µg/m³)**
Lab Area 238 (by grinder stone and by impressions area)	Lanthanum	6	1 (17%)	<0.056	0.140
	Lead	6	0 (0%)	<0.56	<0.064
	Lithium	6	0 (0%)	<0.225	<0.256
	Magnesium	6	0 (0%)	<0.225	<0.256
	Manganese	6	1 (17%)	<0.011	0.041
	Molybdenum	6	0 (0%)	<0.017	<0.019
	Nickel	6	0 (0%)	<0.056	<0.064
	Phosphorus	6	0 (0%)	<0.169	<0.192
	Potassium	6	0 (0%)	<0.563	<0.640
	Selenium	6	0 (0%)	<0.113	<0.128
	Silver	6	0 (0%)	<0.017	<0.019
	Strontium	6	1 (17%)	<0.006	0.011
	Tellurium	6	0 (0%)	<0.113	<0.128
	Thallium	6	0 (0%)	<0.282	<0.320
	Tin	6	0 (0%)	<0.056	<0.064
	Titanium	6	0 (0%)	<0.003	<0.004
	Vanadium	6	0 (0%)	<0.169	<0.192
	Yttrium	6	0 (0%)	<0.006	<0.006
	Zinc	6	0 (0%)	<0.045	<0.051
	Zirconium	6	0 (0%)	<0.011	<0.013
Hallway Outside Laboratory	Aluminum	3	0 (0%)	<0.282	<0.306
	Antimony	3	0 (0%)	<0.113	<0.122
	Arsenic	3	0 (0%)	<0.056	<0.061
	Barium	3	0 (0%)	<0.003	<0.003
	Beryllium	3	0 (0%)	<0.002	<0.002
	Cadmium	3	0 (0%)	<0.006	<0.006
	Calcium	3	0 (0%)	<0.226	<0.245

Table C3. Full-shift area measurements for respirable metals, August 2022.

Work Area	Analyte	N	Above LOD N (%)	Minimum Concentration (µg/m³)	Maximum Concentration (µg/m³)
Hallway Outside Laboratory	Chromium	3	3 (100%)	0.088	0.180
	Cobalt	3	1 (33%)	<0.011	0.023
	Copper	3	3 (100%)	0.054	0.083
	Iron	3	1 (33%)	<0.339	49.0
	Lanthanum	3	0 (0%)	<0.056	<0.061
	Lead	3	0 (0%)	<0.056	<0.061
	Lithium	3	0 (0%)	<0.226	<0.245
	Magnesium	3	0 (0%)	<0.226	<0.245
	Manganese	3	2 (67%)	<0.011	0.140
	Molybdenum	3	0 (0%)	<0.017	<0.018
	Nickel	3	0 (0%)	<0.056	<0.061
	Phosphorus	3	0 (0%)	<0.169	<0.183
	Potassium	3	0 (0%)	<0.565	<0.612
	Selenium	3	0 (0%)	<0.113	<0.122
	Silver	3	0 (0%)	<0.017	<0.018
	Strontium	3	0 (0%)	<0.006	<0.006
	Tellurium	3	0 (0%)	<0.113	<0.122
	Thallium	3	0 (0%)	<0.282	<0.306
	Tin	3	0 (0%)	<0.056	<0.061
	Titanium	3	0 (0%)	<0.003	<0.004
	Vanadium	3	0 (0%)	<0.169	<0.183
	Yttrium	3	0 (0%)	<0.006	<0.006
	Zinc	3	1 (33%)	<0.045	8.50
	Zirconium	3	0 (0%)	<0.011	<0.012
Office 222	Aluminum	3	0 (0%)	<0.278	<0.513
	Antimony	3	0 (0%)	<0.111	<0.205
	Arsenic	3	0 (0%)	<0.056	<0.103

Table C3. Full-shift area measurements for respirable metals, August 2022.

Work Area	Analyte	N	Above LOD N (%)	Minimum Concentration (µg/m³)	Maximum Concentration (µg/m³)
Office 222	Barium	3	1 (33%)	<0.003	0.005
	Beryllium	3	0 (0%)	<0.002	<0.004
	Cadmium	3	0 (0%)	<0.006	<0.010
	Calcium	3	1 (33%)	<0.224	0.467
	Chromium	3	3 (100%)	0.061	0.144
	Cobalt	3	0 (0%)	<0.011	<0.021
	Copper	3	1 (33%)	<0.028	0.069
	Iron	3	0 (0%)	<0.333	<0.616
	Lanthanum	3	0 (0%)	<0.056	<0.103
	Lead	3	0 (0%)	<0.056	<0.103
	Lithium	3	0 (0%)	<0.222	<0.410
	Magnesium	3	0 (0%)	<0.222	<0.410
	Manganese	3	0 (0%)	<0.011	<0.021
	Molybdenum	3	0 (0%)	<0.017	<0.031
	Nickel	3	0 (0%)	<0.056	<0.103
	Phosphorus	3	1 (33%)	<0.167	0.308
	Potassium	3	0 (0%)	<0.556	<1.026
	Selenium	3	1 (33%)	<0.111	0.205
	Silver	3	0 (0%)	<0.017	<0.031
	Strontium	3	1 (33%)	<0.006	0.010
	Tellurium	3	0 (0%)	<0.111	<0.205
	Thallium	3	0 (0%)	<0.278	<0.513
	Tin	3	0 (0%)	<0.056	<0.103
	Titanium	3	0 (0%)	<0.003	<0.006
	Vanadium	3	0 (0%)	<0.167	<0.308
	Yttrium	3	0 (0%)	<0.006	<0.010
	Zinc	3	0 (0%)	<0.044	<0.082

Table C3. Full-shift area measurements for respirable metals, August 2022.

Work Area	Analyte	N	Above LOD N (%)	Minimum Concentration (μg/m³)	Maximum Concentration (μg/m³)
	Zirconium	3	0 (0%)	<0.011	<0.021
Office 228	Aluminum	3	0 (0%)	<0.277	<0.508
	Antimony	3	0 (0%)	<0.111	<0.203
	Arsenic	3	0 (0%)	<0.055	<0.102
	Barium	3	0 (0%)	<0.003	<0.005
	Beryllium	3	0 (0%)	<0.002	<0.004
	Cadmium	3	0 (0%)	<0.006	<0.010
	Calcium	3	0 (0%)	<0.222	<0.406
	Chromium	3	3 (100%)	0.072	0.102
	Cobalt	3	0 (0%)	<0.011	<0.020
	Copper	3	2 (67%)	<0.028	0.061
	Iron	3	0 (0%)	<0.332	<0.609
	Lanthanum	3	0 (0%)	<0.055	<0.102
	Lead	3	0 (0%)	<0.055	<0.102
	Lithium	3	0 (0%)	<0.222	<0.406
	Magnesium	3	0 (0%)	<0.222	<0.406
	Manganese	3	0 (0%)	<0.011	<0.020
Office 228	Molybdenum	3	0 (0%)	<0.017	<0.030
	Nickel	3	0 (0%)	<0.055	<0.102
	Phosphorus	3	1 (33%)	<0.166	0.305
	Potassium	3	0 (0%)	<0.554	<1.02
	Selenium	3	0 (0%)	<0.111	<0.203
	Silver	3	0 (0%)	<0.017	<0.030
	Strontium	3	0 (0%)	<0.006	<0.010
	Tellurium	3	0 (0%)	<0.111	<0.203
	Thallium	3	0 (0%)	<0.277	<0.508
	Tin	3	0 (0%)	<0.055	<0.102

Table C3. Full-shift area measurements for respirable metals, August 2022.

Work Area	Analyte	N	Above LOD N (%)	Minimum Concentration (µg/m³)	Maximum Concentration (µg/m³)
	Titanium	3	0 (0%)	<0.003	<0.006
	Vanadium	3	0 (0%)	<0.166	<0.305
	Yttrium	3	0 (0%)	<0.006	<0.010
	Zinc	3	0 (0%)	<0.044	<0.081
Office 228	Zirconium	3	0 (0%)	<0.011	<0.020
	Aluminum	3	0 (0%)	<0.271	<0.432
	Antimony	3	0 (0%)	<0.108	<0.173
	Arsenic	3	0 (0%)	<0.054	<0.086
	Barium	3	1 (33%)	<0.003	0.004
	Beryllium	3	0 (0%)	<0.002	<0.003
	Cadmium	3	0 (0%)	<0.005	<0.009
	Calcium	3	0 (0%)	<0.217	<0.345
	Chromium	3	3 (100%)	0.065	0.112
	Cobalt	3	0 (0%)	<0.011	<0.017
	Copper	3	1 (33%)	<0.027	0.053
Pano Office	Iron	3	0 (0%)	<0.325	<0.518
	Lanthanum	3	0 (0%)	<0.054	<0.086
	Lead	3	0 (0%)	<0.054	<0.086
	Lithium	3	0 (0%)	<0.217	<0.345
	Magnesium	3	0 (0%)	<0.217	<0.345
	Manganese	3	0 (0%)	<0.011	<0.017
	Molybdenum	3	0 (0%)	<0.016	<0.026
	Nickel	3	0 (0%)	<0.054	<0.086
	Phosphorus	3	1 (33%)	<0.162	0.259
	Potassium	3	0 (0%)	<0.541	<0.863
	Selenium	3	0 (0%)	<0.108	<0.173
	Silver	3	0 (0%)	<0.016	<0.026

Table C3. Full-shift area measurements for respirable metals, August 2022.

Work Area	Analyte	N	Above LOD N (%)	Minimum Concentration (µg/m³)	Maximum Concentration (µg/m³)
Pano Office	Strontium	3	0 (0%)	<0.005	<0.009
	Tellurium	3	0 (0%)	<0.108	<0.173
	Thallium	3	0 (0%)	<0.271	<0.432
	Tin	3	0 (0%)	<0.054	<0.086
	Titanium	3	0 (0%)	<0.003	<0.005
	Vanadium	3	0 (0%)	<0.162	<0.259
	Yttrium	3	0 (0%)	<0.005	<0.009
	Zinc	3	0 (0%)	<0.043	<0.069
	Zirconium	3	0 (0%)	<0.011	<0.017
Sterilization 229	Aluminum	3	0 (0%)	<0.279	<0.521
	Antimony	3	0 (0%)	<0.112	<0.208
	Arsenic	3	0 (0%)	<0.056	<0.104
	Barium	3	1 (33%)	<0.003	0.005
	Beryllium	3	0 (0%)	<0.002	<0.004
	Cadmium	3	0 (0%)	<0.006	<0.010
	Calcium	3	0 (0%)	<0.223	<0.417
	Chromium	3	3 (100%)	0.054	0.146
	Cobalt	3	0 (0%)	<0.011	<0.021
	Copper	3	1 (33%)	<0.028	0.052
	Iron	3	0 (0%)	<0.335	<0.625
	Lanthanum	3	0 (0%)	<0.056	<0.104
	Lead	3	0 (0%)	<0.056	<0.104
	Lithium	3	0 (0%)	<0.223	<0.417
	Magnesium	3	0 (0%)	<0.223	<0.417
	Manganese	3	0 (0%)	<0.011	<0.021
	Molybdenum	3	0 (0%)	<0.017	<0.031
	Nickel	3	0 (0%)	<0.056	<0.104

Table C3. Full-shift area measurements for respirable metals, August 2022.

Work Area	Analyte	N	Above LOD N (%)	Minimum Concentration (µg/m³)	Maximum Concentration (µg/m³)
Sterilization 229	Phosphorus	3	0 (0%)	<0.167	<0.313
	Potassium	3	0 (0%)	<0.558	<1.04
	Selenium	3	0 (0%)	<0.112	<0.208
	Silver	3	0 (0%)	<0.017	<0.031
	Strontium	3	0 (0%)	<0.006	<0.010
	Tellurium	3	0 (0%)	<0.112	<0.208
	Thallium	3	0 (0%)	<0.279	<0.521
	Tin	3	0 (0%)	<0.056	<0.104
	Titanium	3	0 (0%)	<0.003	<0.006
	Vanadium	3	0 (0%)	<0.167	<0.313
	Yttrium	3	0 (0%)	<0.006	<0.010
	Zinc	3	0 (0%)	<0.045	<0.083
	Zirconium	3	0 (0%)	<0.011	<0.021
Breakroom 231	Aluminum	3	0 (0%)	<0.280	<0.518
	Antimony	3	0 (0%)	<0.112	<0.207
	Arsenic	3	0 (0%)	<0.056	<0.104
	Barium	3	0 (0%)	<0.003	<0.005
	Beryllium	3	0 (0%)	<0.002	<0.004
	Cadmium	3	0 (0%)	<0.006	<0.010
	Calcium	3	0 (0%)	<0.224	<0.414
	Chromium	3	3 (100%)	0.067	0.176
	Cobalt	3	0 (0%)	<0.011	<0.021
	Copper	3	2 (67%)	<0.028	0.062
	Iron	3	0 (0%)	<0.336	<0.621
	Lanthanum	3	0 (0%)	<0.056	<0.104
	Lead	3	0 (0%)	<0.056	<0.104
	Lithium	3	0 (0%)	<0.224	<0.414

Table C3. Full-shift area measurements for respirable metals, August 2022.

Work Area	Analyte	N	Above LOD N (%)	Minimum Concentration (µg/m³)	Maximum Concentration (µg/m³)
Breakroom 231	Magnesium	3	0 (0%)	<0.224	<0.414
	Manganese	3	0 (0%)	<0.011	<0.021
	Molybdenum	3	0 (0%)	<0.017	<0.031
	Nickel	3	0 (0%)	<0.056	<0.104
	Phosphorus	3	0 (0%)	<0.168	<0.311
	Potassium	3	0 (0%)	<0.560	<1.04
	Selenium	3	0 (0%)	<0.112	<0.207
	Silver	3	0 (0%)	<0.017	<0.031
	Strontium	3	0 (0%)	<0.006	<0.010
	Tellurium	3	0 (0%)	<0.112	<0.207
	Thallium	3	0 (0%)	<0.280	<0.518
	Tin	3	0 (0%)	<0.056	<0.104
	Titanium	3	0 (0%)	<0.003	<0.006
	Vanadium	3	0 (0%)	<0.168	<0.311
	Yttrium	3	0 (0%)	<0.006	<0.010
	Zinc	3	0 (0%)	<0.045	<0.083
	Zirconium	3	0 (0%)	<0.011	<0.021

N=number of samples; LOD=limit of detection; µg/m³= micrograms cubic meter of air.

Table C4. Full-shift canister area measurements of volatile organic compounds, August 2022.

Work Area	**Analyte**	**N**	**Above LOD N (%)**	**Minimum Concentration (ppb)**	**Maximum Concentration (ppb)**
Treatment Room 221	2,3-Hexanedione	3	0 (0%)	<0.9	<2.0
	2,3-Pentanedione	3	0 (0%)	<0.9	<2.0
	2-Propanol	3	3 (100%)	640	3,000
	Acetone	3	3 (100%)	8.0	19
	Benzene	3	0 (0%)	<0.9	<2.0
	Chloroform	3	0 (0%)	<0.9	<2.0
	Diacetyl	3	0 (0%)	<0.9	<2.0
	Ethanol	3	3 (100%)	110	910
	Ethyl Benzene	3	0 (0%)	<0.9	<2.0
	Methyl Methacrylate	3	0 (0%)	<0.9	<2.0
	Methylene Chloride	3	0 (0%)	<0.9	<2.0
	Toluene	3	1 (33%)	<0.9	2.8
	a-Pinene	3	0 (0%)	<0.9	<2.0
	d-Limonene	3	0 (0%)	<0.9	<2.0
	m,p-Xylene	3	0 (0%)	<2.0	<3.0
	n-Hexane	3	0 (0%)	<0.9	<2.0
	o-Xylene	3	0 (0%)	<0.9	<2.0
	2,3-Hexanedione	3	0 (0%)	<0.9	<2.0
	2,3-Pentanedione	3	0 (0%)	<0.9	<2.0
	2-Propanol	3	3 (100%)	460	2,100
	Acetone	3	3 (100%)	12	21
	Benzene	3	0 (0%)	<0.9	<2.0
	Chloroform	3	0 (0%)	<0.9	<2.0
	Diacetyl	3	0 (0%)	<0.9	<2.0
	Ethanol	3	3 (100%)	290	850
	Ethyl Benzene	3	0 (0%)	<0.9	<2.0
	Methyl Methacrylate	3	0 (0%)	<0.9	<2.0
	Methylene Chloride	3	0 (0%)	<0.9	<2.0
	Toluene	3	1 (33%)	<0.9	0.96
	a-Pinene	3	0 (0%)	<0.9	<2.0
	d-Limonene	3	1 (33%)	<0.9	0.9
	m,p-Xylene	3	0 (0%)	<2.0	<3.0

Work Area	Analyte	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)
Treatment Room 223	n-Hexane	3	0 (0%)	<0.9	<2.0
	o-Xylene	3	0 (0%)	<0.9	<2.0
	2,3-Hexanedione	3	0 (0%)	<0.9	<2.0
	2,3-Pentanedione	3	0 (0%)	<0.9	<2.0
	2-Propanol	3	3 (100%)	1,900	5,300
	Acetone	3	3 (100%)	13	29
	Benzene	3	0 (0%)	<0.9	<2.0
	Chloroform	3	0 (0%)	<0.9	<2.0
	Diacetyl	3	0 (0%)	<0.9	<2.0
Treatment Room 232A	Ethanol	3	3 (100%)	410	1200
	Ethyl Benzene	3	0 (0%)	<0.9	<2.0
	Methyl Methacrylate	3	0 (0%)	<0.9	<2.0
	Methylene Chloride	3	0 (0%)	<0.9	<2.0
	Toluene	3	1 (33%)	<0.9	1.0
	a-Pinene	3	0 (0%)	<0.9	<2.0
	d-Limonene	3	1 (33%)	<0.9	3.2
	m,p-Xylene	3	0 (0%)	<2.0	<3.0
	n-Hexane	3	0 (0%)	<0.9	<2.0
	o-Xylene	3	0 (0%)	<0.9	<2.0
	2,3-Hexanedione	3	0 (0%)	<0.9	<2.0
	2,3-Pentanedione	3	0 (0%)	<0.9	<2.0
	2-Propanol	3	3 (100%)	710	4,000
	Acetone	3	3 (100%)	11	44
	Benzene	3	0 (0%)	<0.9	<2.0
Treatment Room 232B	Chloroform	3	0 (0%)	<0.9	<2.0
	Diacetyl	3	0 (0%)	<0.9	<2.0
	Ethanol	3	3 (100%)	550	1,100
	Ethyl Benzene	3	0 (0%)	<0.9	<2.0
	Methyl Methacrylate	3	0 (0%)	<0.9	<2.0
	Methylene Chloride	3	0 (0%)	<0.9	<2.0
	Toluene	3	1 (33%)	<0.9	1.8
	a-Pinene	3	0 (0%)	<0.9	<2.0
	d-Limonene	3	1 (33%)	<0.9	6.1

Work Area	Analyte	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)
Treatment Room 232B	*m,p*-Xylene	3	0 (0%)	<2.0	<3.0
	n-Hexane	3	0 (0%)	<0.9	<2.0
	o-Xylene	3	0 (0%)	<0.9	<2.0
Lab Area 238	2,3-Hexanedione	4	0 (0%)	<1.0	<1.0
	2,3-Pentanedione	4	0 (0%)	<1.0	<1.0
	2-Propanol	4	4 (100%)	770	1,200
	Acetone	4	4 (100%)	8.5	19
	Benzene	4	0 (0%)	<1.0	<1.0
	Chloroform	4	0 (0%)	<1.0	<1.0
	Diacetyl	4	0 (0%)	<1.0	<1.0
	Ethanol	4	4 (100%)	380	460
	Ethyl Benzene	4	0 (0%)	<1.0	<1.0
	Methyl Methacrylate	4	0 (0%)	<1.0	<1.0
	Methylene Chloride	4	0 (0%)	<1.0	<1.0
	Toluene	4	1 (25%)	<1.0	1.2
	a-Pinene	4	0 (0%)	<1.0	<1.0
	d-Limonene	4	2 (50%)	<1.0	4.5
	m,p-Xylene	4	0 (0%)	<2.0	<2.0
	n-Hexane	4	0 (0%)	<1.0	<1.0
	o-Xylene	4	0 (0%)	<1.0	<1.0
Lab (by grinder stone and by impressions area) or Hallway Outside Lab	2,3-Hexanedione	4	0 (0%)	<0.9	<0.9
	2,3-Pentanedione	4	0 (0%)	<0.9	<0.9
	2-Propanol	4	4 (100%)	190	490
	Acetone	4	4 (100%)	6.8	11
	Benzene	4	0 (0%)	<0.9	<0.9
	Chloroform	4	0 (0%)	<0.9	<0.9
	Diacetyl	4	0 (0%)	<0.9	<0.9
	Ethanol	4	4 (100%)	290	350
	Ethyl Benzene	4	0 (0%)	<0.9	<0.9
	Methyl Methacrylate	4	0 (0%)	<0.9	<0.9
	Methylene Chloride	4	3 (75%)	<0.9	1.4
	Toluene	4	0 (0%)	<0.9	<0.9
	a-Pinene	4	0 (0%)	<0.9	<0.9

Work Area	Analyte	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)
Lab (by grinder stone and by impressions area) or Hallway Outside Lab	d-Limonene	4	0 (0%)	<0.9	<0.9
	m,p-Xylene	4	0 (0%)	<2.0	<2.0
	n-Hexane	4	0 (0%)	<0.9	<0.9
	o-Xylene	4	0 (0%)	<0.9	<0.9
Hallway Outside Laboratory	2,3-Hexanedione	2	0 (0%)	<1.0	<1.0
	2,3-Pentanedione	2	0 (0%)	<1.0	<1.0
	2-Propanol	2	2 (100%)	1,100	1,200
	Acetone	2	2 (100%)	19	19
	Benzene	2	0 (0%)	<1.0	<1.0
	Chloroform	2	0 (0%)	<1.0	<1.0
	Diacetyl	2	0 (0%)	<1.0	<1.0
	Ethanol	2	2 (100%)	410	560
	Ethyl Benzene	2	0 (0%)	<1.0	<1.0
	Methyl Methacrylate	2	0 (0%)	<1.0	<1.0
	Methylene Chloride	2	0 (0%)	<1.0	<1.0
	Toluene	2	1 (50%)	<1.0	1.6
	a-Pinene	2	0 (0%)	<1.0	<1.0
	d-Limonene	2	1 (50%)	<1.0	2.0
	m,p-Xylene	2	0 (0%)	<2.0	<2.0
	n-Hexane	2	0 (0%)	<1.0	<1.0
	o-Xylene	2	0 (0%)	<1.0	<1.0
Office 222	2,3-Hexanedione	3	0 (0%)	<0.9	<2.0
	2,3-Pentanedione	3	0 (0%)	<0.9	<2.0
	2-Propanol	3	3 (100%)	500	2,800
	Acetone	3	3 (100%)	13	34
	Benzene	3	0 (0%)	<0.9	<2.0
	Chloroform	3	0 (0%)	<0.9	<2.0
	Diacetyl	3	0 (0%)	<0.9	<2.0
	Ethanol	3	3 (100%)	150	790
	Ethyl Benzene	3	0 (0%)	<0.9	<2.0
	Methyl Methacrylate	3	0 (0%)	<0.9	<2.0
	Methylene Chloride	3	1 (33%)	<0.9	2.1
	Toluene	3	2 (67%)	<=1.1	1.2

Work Area	Analyte	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)
Office 222	a-Pinene	3	0 (0%)	<0.9	<2.0
	d-Limonene	3	2 (67%)	<=1.7	1.9
	m,p-Xylene	3	0 (0%)	<2.0	<3.0
	n-Hexane	3	0 (0%)	<0.9	<2.0
	o-Xylene	3	0 (0%)	<0.9	<2.0
Office 228	2,3-Hexanedione	3	0 (0%)	<0.9	<2.0
	2,3-Pentanedione	3	0 (0%)	<0.9	<2.0
	2-Propanol	3	3 (100%)	280	900
	Acetone	3	3 (100%)	8.6	22
	Benzene	3	0 (0%)	<0.9	<2.0
	Chloroform	3	0 (0%)	<0.9	<2.0
	Diacetyl	3	0 (0%)	<0.9	<2.0
	Ethanol	3	3 (100%)	210	450
	Ethyl Benzene	3	0 (0%)	<0.9	<2.0
	Methyl Methacrylate	3	0 (0%)	<0.9	<2.0
	Methylene Chloride	3	0 (0%)	<0.9	<2.0
	Toluene	3	0 (0%)	<0.9	<2.0
	a-Pinene	3	0 (0%)	<0.9	<2.0
	d-Limonene	3	0 (0%)	<0.9	<2.0
	m,p-Xylene	3	0 (0%)	<2.0	<3.0
	n-Hexane	3	0 (0%)	<0.9	<2.0
	o-Xylene	3	0 (0%)	<0.9	<2.0
Pano Office	2,3-Hexanedione	3	0 (0%)	<0.9	<2.0
	2,3-Pentanedione	3	0 (0%)	<0.9	<2.0
	2-Propanol	3	3 (100%)	110	710
	Acetone	3	3 (100%)	7.3	18
	Benzene	3	0 (0%)	<0.9	<2.0
	Chloroform	3	0 (0%)	<0.9	<2.0
	Diacetyl	3	0 (0%)	<0.9	<2.0
	Ethanol	3	3 (100%)	210	340
	Ethyl Benzene	3	0 (0%)	<0.9	<2.0
	Methyl Methacrylate	3	0 (0%)	<0.9	<2.0
	Methylene Chloride	3	0 (0%)	<0.9	<2.0

Work Area	Analyte	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)
Pano Office	Toluene	3	0 (0%)	<0.9	<2.0
	a-Pinene	3	0 (0%)	<0.9	<2.0
	d-Limonene	3	0 (0%)	<0.9	<2.0
	m,p-Xylene	3	0 (0%)	<2.0	<3.0
	n-Hexane	3	0 (0%)	<0.9	<2.0
	o-Xylene	3	0 (0%)	<0.9	<2.0
Sterilization 229	2,3-Hexanedione	3	0 (0%)	<1.0	<2.0
	2,3-Pentanedione	3	0 (0%)	<1.0	<2.0
	2-Propanol	3	3 (100%)	500	5,300
	Acetone	3	3 (100%)	10	29
	Benzene	3	0 (0%)	<1.0	<2.0
	Chloroform	3	0 (0%)	<1.0	<2.0
	Diacetyl	3	0 (0%)	<1.0	<2.0
	Ethanol	3	3 (100%)	240	1,200
	Ethyl Benzene	3	0 (0%)	<1.0	<2.0
	Methyl Methacrylate	3	0 (0%)	<1.0	<2.0
	Methylene Chloride	3	0 (0%)	<1.0	<2.0
	Toluene	3	2 (67%)	<=1.0	1.2
	a-Pinene	3	0 (0%)	<1.0	<2.0
	d-Limonene	3	1 (33%)	<1.0	3.2
	m,p-Xylene	3	0 (0%)	<2.0	<3.0
	n-Hexane	3	0 (0%)	<1.0	<2.0
	o-Xylene	3	0 (0%)	<1.0	<2.0
Breakroom 231	2,3-Hexanedione	3	0 (0%)	<0.9	<2.0
	2,3-Pentanedione	3	0 (0%)	<0.9	<2.0
	2-Propanol	3	3 (100%)	320	790
	Acetone	3	3 (100%)	12	17
	Benzene	3	0 (0%)	<0.9	<2.0
	Chloroform	3	0 (0%)	<0.9	<2.0
	Diacetyl	3	0 (0%)	<0.9	<2.0
	Ethanol	3	3 (100%)	280	400
	Ethyl Benzene	3	0 (0%)	<0.9	<2.0
	Methyl Methacrylate	3	0 (0%)	<0.9	<2.0

Work Area	**Analyte**	**N**	**Above LOD N (%)**	**Minimum Concentration (ppb)**	**Maximum Concentration (ppb)**
Breakroom 231	Methylene Chloride	3	1 (33%)	<0.9	0.96
	Toluene	3	0 (0%)	<0.9	<2.0
	a-Pinene	3	0 (0%)	<0.9	<2.0
	d-Limonene	3	1 (33%)	<0.9	11
	m,p-Xylene	3	0 (0%)	<2.0	<3.0
	n-Hexane	3	0 (0%)	<0.9	<2.0
	o-Xylene	3	0 (0%)	<0.9	<2.0

N=number of samples; LOD=limit of detection; ppb=parts per billion.

Table C5. Instantaneous task-based canister measurements of volatile organic compounds collected near the breathing zone of employees while performing tasks in the laboratory area, August 2022.

Analyte	Task Description	Result Concentration (ppb)
2,3-Hexanedione	Mouthguard grinding with no LEV	<0.3
	Retainer grinding while using LEV	<0.3
	Retainer molding on square heater with no LEV	<0.3
	Retainer trimming with the soldering iron while using LEV	<0.3
	Mouthguard grinding with the handheld grinder with no LEV	<0.3
	Mouthguard molding using the round heater with no LEV	0.33
2,3-Pentanedione	Mouthguard grinding with no LEV	<0.3
	Retainer grinding while using LEV	<0.3
	Retainer molding on square heater with no LEV	<0.3
	Retainer trimming with the soldering iron while using LEV	<0.3
	Mouthguard grinding with the handheld grinder with no LEV	<0.3
	Mouthguard molding using the round heater with no LEV	<0.3
2-Propanol (Isopropyl alcohol)	Mouthguard grinding with no LEV	570
	Retainer grinding while using LEV	260
	Retainer molding on square heater with no LEV	78
	Retainer trimming with the soldering iron while using LEV	94
	Mouthguard grinding with the handheld grinder with no LEV	69
	Mouthguard molding using the round heater with no LEV	75
Acetone	Mouthguard grinding with no LEV	11
	Retainer grinding while using LEV	7.5
	Retainer molding on square heater with no LEV	11
	Retainer trimming with the soldering iron while using LEV	11
	Mouthguard grinding with the handheld grinder with no LEV	8.0
	Mouthguard molding using the round heater with no LEV	10

a-Pinene	Mouthguard grinding with no LEV	<0.3
	Retainer grinding while using LEV	<0.3
	Retainer molding on square heater with no LEV	<0.3
	Retainer trimming with the soldering iron while using LEV	<0.3
	Mouthguard grinding with the handheld grinder with no LEV	<0.3
	Mouthguard molding using the round heater with no LEV	<0.3
Benzene	Mouthguard grinding with no LEV	<0.3
	Retainer grinding while using LEV	<0.3
	Retainer molding on square heater with no LEV	<0.3
	Retainer trimming with the soldering iron while using LEV	1.3
	Mouthguard grinding with the handheld grinder with no LEV	<0.3
	Mouthguard molding using the round heater with no LEV	<0.3
Chloroform	Mouthguard grinding with no LEV	<0.3
	Retainer grinding while using LEV	<0.3
	Retainer molding on square heater with no LEV	<0.3
	Retainer trimming with the soldering iron while using LEV	<0.3
	Mouthguard grinding with the handheld grinder with no LEV	<0.3
	Mouthguard molding using the round heater with no LEV	<0.3
Diacetyl	Mouthguard grinding with no LEV	<0.3
	Retainer grinding while using LEV	<0.3
	Retainer molding on square heater with no LEV	<0.3
	Retainer trimming with the soldering iron while using LEV	0.4
	Mouthguard grinding with the handheld grinder with no LEV	<0.3
	Mouthguard molding using the round heater with no LEV	0.35
d-Limonene	Mouthguard grinding with no LEV	0.43
	Retainer grinding while using LEV	<0.3
	Retainer molding on square heater with no LEV	<0.3
	Retainer trimming with the soldering iron while using LEV	<0.3

d-Limonene	Mouthguard grinding with the handheld grinder with no LEV	0.76
	Mouthguard molding using the round heater with no LEV	0.91
Ethanol	Mouthguard grinding with no LEV	360
	Retainer grinding while using LEV	570
	Retainer molding on square heater with no LEV	120
	Retainer trimming with the soldering iron while using LEV	130
	Mouthguard grinding with the handheld grinder with no LEV	510
	Mouthguard molding using the round heater with no LEV	270
Ethyl Benzene	Mouthguard grinding with no LEV	<0.3
	Retainer grinding while using LEV	<0.3
	Retainer molding on square heater with no LEV	<0.3
	Retainer trimming with the soldering iron while using LEV	<0.3
	Mouthguard grinding with the handheld grinder with no LEV	<0.3
	Mouthguard molding using the round heater with no LEV	<0.3
m,p-Xylene	Mouthguard grinding with no LEV	<0.5
	Retainer grinding while using LEV	<0.5
	Retainer molding on square heater with no LEV	<0.5
	Retainer trimming with the soldering iron while using LEV	0.66
	Mouthguard grinding with the handheld grinder with no LEV	<0.5
	Mouthguard molding using the round heater with no LEV	<0.5
Methyl Methacrylate	Mouthguard grinding with no LEV	<0.3
	Retainer grinding while using LEV	<0.3
	Retainer molding on square heater with no LEV	<0.3
	Retainer trimming with the soldering iron while using LEV	<0.3
	Mouthguard grinding with the handheld grinder with no LEV	<0.3
	Mouthguard molding using the round heater with no LEV	<0.3
Methylene Chloride	Mouthguard grinding with no LEV	<0.3
	Retainer grinding while using LEV	<0.3

Methylene Chloride	Retainer molding on square heater with no LEV	<0.3
	Retainer trimming with the soldering iron while using LEV	<0.3
	Mouthguard grinding with the handheld grinder with no LEV	0.35
	Mouthguard molding using the round heater with no LEV	0.41
n-Hexane	Mouthguard grinding with no LEV	<0.3
	Retainer grinding while using LEV	<0.3
	Retainer molding on square heater with no LEV	<0.3
	Retainer trimming with the soldering iron while using LEV	<0.3
	Mouthguard grinding with the handheld grinder with no LEV	<0.3
	Mouthguard molding using the round heater with no LEV	<0.3
o-Xylene	Mouthguard grinding with no LEV	<0.3
	Retainer grinding while using LEV	<0.3
	Retainer molding on square heater with no LEV	<0.3
	Retainer trimming with the soldering iron while using LEV	<0.3
	Mouthguard grinding with the handheld grinder with no LEV	<0.3
	Mouthguard molding using the round heater with no LEV	<0.3
Toluene	Mouthguard grinding with no LEV	0.75
	Retainer grinding while using LEV	<0.3
	Retainer molding on square heater with no LEV	<0.3
	Retainer trimming with the soldering iron while using LEV	0.62
	Mouthguard grinding with the handheld grinder with no LEV	0.34
	Mouthguard molding using the round heater with no LEV	0.46

N=number of samples; LOD=limit of detection; ppb=parts per billion.

Table C6. Instantaneous canister measurements of sources of volatile organic compounds during specific tasks in the laboratory area, August 2022.

Analyte	**Source Description (measurements collected near sources, e.g. retainer or mouthguard)**	**Result Concentration (ppb)**
2,3-Hexanedione	Essix retainer trimming with soft tray trimmer and no LEV	0.30
	Essix retainer trimming with soft tray trimmer while using LEV	0.70
	Acrylic mouthguard trimming with soldering iron while using LEV	0.30
2,3-Pentanedione	Essix retainer trimming with soft tray trimmer and no LEV	0.30
	Essix retainer trimming with soft tray trimmer while using LEV	0.70
	Acrylic mouthguard trimming with soldering iron while using LEV	0.30
2-Propanol (Isopropyl alcohol)	Essix retainer trimming with soft tray trimmer and no LEV	1500
	Essix retainer trimming with soft tray trimmer while using LEV	600
	Acrylic mouthguard trimming with soldering iron while using LEV	54
Acetone	Essix retainer trimming with soft tray trimmer and no LEV	17
	Essix retainer trimming with soft tray trimmer while using LEV	18
	Acrylic mouthguard trimming with soldering iron while using LEV	460
Benzene	Essix retainer trimming with soft tray trimmer and no LEV	120
	Essix retainer trimming with soft tray trimmer while using LEV	3.3
	Acrylic mouthguard trimming with soldering iron while using LEV	44
Chloroform	Essix retainer trimming with soft tray trimmer and no LEV	1.8
	Essix retainer trimming with soft tray trimmer while using LEV	0.70
	Acrylic mouthguard trimming with soldering iron while using LEV	0.30

Analyte	Source Description (measurements collected near sources, e.g. retainer or mouthguard)	Result Concentration (ppb)
Diacetyl	Essix retainer trimming with soft tray trimmer and no LEV	0.69
	Essix retainer trimming with soft tray trimmer while using LEV	0.70
	Acrylic mouthguard trimming with soldering iron while using LEV	2.0
Ethanol	Essix retainer trimming with soft tray trimmer and no LEV	310
	Essix retainer trimming with soft tray trimmer while using LEV	350
	Acrylic mouthguard trimming with soldering iron while using LEV	790
Ethyl Benzene	Essix retainer trimming with soft tray trimmer and no LEV	3.7
	Essix retainer trimming with soft tray trimmer while using LEV	0.70
	Acrylic mouthguard trimming with soldering iron while using LEV	1.8
Methyl Methacrylate	Essix retainer trimming with soft tray trimmer and no LEV	0.30
	Essix retainer trimming with soft tray trimmer while using LEV	0.70
	Acrylic mouthguard trimming with soldering iron while using LEV	0.30
Methylene Chloride	Essix retainer trimming with soft tray trimmer and no LEV	0.37
	Essix retainer trimming with soft tray trimmer while using LEV	0.70
	Acrylic mouthguard trimming with soldering iron while using LEV	0.30
Toluene	Essix retainer trimming with soft tray trimmer and no LEV	60
	Essix retainer trimming with soft tray trimmer while using LEV	1.7
	Acrylic mouthguard trimming with soldering iron while using LEV	8.4

Analyte	Source Description (measurements collected near sources, e.g. retainer or mouthguard)	Result Concentration (ppb)
a-Pinene	Essix retainer trimming with soft tray trimmer and no LEV	0.30
	Essix retainer trimming with soft tray trimmer while using LEV	0.70
	Acrylic mouthguard trimming with soldering iron while using LEV	0.30
d-Limonene	Essix retainer trimming with soft tray trimmer and no LEV	0.56
	Essix retainer trimming with soft tray trimmer while using LEV	3.5
	Acrylic mouthguard trimming with soldering iron while using LEV	0.30
m,p-Xylene	Essix retainer trimming with soft tray trimmer and no LEV	140
	Essix retainer trimming with soft tray trimmer while using LEV	2.0
	Acrylic mouthguard trimming with soldering iron while using LEV	0.84
n-Hexane	Essix retainer trimming with soft tray trimmer and no LEV	0.30
	Essix retainer trimming with soft tray trimmer while using LEV	0.70
	Acrylic mouthguard trimming with soldering iron while using LEV	36
o-Xylene	Essix retainer trimming with soft tray trimmer and no LEV	3.9
	Essix retainer trimming with soft tray trimmer while using LEV	0.70
	Acrylic mouthguard trimming with soldering iron while using LEV	1.0

LEV=Local exhaust ventilation; N=number of samples; LOD=limit of detection; ppb=parts per billion; "—" indicates measurements above the calibration maximum.

Table C7. Instantaneous canister measurements of volatile organic compounds collected in the laboratory area after finishing molding, trimming, and grinding a mouthguard.

Analyte	**Result Concentration (ppb)**
2,3-Hexanedione	0.30
2,3-Pentanedione	0.30
2-Propanol	390
Acetone	18
Benzene	0.54
Chloroform	0.30
Diacetyl	0.36
Ethanol	710
Ethyl Benzene	0.31
Methyl Methacrylate	0.30
Methylene Chloride	0.30
Toluene	1.4
a-Pinene	0.30
d-Limonene	0.70
m,p-Xylene	0.63
n-Hexane	1.1
o-Xylene	0.56

N=number of samples; LOD=limit of detection; ppb=parts per billion; "—" indicates measurements above the calibration maximum.

Section D: Occupational Exposure Limits

NIOSH investigators refer to mandatory (legally enforceable) and recommended occupational exposure limits (OELs) for chemical, physical, and biological agents when evaluating workplace hazards. OELs have been developed by federal agencies and safety and health organizations to prevent adverse health effects from workplace exposures. Generally, OELs suggest levels of exposure that most employees may be exposed to for up to 10 hours per day, 40 hours per week, for a working lifetime, without experiencing adverse health effects.

However, not all employees will be protected if their exposures are maintained below these levels. Some may have adverse health effects because of individual susceptibility, a pre-existing medical condition, or a hypersensitivity (allergy). In addition, some hazardous substances act in combination with other exposures, with the general environment, or with medications or personal habits of the employee to produce adverse health effects. Most OELs address airborne exposures, but some substances can be absorbed directly through the skin and mucous membranes.

Most OELs are expressed as a time-weighted (TWA) exposure. A TWA refers to the average exposure during a normal 8- to 10-hour workday. Some chemical substances and physical agents have recommended short-term exposure limits (STEL) or ceiling values. Unless otherwise noted, the STEL is a 15-minute TWA exposure. It should not be exceeded at any time during a workday. The ceiling limit should not be exceeded at any time.

In the United States, OELs have been established by federal agencies, professional organizations, state and local governments, and other entities. Some OELs are legally enforceable limits; others are recommendations.

- OSHA, and agency of the U.S. Department of Labor, publishes permissible exposure limits [29 CFR 1910 for general industry; 29 CFR 1926 for construction industry; and 29 CFR 1917 for maritime industry] called PELs. These limits are enforceable in workplaces covered under the Occupational Safety and Health Act of 1970.
- NIOSH recommended exposure limits (RELs) are recommendations based on a critical review of scientific and technical information and the adequacy of methods to identify and control the hazard. NIOSH RELs are published in the *NIOSH Pocket Guide to Chemical Hazards* [NIOSH 2020]. NIOSH also recommends risk management practices (e.g., engineering controls, safe work practices, employee education/training, personal protective equipment, and exposure and medical monitoring) to minimize the risk of exposure and adverse health effects.
- Other set of OELs commonly used and cited in the United States include the threshold limit values or TLV®s, which are recommended by the American Conference of Governmental Industrial Hygienists (ACGIH®). The ACGIH TLVs are developed by committee members of this professional organization from a review of the published, peer-reviewed literature. TLVs are not consensus standards. They are considered voluntary exposure guidelines for use by industrial

hygienists and others trained in this discipline “to assist in the control of health hazards” [ACGIH 2023].

Outside the United States, OELs have been established by various agencies and organizations and include legal and recommended limits. The Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (Institute for Occupational Safety and Health of the German Social Accident Insurance) maintains a database of international OELs from European Union member states, Canada (Québec), Japan, Switzerland, and the United States. The database, available at http://www.dguv.de/ifa/GESTIS/GESTIS-Stoffdatenbank/index-2.jsp, contains international limits for more than 2,000 hazardous substances and is updated periodically.

OSHA (Public Law 91-596) requires an employer to furnish employees a place of employment free from recognized hazards that cause or are likely to cause death or serious physical harm. This is true in the absence of a specific OEL. It also is important to keep in mind that OELs may not reflect current health-based information.

When multiple OELs exist for a substance or agent, NIOSH investigators generally encourage employers to use the lowest OEL when making risk assessment and risk management decisions.

Section E: References

Contact Dermatitis

Ahlström, MG, Thyssen JP, Wennervaldt M, Menné T, & Johansen JD [2019]. Nickel allergy and allergic contact dermatitis: A clinical review of immunology, epidemiology, exposure, and treatment. Contact Dermatitis *81*(4):227-241, https://doi.org/10.1111/cod.13327.

ATSDR [2023]. What are the physiologic effects of chromium exposure? U.S, Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, https://www.atsdr.cdc.gov/csem/chromium/physiologic_effects_of_chromium_exposure.html.

Bregnbak, D, Johansen JD, Jellesen MS, Zachariae C, Menné T, Thyssen JP [2015]. Chromium allergy and dermatitis: prevalence and main findings. Contact Dermatitis *73*(5):261-280, https://doi.org/10.1111/cod.12436.

Forte G, Petrucci F, Bocca B [2008]. Metal allergens of growing significance: epidemiology, immunotoxicology, strategies for testing and prevention. Inflamm Allergy Drug Targets *7*(3):145-162, https://doi.org/10.2174/187152808785748146.

Iyer VJ, Banerjee G, Govindram CB, Kamath V, Shinde S, Gaikwad A, Jerajani HR, Raman G, Cherian KM [2002]. Role of different valence states of chromium in the elicitation of allergic contact dermatitis. Contact Dermatitis *47*(6):357-360, https://doi.org/10.1034/j.1600-0536.2002.470608.x.

Lansdown AB [1995]. Physiological and toxicological changes in the skin resulting from the action and interaction of metal ions. Crit Rev Toxicol *25*(5):397-462, https://doi.org/10.3109/10408449509049339.

Idiopathic Pulmonary Fibrosis

Abramson MJ, Murambadoro T, Alif SM, Benke G, Dharmage S, Glaspole I, Hopkins P, Hoy R, Klebe S, Moodley Y, Rawson S, Reynolds P, Wolfe R, Walters EH, Corte TJ, The Australian I.P.F. Registry F O R European Respiratory Journal Sep 2018, 52 (suppl 62) PA5068; https://erj.ersjournals.com/content/52/suppl_62/PA5068.

Nett RJ, Cummings KJ, Cannon B, Cox-Ganser J, Nathan SD [2018]. Dental personnel treated for idiopathic pulmonary fibrosis at a tertiary care center—Virginia, 2000–2015. MMWR Morb Mortal Wkly Rep 67(9):270-273, https://doi.org/10.15585/mmwr.mm6709a2.

Work-related Asthma

AOEC [2015]. Comprehensive occupational & environmental exposure database. Association of Occupational and Environmental Clinics, http://www.aoecdata.org/ExpCodeLookup.aspx.
Fernández-Nieto M, Quirce S, Carnés J, Sastre J [2006]. Occupational asthma due to chromium and nickel salts. Int Arch Occup Environ health *79*(6):483-486, https://doi.org/10.1007/s00420-005-0078-z.

Henneberger PK, Redlich CA, Callahan DB, Harber P, Lemière C, Martin J, Tarlo SM, Vandenplas O, Torén K; ATS Ad Hoc Committee on Work-Exacerbated Asthma [2011]. An official American Thoracic Society statement: work-exacerbated asthma. Am J Respir Crit

Care Med 184(3):368–378, https://doi.org/10.1164/rccm.812011ST.

Olaguibe JM, Basomba A [1989] Occupational asthma induced by chromium salts. Allergol Immunopathol (Madr) *17*(3):133-136.

OSHA [2014]. OSHA fact sheet: Do you have work-related asthma? A guide for you and your doctor. U.S. Department of Labor, Occupational Safety and Health Administration, https://www.osha.gov/Publications/OSHA3707.pdf.

Park HS, Yu HJ, Jung KS [1994]. Occupational asthma caused by chromium. Clin Exp Allergy *24*(7):676-681, https://doi.org/10.1111/j.1365-2222.1994.tb00972.x.

Tarlo SM [2016]. Update on work-exacerbated asthma. Int J Occup Med Environ Health *29*(3):369-374, https://doi.org/10.13075/ijomeh.1896.00676.

Tarlo SM, Lemiere C [2014]. Occupational asthma. N Engl J Med 370(7):640-649, https://doi.org/10.1056/nejmra1301758.

Venables KM, Chan-Yeung M [1997]. Occupational asthma. Lancet *349*(9063):1465-1469, https://doi.org/10.1016/S0140-6736(96)07219-4.

Methods

NIOSH [1998]. Particulates not otherwise regulated, respirable: Method 0600. NIOSH Manual of Analytical Methods (NMAM™) Fourth Edition. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 94-113, https://www.cdc.gov/niosh/docs/2003-154/pdfs/0600.pdf.

NIOSH [2003a]. Silica, Crystalline, by XED (filter redeposition): Method 7500. NIOSH Manual of Analytical Methods (NMAM™) Fourth Edition. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication, https://www.cdc.gov/niosh/docs/2003-154/pdfs/7500.pdf.

NIOSH [2003b]. Elements by ICP (Hot Block/HCl/HNO3 Digestion): Method 7303. NIOSH Manual of Analytical Methods (NMAM™) Fourth Edition. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication, https://www.cdc.gov/niosh/docs/2003-154/pdfs/7303.pdf.

NIOSH [2018]. Volatile organic compounds, C1 to C10, Canister method: Method 3900. NIOSH Manual of Analytical Methods (NMAM®) Fifth Edition. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication, https://www.cdc.gov/niosh/nmam/pdf/3900.pdf.

Occupational Exposure Limits

ACGIH [2023]. 2023 TLVs® and BEIs®: threshold limit values for chemical substances and physical agents and biological exposure indices. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

NIOSH [2020]. NIOSH pocket guide to chemical hazards. Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, https://www.cdc.gov/niosh/npg/.

OSHA [2021a]. Permissible exposure limits – annotated tables. U.S. Department of Labor, Occupational Safety and Health Administration, https://www.osha.gov/annotated-pels/table-z-1.

OSHA [2023a]. Particulates not otherwise regulated, total and respirable dust (PNOR). U.S. Department of Labor, Occupational Safety and Health Administration, https://www.osha.gov/chemicaldata/801.

Health Effects and Exposure Limits

NIOSH [2019a]. Silica, crystalline (as respirable dust). NIOSH pocket guide to chemical hazards. Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, https://www.cdc.gov/niosh/npg/npgd0684.html.

NIOSH [2019b]. Zinc oxide. NIOSH pocket guide to chemical hazards. Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, https://www.cdc.gov/niosh/npg/npgd0675.html.

NIOSH [2019c]. Chromium metal. NIOSH pocket guide to chemical hazards. Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, https://www.cdc.gov/niosh/npg/npgd0141.html.

NIOSH [2019d]. Copper (dusts and mists, as Cu). NIOSH pocket guide to chemical hazards. Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, https://www.cdc.gov/niosh/npg/npgd0150.html.

NIOSH [2019d]. Nickel metal and other compounds (as Ni). NIOSH pocket guide to chemical hazards. Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, https://www.cdc.gov/niosh/npg/npgd0445.html.

NIOSH [2019e]. Methylene chloride. NIOSH pocket guide to chemical hazards. Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, https://www.cdc.gov/niosh/npg/npgd0414.html.

NIOSH [2019f]. Ethyl alcohol. NIOSH pocket guide to chemical hazards. Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, https://www.cdc.gov/niosh/npg/npgd0262.html.

NIOSH [2019g]. Isopropyl alcohol. NIOSH pocket guide to chemical hazards. Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, https://www.cdc.gov/niosh/npg/npgd0359.html.

NIOSH [2019h]. Acetone. NIOSH pocket guide to chemical hazards. Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, https://www.cdc.gov/niosh/npg/npgd0004.html.

NIOSH [2019i]. Toulene. NIOSH pocket guide to chemical hazards. Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, https://www.cdc.gov/niosh/npg/npgd0619.html.

NIOSH [2019j]. Methylene chloride. NIOSH pocket guide to chemical hazards. Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, https://www.cdc.gov/niosh/npg/npgd0414.html.

NIOSH [2019k]. Benzene. NIOSH pocket guide to chemical hazards. Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, https://www.cdc.gov/niosh/npg/npgd0049.html.

NIOSH [2020]. NIOSH pocket guide to chemical hazards. Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, https://www.cdc.gov/niosh/npg/default.html.

NIOSH [2023]. Health risks of silica exposure and medical monitoring. Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, https://www.cdc.gov/niosh/topics/silica/risks.html.

OSHA [2021]. OSHA occupational chemical database: benzene. U.S. Department of Labor, Occupational Safety and Health Administration, https://www.osha.gov/chemicaldata/491.

OSHA [2023]. OSHA occupational chemical database: methylene chloride. U.S. Department of Labor, Occupational Safety and Health Administration, https://www.osha.gov/chemicaldata/572.

Ventilation

ASHRAE [2013]. HVAC design manual for hospitals and clinics, 2nd ed. Atlanta, GA: ASHRAE.

ANSI/ASHRAE [2020]. Standard 55-2020 Thermal environmental conditions for human occupancy. Atlanta, GA: ASHRAE.

ANSI/ASHRAE [2022]. Standard 62.1-2022 Ventilation for acceptable indoor air quality, Atlanta, GA: ASHRAE.

ANSI/ASHRAE/ASHE [2021]. Standard 170-2021 Ventilation of health care facilities. Atlanta, GA: ASHRAE.

EPA [2023]. The inside story: A guide to indoor air quality, U.S. Environmental Protection Agency, http://www.epa.gov/indoor-air-quality-iaq/inside-story-guide-indoor-air-quality.

Respiratory Protection

NIOSH [2010]. How to properly put on and take off a disposable respirator. Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, https://www.cdc.gov/niosh/docs/2010-133/pdfs/2010-133.pdf.

NIOSH [2015]. Hospital Respiratory Protection Program Toolkit: Resources for Respirator Program Administrators. Atlanta, GA: Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication Number 2015-117 (revised 04/2022), https://doi.org/10.26616/NIOSHPUB2015117revised042022.

NIOSH [2022]. The respiratory protection information trusted source. Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, https://www.cdc.gov/niosh/npptl/topics/respirators/disp_part/respsource.html.

OSHA [1998]. Appendix D to § 1910.134 (mandatory) information for employees using respirators when not required under the standard. U.S. Department of Labor, Occupational Safety and Health Administration, https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.134AppD.

OSHA [2011]. Small entity compliance guide for the respiratory protection standard . U.S. Department of Labor, Occupational Safety and Health, OSHA 3384-09, https://www.osha.gov/sites/default/files/publications/3384small-entity-for-respiratory-protection-standard-rev.pdf.

OHSA [2012]. Transcript for the OSHA training video entitlted voluntary use of respirators. U.S. Department of Labor, Occupational Safety and Health Administration, https://www.osha.gov/video/respiratory-protection/voluntary-use/transcript.

OSHA [2018]. Interpretation letter to Mr. Donald Porter (dated April 26, 2018). U.S. Department of Labor, Occupational Safety and Health Administration, https://www.osha.gov/laws-regs/standardinterpretations/2018-04-26.

Safety Data Sheets and Hazard Communication

OSHA [2016]. Hazard communication - hazard classification guidance for manufacturers, importers, and employers. U.S. Department of Labor, Occupational Safety and Health, OSHA 3844-02, https://www.osha.gov/sites/default/files/publications/OSHA3844.pdf.

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HHE Report No. 2019-0232-3394