Evaluation of exposures and respiratory health at a coffee roasting and flavoring facility

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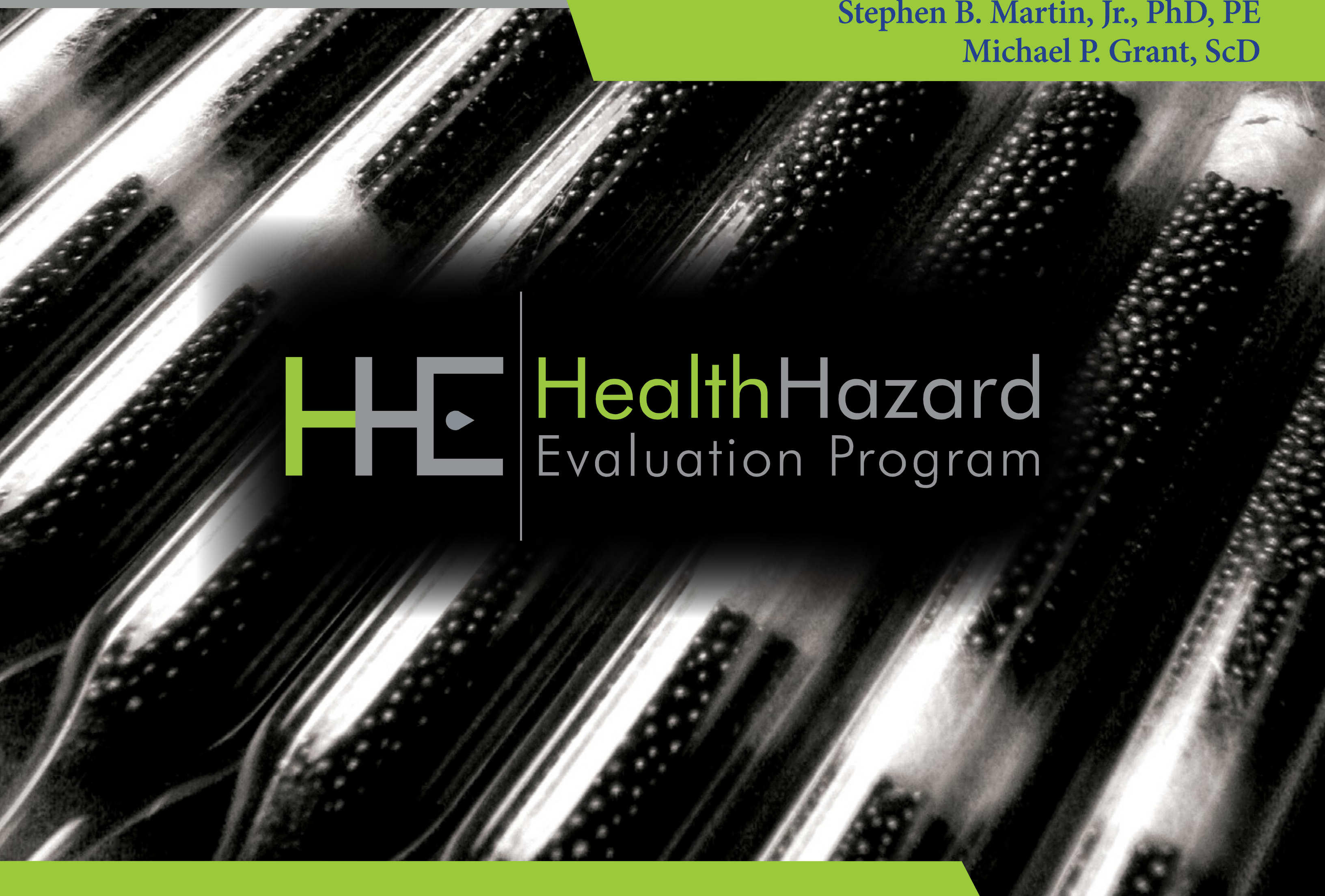

Report No. 2017-0020-3316
April 2018

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

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The employer is required to post a copy of this report for 30 days at or near the workplace(s) of affected employees. The employer must take steps to ensure that the posted report is not altered, defaced, or covered by other material.

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

Highlights of this Evaluation

The Health Hazard Evaluation Program of the National Institute for Occupational Safety and Health received a request from management of a coffee roasting and flavoring facility regarding concerns about repetitive motion injuries, potential burns, general warehouse safety, and exposures to and health effects from green coffee bean dust, diacetyl, and 2,3-pentanedione during coffee processing.

What We Did

- We visited the coffee roasting and flavoring facility during January 10–12, 2017.
- We collected full-shift (hours), task (minutes), and instantaneous (seconds) air samples to measure concentrations of the alpha-diketones diacetyl, 2,3-pentanedione, and 2,3-hexanedione.
- We collected roasted coffee beans (whole bean) and liquid flavoring to measure their emission potential for diacetyl, 2,3-pentanedione, and 2,3-hexanedione.
- We measured real-time air levels of carbon monoxide and carbon dioxide.
- We administered a health questionnaire to employees and performed breathing tests.
- We observed production practices, including receiving green bean shipments, storage, roasting, flavoring, grinding, packaging, and preparing for delivery and shipment.

What We Found

- During personal full-shift sampling, some employees were exposed to diacetyl at concentrations above the National Institute for Occupational Safety and Health recommended exposure limit for diacetyl of 5 parts per billion, with the highest measured concentration of 20.7 parts per billion.
- During personal full-shift sampling, one employee sample was above the National Institute for Occupational Safety and Health

We evaluated respiratory health and airborne exposures to alpha-diketones (diacetyl, 2,3-pentanedione, and 2,3-hexanedione), other volatile organic compounds, carbon monoxide, and carbon dioxide during coffee roasting, flavoring, grinding, and packaging. All four of the personal full-shift samples collected in the production area exceeded the NIOSH recommended exposure limit for diacetyl of 5 parts per billion. One of the four personal full-shift samples collected in the production area exceeded the NIOSH recommended exposure limit for 2,3-pentanedione of 9.3 parts per billion. In addition, air sampling during short-term tasks identified several tasks (e.g., flavoring roasted coffee beans and grinding flavored and unflavored coffee) with higher exposures to alpha-diketones, including diacetyl, than other tasks. Air concentrations of diacetyl and 2,3-pentanedione increased over the course of the work shift. Some employees reported eye, nose, or sinus symptoms or wheezing or whistling in the chest. We recommend installing local exhaust ventilation near flavoring and grinding activities, implementing administrative controls such as modification of work practices, and training employees about work-place hazards. We also recommend instituting a medical monitoring program.

recommended exposure limit for 2,3-pentanedione of 9.3 parts per billion with a measured concentration of 24.0 parts per billion.

- Levels of diacetyl and 2,3-pentanedione from personal short-term sampling were higher for tasks involving flavoring, grinding roasted coffee beans, and weighing and packaging roasted coffee.
- Diacetyl, 2,3-pentanedione, or 2,3-hexanedione were measured in all instantaneous canister samples collected from grinding flavored coffee, flavoring coffee, and the headspace of the liquid flavoring.
- All tested roasted coffee beans emitted diacetyl or 2,3-pentanedione.
- Carbon monoxide levels were generally low throughout the facility but higher near grinding activity.
- Some employees reported eye, nose, or sinus symptoms. Some employees reported their symptoms were caused or aggravated by green beans, burlap bags, or by grinding or flavoring coffee.
- Some employees reported wheezing or whistling in the chest that was aggravated by green coffee beans.
- One spirometry test result indicated mild obstruction.
- The flavoring, grinding, and packaging processes presented risk factors for repetitive strain injuries and burns.

What the Employer Can Do

- Ensure employees understand potential hazards (e.g., diacetyl, 2,3-pentanedione, carbon monoxide, carbon dioxide, and green and roasted coffee dust) in the workplace and how to protect themselves.
- Follow manufacturer's guidelines for periodic cleaning of the roasters' exhausts.
- Limit access to the area while higher exposure tasks are occurring.
- Continue to cover bins of roasted coffee beans to reduce emissions of alpha-diketones, carbon monoxide, and carbon dioxide into the air.
- Automate transfer of roasted beans, whenever possible, to minimize manual handling.
- Install local exhaust ventilation to reduce air concentrations of alpha-diketones during the following tasks: 1) flavoring coffee; 2) blending roasted coffee by hand, if an alternative method cannot be provided; 3) grinding roasted coffee; and 4) weighing and packaging roasted coffee.
- Conduct follow-up air sampling to verify that the modifications have been effective in reducing exposures to below the recommended exposure limits.
- If follow-up air sampling after engineering controls have been installed and administrative controls are implemented indicates levels of diacetyl or 2,3-pentanedione are above their respective National Institute for Occupational Safety

and Health recommended exposure limit or short-term exposure limit, or if a long delay is anticipated before these controls can be put into place, we recommend respiratory protection be used during tasks with elevated exposures.

- Require lift gates for all deliveries of green beans.
- Eliminate the use of compressed air as much as possible during cleaning. Instead, use a vacuum system with a high-efficiency particle air filter and wet methods whenever possible.
- Encourage employees to report new, worsening, or ongoing respiratory symptoms to their personal healthcare providers and to a designated individual at the workplace.
- Institute a medical monitoring program for employees who work in the production area.

What Employees Can Do

- Whenever possible, avoid spending time in the immediate area during flavoring, grinding, and packaging.
- As much as possible, avoid placing your head directly above or inside roasted bean storage bins.
- Use any local exhaust ventilation as instructed by your employer when it is installed.
- Pour green beans into the roaster hopper from the control panel side of the roaster to help prevent the possibility of contact with the hot roaster exhaust duct.
- Report new, persistent, or worsening respiratory symptoms to your personal healthcare provider(s) and a designated individual at your workplace.
- Participate in any personal air sampling offered by your employer.
- Participate in your employer's medical monitoring program as instructed by your employer.

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Abbreviations

µg	Microgram
°F	degrees Fahrenheit
ACGIH®	American Conference of Governmental Industrial Hygienists
APF	Assigned protection factor
AX	Area of reactance
CFR	Code of Federal Regulations
CO	Carbon monoxide
CO_2	Carbon dioxide
COPD	Chronic obstructive pulmonary disease
DR5-R20	The difference between resistance at 5 and 20 Hertz
FEV_1	1-second forced expiratory volume
Fres	Resonant frequency
FVC	Forced vital capacity
kPa/(L/s)	Kilopascals per liter per second
IDLH	Immediately dangerous to life or health
LOD	Limit of detection
mL	Milliliter
mL/min	Milliliter per minute
NHANES	National Health and Nutrition Examination Survey
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PEL	Permissible exposure limit
ppb	Parts per billion
ppm	Parts per million
R5	Resistance at 5 Hertz
R20	Resistance at 20 Hertz
REL	Recommended exposure limit
RH	Relative humidity
STEL	Short-term exposure limit
TLV®	Threshold limit value
TVOC	Total volatile organic compounds
TWA	Time-weighted average
VOC	Volatile organic compound
X5	Reactance at 5 Hertz

Summary

In November 2016, the Health Hazard Evaluation Program of the National Institute for Occupational Safety and Health received a request from management of a coffee roasting and flavoring facility with six employees regarding repetitive motion injuries, potential burns, general warehouse safety, and potential employee exposure to green coffee bean dust, diacetyl, and 2,3-pentanedione during coffee processing. In January 2017, we observed work practices and conducted an industrial hygiene survey and a medical survey at the facility. The industrial hygiene survey consisted of collecting personal breathing zone and area air samples for alpha-diketones (i.e., diacetyl, 2,3-pentanedione, and 2,3-hexanedione), carbon monoxide, and carbon dioxide. Bulk samples of whole bean coffee and flavoring were collected to evaluate the potential for emission of diacetyl, 2,3-pentanedione, and 2,3-hexanedione. We used continuous monitoring instruments to measure total volatile organic compounds, carbon monoxide, carbon dioxide, temperature, and relative humidity in specific areas and during tasks. The medical survey consisted of a health questionnaire and breathing tests. One interim report with recommendations was sent to the company following our visit.

Overall, full-shift time-weighted average air concentrations of diacetyl and 2,3-pentanedione were higher in flavoring and grinding areas of the facility. All four of the personal full-shift samples collected in the production area exceeded the NIOSH recommended exposure limit for diacetyl of 5 parts per billion, with a maximum measured concentration of 20.7 parts per billion. One of the four personal full-shift samples collected in the production area exceeded the NIOSH recommended exposure limit for 2,3-pentanedione of 9.3 parts per billion, with a maximum measured concentration of 24.0 parts per billion. We identified some work tasks that resulted in relatively higher air concentrations of diacetyl than other tasks. Specifically, flavoring roasted coffee beans by hand, grinding flavored and unflavored roasted coffee beans, and weighing and packaging roasted coffee were associated with higher diacetyl levels. Some employees reported eye, nose, or sinus symptoms or wheezing or whistling in the chest that was aggravated at work. We also observed tasks that presented risk factors for repetitive strain injuries and burns, specifically the flavoring, grinding, and packaging processes. We recommend installing local exhaust ventilation, implementing administrative controls such as modification of work practices, and training employees about workplace hazards. We also recommend a medical monitoring program to identify any employees who might be developing work-related lung disease (e.g., asthma, obliterative bronchiolitis) and to help management prioritize interventions to prevent occupational lung disease.

Introduction

In November 2016, the Health Hazard Evaluation Program of the National Institute for Occupational Safety and Health (NIOSH) received a request from management at a coffee roasting and flavoring facility. The request stated concerns about repetitive motion injuries, potential burns, general warehouse safety, and potential employee exposure to green coffee bean dust, diacetyl, and 2,3-pentanedione during coffee processing. In January 2017, we observed work practices and conducted an industrial hygiene survey and a medical survey at the facility. We collected personal and area breathing zone air samples for volatile organic compounds (VOCs), including diacetyl, 2,3-pentanedione, and 2,3-hexanedione. We also monitored carbon monoxide (CO), carbon dioxide (CO_2), and total volatile organic compounds (TVOCs). The medical survey consisted of a health questionnaire and breathing tests. After the visit, we provided an interim report with recommendations.

Background

Diacetyl and 2,3-Pentanedione

Diacetyl (2,3-butanedione) and 2,3-pentanedione (acetyl propionyl) are VOCs known as alpha-diketones that are added as ingredients in food flavorings used in some food products such as microwave popcorn, bakery mixes, and flavored coffee [Day et al. 2011; Kanwal et al. 2006; Bailey et al. 2015]. Diacetyl, 2,3-pentanedione, other VOCs, and gases such as CO and CO_2 are naturally produced and released during the coffee roasting process [Duling et al. 2016; Raffel and Thompson 2013; Daglia et al. 2007; Nishimura et al. 2003; Newton 2002]. Grinding roasted coffee beans produces a greater surface area for off-gassing (sometimes called degassing) of these compounds [Akiyama et al. 2003]. Often, coffee roasting facilities package newly roasted coffee in permeable bags or in bags fitted with one-way valves to allow the coffee to off-gas after it is packaged. Sometimes, newly roasted coffee is placed in bins or containers and allowed to off-gas before packaging.

NIOSH has recommended exposure limits (RELs) for diacetyl and 2,3-pentanedione in workplace air (Table 1). The NIOSH objective in establishing RELs for diacetyl and 2,3-pentanedione is to reduce the risk of respiratory impairment (decreased lung function) and the severe irreversible lung disease obliterative bronchiolitis associated with occupational exposure to these chemicals. The NIOSH RELs are intended to protect workers exposed to diacetyl or 2,3-pentanedione for a 45-year working lifetime. The REL for diacetyl is based on a quantitative risk assessment which necessarily contains assumptions and some uncertainty. Analytical limitations current at the time were taken into consideration in setting the REL for 2,3-pentanedione. The RELs should be used as guidelines to indicate when steps should be taken to reduce exposures in the workplace.

These exposure limits and the accompanying recommendations for control of exposures were derived from a risk assessment of flavoring-exposed workers. At an exposure equal to the diacetyl REL, the risk of adverse health effects is low. NIOSH estimated that about 1 in 1,000 workers exposed to diacetyl levels of 5 parts per billion (ppb) as a time-weighted average

(TWA) for 8 hours a day, 40 hours a week for a 45-year working lifetime would develop reduced lung function (defined as forced expiratory volume in one second [FEV1] below the lower limit of normal) as a result of that exposure. NIOSH predicted that around 1 in 10,000 workers exposed to diacetyl at 5 ppb for a 45-year working lifetime would develop more severe lung function reduction (FEV1 below 60% predicted, defined as moderately severe by the American Thoracic Society [Pellegrino et al. 2005]). Workers exposed for less time would be at lower risk for adverse lung effects.

2,3-Hexanedione

2,3-Hexanedione is also an alpha-diketone that is sometimes used as a substitute for diacetyl and is produced naturally during coffee roasting. In a study using animals, there was some evidence that 2,3-hexanedione might also damage the lungs, but it appeared to be less toxic than diacetyl and 2,3-pentanedione [Morgan et al. 2016]. There are no established occupational exposure limits for 2,3-hexanedione.

Carbon Monoxide and Carbon Dioxide

CO and CO_2 are gases produced by combustion. They are also produced as a result of reactions that take place during coffee roasting. These gases are released during and after roasting and grinding in a process called off-gassing [Anderson et al. 2003]. High exposures to CO and CO_2 can cause headache, dizziness, fatigue, nausea, altered mentation, rapid breathing, impaired consciousness, coma, and death [Newton 2002; Nishimura et al. 2003; Langford 2005; CDC 2013a; Raffel and Thompson 2013; Rose et al. 2017]. Occupational exposure limits for CO and CO_2 are listed in Table 1.

Exposure Limits

We utilize mandatory (legally enforceable) and recommended occupational exposure limits (OELs) when evaluating workplace hazards. OELs have been developed by federal agencies and safety and health organizations to prevent adverse health effects from workplace exposures.

Occupational Safety and Health Administration (OSHA) [Mandatory]

The U.S. Department of Labor's OSHA permissible exposure limits (PELs) are legal limits that are enforceable in workplaces covered under the Occupational Safety and Health Act. OSHA PELs represent the legal maximum for a TWA exposure to a physical or chemical agent over a work shift [OSHA 2016]. OSHA short-term exposure limits (STELs) are the legal maximum average exposure for a 15-minute time period. Some chemicals also have an OSHA ceiling value, which represent levels that must not be exceeded at any time. Currently, there are no PELs for diacetyl, 2,3-pentanedione, or 2,3-hexanedione. For substances for which an OSHA PEL has not been issued, violation of the OSHA General Duty Clause can be considered using available occupational exposure references and recommendations [OSHA 1993; OSHA 2003], such as the American Conference of Governmental Industrial Hygienists (ACGIH®) Threshold Limit Values (TLVs®) and NIOSH RELs.

American Conference of Governmental Industrial Hygienists (ACGIH) [Recommendations]

ACGIH is a professional, not-for-profit scientific association that reviews existing published, peer-reviewed scientific literature and publishes recommendations for levels of substances in air based on an 8-hour workday and 40-hour workweek. These recommendations are called TLVs [ACGIH 2017a]. ACGIH TLVs are not standards; they are health-based guidelines derived from scientific and toxicological information. ACGIH provides TLV-TWA guidelines that are levels that should not be exceeded during any 8-hour workday of a 40-hour workweek. ACGIH also provides TLV-STEL guidelines which are 15-minute exposure levels that should not be exceeded during a workday. Exposures above the TLV-TWA but less than the TLV-STEL should be (1) less than 15 minutes, (2) occur no more than four times a day, and (3) be at least 60 minutes between exposures [ACGIH 2017a]. Additionally, ACGIH provides TLV-Ceiling values, which are levels that should not be exceeded at any time during a work shift. The ACGIH TLV-TWA for diacetyl is 10 ppb. The TLV-STEL for diacetyl is 20 ppb. Currently, there is no TLV-TWA or TLV-STEL for 2,3-pentanedione. ACGIH has placed 2,3-pentanedione on the 2017 list of Chemical Substances and Other Issues Under Study [ACGIH 2017b].

<u>National Institute for Occupational Safety and Health (NIOSH) [Recommendations]</u>
NIOSH provides RELs as TWA concentrations that should not be exceeded over an 8- or 10-hour work shift, during a 40-hour workweek [NIOSH 2010]. RELs are intended to be protective over a 45-year working lifetime. NIOSH also provides STELs which are 15-minute TWA exposures that should not be exceeded at any time during a workday [NIOSH 2010]. Some chemicals have ceiling values, which are concentrations that should not be exceeded at any time [NIOSH 2010]. For some chemicals, NIOSH has established an Immediately Dangerous to Life or Health (IDLH) value. An IDLH value is a concentration of an air contaminant that can cause death or immediate or delayed permanent adverse health effects, or prevent escape from such an environment. Currently, NIOSH has RELs and STELs for diacetyl and 2,3-pentanedione. NIOSH does not have a REL or a STEL for 2,3-hexanedione. NIOSH does not have ceiling limits or IDLH values for diacetyl, 2,3-pentanedione, or 2,3-hexanedione.

For diacetyl and 2,3-pentanedione, the NIOSH RELs are 5.0 ppb and 9.3 ppb, respectively, as a TWA for up to an 8-hour workday during a 40-hour workweek (Table 1). The NIOSH STELs are 25 ppb for diacetyl and 31 ppb for 2,3-pentanedione [NIOSH 2016]. The NIOSH exposure limits do not differentiate between natural and synthetic chemical origin of diacetyl or 2,3-pentanedione. Although the NIOSH exposure limit for 2,3-pentanedione is above that of diacetyl, 2,3-pentanedione has been shown to be as hazardous as diacetyl [Hubbs et al. 2012; Morgan et al. 2012]. The NIOSH REL is higher for 2,3-pentanedione than for diacetyl largely because analytic measures were not available in a validated OSHA method to detect 2,3-pentanedione at lower levels. The hazard potential probably increases when these chemicals occur in combination with each other; having exposure to chemicals with the same functional alpha-diketone group and effect on the same system or organ (e.g., lungs) can result in additive effects [ACGIH 2017a]. In addition to the REL, NIOSH also recommends an action level for diacetyl of 2.6 ppb to be used with exposure monitoring in an effort to ensure employee exposures are routinely below the diacetyl REL. When exposures exceed the action level, employers should take corrective action (i.e., determine the source of exposure, identify methods for controlling exposure) to ensure that exposures are maintained below the NIOSH REL for diacetyl [NIOSH 2016].

Table 1. Personal exposure limits for compounds sampled during the NIOSH survey, January 2017.

Compound	OSHA*	ACGIH		NIOSH		
	PEL	TLV	STEL	REL	STEL	IDLH
Diacetyl	—	10 ppb	20 ppb	5.0 ppb†	25 ppb	—
2,3-Pentanedione	—	—	—	9.3 ppb†	31 ppb	—
2,3-Hexanedione	—	—	—	—	—	—
Carbon dioxide‡	5,000 ppm	5,000 ppm	30,000 ppm	5,000 ppm	30,000 ppm	40,000 ppm
Carbon monoxide‡	50 ppm	25 ppm	—	35 ppm	200 ppm (ceiling limit)§	1,200 ppm

Note: OSHA=Occupational Safety and Health Administration; ACGIH=American Conference of Governmental Industrial Hygienists; NIOSH=National Institute for Occupational Safety and Health; PEL=permissible exposure limit; TLV=threshold limit value; STEL=short-term exposure limit; REL=recommended exposure limit; IDLH=immediately dangerous to life or health; ppb=parts per billion; ppm=parts per million; "—"=no exposure limit available.
***There are no OSHA STELs for the compounds in the table.**
†The NIOSH RELs for diacetyl and 2,3-pentanedione are time-weighted averages for up to an 8-hour day, during a 40-hour workweek.
‡OSHA and NIOSH limits are designed for occupational exposure measurements in manufacturing and other trades that have potential sources of carbon dioxide or carbon monoxide (e.g., coffee roasting, welding, vehicle exhaust, diesel engine exhaust). Typical levels of carbon monoxide in offices are 0–5 ppm. In office settings, carbon dioxide generally should not be greater than 700 ppm above outdoor carbon dioxide levels; this typically corresponds to indoor concentrations below 1,200 ppm.
§This is the NIOSH ceiling exposure limit for carbon monoxide. A ceiling concentration should not be exceeded at any time.

Obliterative Bronchiolitis

Obliterative bronchiolitis is a serious, often disabling, lung disease that involves scarring of the very small airways (i.e., bronchioles). Symptoms of this disease might include cough, shortness of breath on exertion, or wheeze, that do not typically improve away from work [NIOSH 2012]. Occupational obliterative bronchiolitis has been identified in flavoring manufacturing workers and microwave popcorn workers who worked with flavoring chemicals or butter flavorings [Kreiss 2013; Kim et al. 2010; Kanwal et al. 2006]. It has also been identified in employees at a coffee roasting and packaging facility that produced unflavored and flavored coffee [CDC 2013b]. A NIOSH health hazard evaluation at that facility found diacetyl and 2,3-pentanedione concentrations in the air that were elevated and identified three sources: 1) flavoring chemicals added to roasted coffee beans in the flavoring area; 2) grinding unflavored roasted coffee beans and packaging unflavored ground and whole bean roasted coffee in a distinct area of the facility, and 3) storing roasted coffee in hoppers, on a mezzanine above the grinding/packaging process, to off-gas [Duling et al. 2016]. At the time of the health hazard evaluation, workers had excess shortness of breath and obstruction on spirometry, both consistent with undiagnosed lung disease. Respiratory illness was associated with exposure and not limited to the flavoring areas [Bailey et al.

2015]. However, all workers who were diagnosed with obliterative bronchiolitis had worked in the flavoring area. To date, no cases of obliterative bronchiolitis have been reported in workers at coffee roasting and packaging facilities that produce only unflavored coffee.

Work-related Asthma
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]. 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 might 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.

Green and roasted coffee dust and castor beans (from cross-contamination of bags used to transport coffee) are known risk factors for occupational asthma [Figley and Rawling 1950; Karr et al. 1978; Zuskin et al. 1979, 1985; Thomas et al. 1991]. Persons who become sensitized (develop an immune reaction) to coffee dust can subsequently react to relatively low concentrations in the air. Others might experience irritant-type symptoms from exposure to coffee dust [Oldenburg et al. 2009].

Based on the findings of previous NIOSH health hazard evaluations regarding alpha-diketones, the coffee roasting and flavoring company wanted to characterize concentrations of alpha-diketones in the facility. Because of concerns about repetitive motion injuries, potential burns, general warehouse safety, and respiratory health from alpha-diketones, in November 2016, the management submitted a health hazard evaluation request to NIOSH.

Process Description

Personnel
The coffee roasting and flavoring company employed six employees. During our visit, two employees worked production, two employees worked administrative, one employee worked deliveries, and one employee was on leave.

Facility
The coffee roasting and flavoring company was located in a single-story building with a production area and a conference/administration area. The facility was approximately 1,300 square feet. The production area included the production office, cold brew storage, supply storage, roaster, flavoring, grinding and weigh/pack, and green bean storage. The facility roasted, ground, flavored, and packaged coffee for wholesale to local businesses and churches. Roasted beans were packaged either whole or ground and either flavored or unflavored, depending on the needs of the customer.

Green Beans

The coffee roasting and flavoring facility received green coffee beans in burlap bags from Nicaragua, Brazil, Kenya, Costa Rica, Ethiopia, Colombia, and Tanzania. Bags of green coffee beans delivered to the facility were manually unloaded from delivery trucks. The green coffee beans were stored on pallets located next to the roaster.

Roasting

The roaster was turned on to begin heating to the desired roasting temperature. To prepare a batch of coffee beans for roasting, the roaster operator scooped the desired amount of coffee beans from a bag of green coffee beans into a five-gallon bucket. The green beans were then dumped into the hopper at the top of the roaster. The beans were heated to a specific temperature and time period for the desired roast. Time and temperature varied among different types of roasts. Once the beans were roasted for the desired amount of time, the roaster operator pulled a lever that allowed the roasted beans to drop into a cooling bin where they were agitated by a rotating arm. The cooling bin utilized a downdraft exhaust system that drew air over the roasted beans to accelerate cooling. The downdraft system exhausted through the roaster and then to the outside through a ventilation pipe. The roaster operator monitored the roasting equipment throughout the roasting and cooling process. After cooling, the roasted beans were dispensed from the cooling bin into 10-gallon plastic storage containers with lids. The roaster operator manually moved the plastic storage containers to a storage area located underneath the grinding bench approximately 15 feet away.

Flavoring

Approximately 12 quarts of roasted coffee beans were scooped into an 18-quart bucket for flavoring. The only flavoring used during our visit was a butterscotch flavor. The employee measured the desired amount of flavoring into a measuring cup. The flavoring was then poured over the roasted beans. A lid was put onto the 18-quart bucket, and the employee shook the bucket overhead for approximately 30 seconds to one minute to mix the flavoring.

Grinding

The majority of roasted coffee was ground. In the grinding area, roasted beans were poured from the plastic storage containers or flavoring mixing bucket into the tops of the grinders. The ground coffee was collected in a large plastic bag and stored for weighing and packaging. There were four grinding machines, one for flavored coffee and three for unflavored coffee.

Weighing and Packaging

Coffee was packaged into 4-ounce, 6-ounce, 5-pound, and 11-pound packages. For whole bean coffee, orders were filled by scooping roasted beans from the desired storage containers, weighing the beans on a scale, and then placing the beans into a bag and sealing the bag with a heat sealer. For ground coffee, orders were filled by scooping ground coffee from the large plastic bags in the grinding area, weighing the ground coffee on a scale, and then scooping the weighed coffee into a bag and sealing the bag with a heat sealer. Completed orders were stored on a bench top located next to the grinding area.

Cleaning Activities
An employee used a portable vacuum and air compressor to clean the roaster and remove accumulated chaff under the cooling bin. Then the employee would wipe the exterior of the roaster down with paper towels and water.

Cold-brew and Nitro Coffee
The facility would brew coffee and store cold-brew coffee in the production office/cold brew storage area. Nitro coffee was produced from cold brew by pressurizing the cold-brew coffee with nitrogen inside of a keg. The cold-brew coffee and nitro coffee were delivered to local churches and businesses.

Personal Protective Equipment
Employees were not required to wear a company uniform or protective clothing. We did not observe employees wearing respiratory protection for chemicals or dust during our visit; however, we observed N95 respirators available for voluntary use.

Methods

We visited the coffee roasting and flavoring facility in January 2017. We held an opening meeting with management and employees, observed work practices, collected bulk samples and air samples, and conducted a medical survey. At the conclusion of our site visit, we held a closing meeting with management and employees. We provided a letter detailing our evaluation and preliminary recommendations to management in February 2017.

We had the following objectives for the health hazard evaluation:

1. Measure employees' exposure to diacetyl, 2,3-pentanedione, and 2,3-hexanedione during coffee processing;
2. Identify process areas or work tasks associated with emissions of diacetyl, 2,3-pentanedione, and 2,3-hexanedione;
3. Measure levels of CO and CO_2 throughout the facility;
4. Determine prevalence of mucous membrane, respiratory, and systemic symptoms among employees and if those symptoms were work-related or aggravated by work;
5. Determine if employees had abnormal lung function tests; and
6. Evaluate ergonomic stressors and potential for burns by observing work practices and asking relevant open-ended questions.

Industrial Hygiene Survey
Sampling Times for Alpha-Diketones
We designed the sampling strategy to assess full-shift exposures and to identify tasks and processes that were the greatest contributors to worker exposure to alpha-diketones. Sampling was conducted over two days during the site visit. For diacetyl, 2,3-pentanedione,

and 2,3-hexanedione, air samples were collected over seconds, minutes, and hours. Samples collected over hours can help determine average concentrations that can be compared to the NIOSH RELs for diacetyl and 2,3-pentanedione. These average concentrations might not tell us about short-term peak exposures that could be relevant to respiratory health, particularly when tasks are repeated multiple times per day. Therefore, during particular tasks, we collected air samples over several minutes. We also conducted instantaneous sampling over seconds to help identify point sources of alpha-diketones.

Employees that participated in air sampling were given the opportunity to request their individual air sampling results.

Air Sampling and Analysis Using Modified Occupational Safety and Health Administration (OSHA) Methods 1013/1016

We collected personal and area air samples for diacetyl, 2,3-pentanedione, and 2,3-hexanedione on silica gel sorbent tubes during the industrial hygiene survey over two days. The samples were collected and analyzed according to the modified OSHA sampling and analytical Methods 1013/1016 [OSHA 2008; OSHA 2010; LeBouf and Simmons 2017]. In accordance with the two methods, two glass silica gel sorbent tubes were connected by a piece of tubing and inserted into a protective, light-blocking cover. The tubes were connected in series to a sampling pump pulling air through the tubes at a flow rate of 50 milliliters per minute (mL/min). The sampling setup was attached to an employee's breathing zone or placed in an area basket in various places throughout the facility. For full-shift sampling, we collected two consecutive 3-hour samples and calculated the TWA concentration from the two samples, assuming that the total 6-hour monitoring results reflected a full work shift (8-hour) TWA exposure. Although this might introduce some error, it is a conservative approach that is more protective of employees than the alternative assumption of no exposure during the last two hours of the shift. We refer to these samples as "full-shift samples" throughout this report. We also collected short-term task based samples in the same manner, but the sampling pump flow rate was 200 mL/min as detailed in OSHA Methods 1013 and 1016 [OSHA 2008; 2010]. Sampling times were dependent on the duration of the task being performed.

Analyses of the samples were performed in the NIOSH Respiratory Health Division's Organics Laboratory. The samples were extracted for one hour in 95% ethanol: 5% water containing 3-pentanone as an internal standard. Samples were analyzed using an Agilent 7890/7001 gas chromatograph/mass spectrometer system operated in selected ion monitoring mode for increased sensitivity compared to the traditional flame ionization detector used in OSHA Methods 1013 and 1016 [LeBouf and Simmons 2017].

A limit of detection (LOD) is the lowest mass that an instrument can detect above background and is a criteria used to determine whether to report a result from a sample. LODs for the visit were 0.01 micrograms per sample (µg/sample) for diacetyl, 0.01 µg/sample for 2,3-pentanedione, and 0.01 µg/sample for 2,3-hexanedione; these were based on the lowest mass used in the calibration curve. These equate to 0.32 ppb for diacetyl, 0.27 ppb for 2,3-pentanedione, and 0.24 ppb for 2,3-hexanedione for a typical full-shift TWA air sample but will vary depending on the volume of air collected during the sampling period. The LODs for task samples are generally higher than typical LOD values for full-shift samples, because the air volumes collected during task samples are lower. When the values presented in the report are from samples below the LOD they are denoted by a "<" symbol.

Air Sampling and Analysis Using Evacuated Canisters

We collected instantaneous source air samples for VOCs including diacetyl, 2,3-pentanedione, and 2,3-hexanedione using evacuated canisters. We also collected instantaneous air samples before and after the work shift to determine if air concentrations of alpha-diketones increased over a work shift. The evacuated canister sampling setup consisted of a 450-milliliter (mL) evacuated canister equipped with an instantaneous flow controller that was designed for a short sampling duration (less than 30 seconds). Instantaneous samples were taken by opening the evacuated canister to grab a sample of air to help identify point sources of alpha-diketones. For source air samples, a NIOSH employee placed the inlet of the flow controller directly at the source of interest.

The canister air samples were analyzed using a pre-concentrator/gas chromatograph/mass spectrometer system pursuant to a published method validation study [LeBouf et al. 2012], with the following modifications: the pre-concentrator was a Model 7200 (Entech Instruments, Inc., Simi Valley, CA) and included the compounds diacetyl, 2,3-pentanedione, 2,3-hexanedione, acetaldehyde, acetone, acetonitrile, benzene, chloroform, d-limonene, ethanol, ethylbenzene, isopropyl alcohol, methyl methacrylate, methylene chloride, styrene, toluene, alpha-pinene, m,p-xylene, and o-xylene. At present, this canister method is partially validated [LeBouf et al. 2012] and not considered the standard method. LODs were 0.26 ppb for diacetyl, 0.36 ppb for 2,3-pentanedione, and 0.64 ppb for 2,3-hexanedione based on a three-times dilution factor, which is typical for restricted flow controller samplers. However, LODs are dependent on the pressure inside each canister after the samples have been collected, and they might be higher or lower than typical LOD values.

Bulk Sampling and Headspace Analysis

We used 50-mL sterile polypropylene centrifuge tubes to collect approximately 40-mL bulk samples of roasted whole bean coffee and liquid flavoring. For headspace analysis of alpha-diketones, we transferred 1 gram of solid bulk material into a sealed 40-mL amber volatile organic analysis vial and let it rest for 24 hours at room temperature (70°F) in the laboratory. Then 2 mL of headspace air was transferred to a 450-mL canister and pressurized to approximately 1.5 times atmospheric pressure. Using the canister analysis system, the concentrations were calculated in ppb of analytes in the headspace as an indicator of emission potential.

Real-time Air Sampling

We used RAE Systems (San Jose, CA) ppbRAE 3000 (Model #PGM-7340) and Ion Science (Stafford, TX) Tiger Handheld VOC monitors to measure concentrations of TVOCs in the air. The TVOC monitors have a non-specific photoionization detector that responds to chemicals with ionization potentials below the energy of the lamp. This sampling was conducted to identify areas where coffee could be releasing TVOCs. Areas where higher concentrations of

TVOCs are measured might benefit from further sampling to characterize specific exposures to alpha-diketones. We also collected real-time measurements of CO_2, CO, temperature, and relative humidity (RH) using TSI Incorporated (Shoreview, MN) VelociCalc Model 9555-X Multi-Function Ventilation Meters equipped with Model 982 IAQ probes. All real-time instruments were set to log data at 10-second intervals.

Personal Carbon Monoxide (CO) Sampling
Some employees wore Dräger (Lübeck, Germany) Pac 7000 personal single gas detectors to monitor personal CO exposures. Personal CO monitors were set to log data at 10-second intervals.

Repetitive Motion Injuries, Burns, and Safety Concerns
We evaluated the work environment and production tasks for ergonomics, burn potential, and general small warehouse safety issues by observing and documenting work practices.

NIOSH Medical Survey
Participants
We invited all current employees to participate in the medical survey at the workplace on January 12, 2017. Participation was voluntary; written informed consent was obtained from each participant before testing. The survey included, in the order performed, a medical and work history questionnaire, quantification of exhaled nitric oxide, impulse oscillometry, spirometry, and if indicated the administration of a bronchodilator with repeat impulse oscillometry and spirometry. We mailed participants their individual reports explaining their breathing test results and recommended each participant provide the information to their personal physician.

Questionnaire
We used an interviewer-administered computerized questionnaire to ascertain symptoms and diagnoses, work history at this coffee roasting and flavoring facility and other coffee or flavoring companies, and cigarette smoking history. Questions on respiratory health were derived from five standardized questionnaires, the European Community Respiratory Health Survey [Burney et al. 1994; ECRHS 2014], the American Thoracic Society adult respiratory questionnaire (ATS-DLD-78) [Ferris 1978], the International Union Against Tuberculosis and Lung Disease [Burney and Chinn 1987; Burney et al. 1989], and the Third National Health and Nutrition Examination Survey (NHANES III) [CDC 1996] and NHANES 2007-2012 questionnaires [CDC 2017a]. Some of the questions appeared on more than one of the standardized questionnaires. We also supplemented our questionnaire with additional respiratory and systemic symptom questions and open-ended questions about concerns regarding repetitive motion injuries and burns.

Spirometry
The purpose of the spirometry test was to determine a person's ability to move air out of their lungs. Test results were compared to expected normal values. The test included three measurements or calculations: 1) forced vital capacity (FVC), (the total amount of air the participant can forcefully blow out after taking a deep breath), 2) FEV1 (the amount of air

that the participant can blow out in the first second of exhaling), and 3) the ratio of FEV1 to FVC. We used American Thoracic Society criteria for acceptability and repeatability [Miller et al. 2005].

We used a volume spirometer (dry rolling seal spirometer) to measure exhaled air volume and flow rates. We used equations for predicted values and lower limits of normal derived from NHANES III data to define abnormal spirometry [Hankinson et al. 1999]. We defined obstruction as an FEV_1/ FVC ratio less than the lower limit of normal with FEV_1 less than the lower limit of normal; restriction as a normal FEV_1/FVC ratio with FVC less than the lower limit of normal; and mixed obstruction and restriction as having FEV_1, FVC, and FEV_1/FVC ratio all less than the lower limit of normal. We used the FEV_1 percent predicted to categorize such abnormalities as mild, moderate, moderately severe, severe, or very severe [Pellegrino et al. 2005].

Impulse Oscillometry

Many occupational lung diseases (e.g., chronic obstructive pulmonary disease (COPD), asthma) involve the small airways; however, this part of the lung is difficult to evaluate non-invasively. Oscillometry is a helpful technology to understand the effects of occupational exposures on the small airways. There are no contraindications to the test as this test is conducted using regular breathing and does not require a forceful exhalation [Smith et al. 2005]. Spirometry can be normal despite respiratory symptoms or evidence of small airways disease on lung biopsy [King et al. 2011; Oppenheimer et al. 2007]; therefore, oscillometry results complement spirometry and can be used when spirometry is not possible because of a contraindication.

We used an impulse oscillometry machine (CareFusion Corp., San Diego, CA) to measure resistance (R), the energy required to propagate the pressure wave through the airways, and reactance (X), which reflects the viscoelastic properties of the respiratory system. The impulse oscillometry testing machine sends sound waves called pressure oscillations at different frequencies (e.g., 5 Hertz and 20 Hertz) into the airways to measure how airways respond to these small pressures. The test calculates 1) the airway resistance at different frequencies including 5 Hertz (R5) and 20 Hertz (R20), and the difference between R5 and R20 (DR5-R20); 2) the reactance at different frequencies including 5 Hertz (X5); 3) resonant frequency (Fres) which is the frequency where there is no airway reactance; and 4) the total reactance (AX) at all frequencies between 5 Hertz and the Fres. The predicted values for R and X were based on sex and age according to reference values recommended by the manufacturer [Vogel and Smidt 1994]. R5 was considered abnormal (elevated) if the measured value was equal to or greater than 140 percent of the predicted R5. X5 was considered abnormal (decreased) if the value of the predicted X5 minus measured X5 was equal to or greater than 0.15 kilopascals per liter per second (kPa/(L/s)). DR5-R20 values greater than 30% were considered abnormal and evidence of frequency dependence [Smith 2015]. We interpreted the test as normal if both the R5 and X5 were normal [Smith 2015]. We defined possible large (central) airways abnormality as a normal X5 and elevated R5 with no evidence of frequency dependence. We defined a possible small airways abnormality if there was evidence of frequency dependence and/or a decreased X5 with or without an elevated R5. We defined possible combined small (peripheral) and large (central airways) abnormality as a decreased X5 and elevated R5 with no evidence of frequency dependence.

Bronchodilator Reversibility Testing for Impulse Oscillometry and Spirometry
If a participant had abnormal impulse oscillometry or spirometry, we offered a bronchodilator inhaler medication (i.e., albuterol), which can open the airways in some individuals (e.g., asthmatics) and then repeated both tests after the participant received the bronchodilator. For oscillometry, we defined reversibility (improvement) after bronchodilator administration as a decrease of at least 20% of either Fres or R5 or a decrease of 40% for AX. For spirometry, we defined reversibility (improvement) as increases of at least 12% and 200 mL for either FEV_1 or FVC after bronchodilator administration.

Fractional Exhaled Nitric Oxide (FeNO)
We used the NIOX MINO® device (Aerocrine Inc., Morrisville, NC) to measure the amount of nitric oxide in the air the participant breathed out. Nitric oxide is a gas that is produced by the airways, and elevated levels can be a sign of eosinophilic airway inflammation in asthma [Dweik et al. 2011]. In adults, fractional nitric oxide concentration in exhaled breath levels above 50 ppb are considered elevated. In adults with asthma, elevated levels might indicate that their asthma is uncontrolled [Dweik et al. 2011].

Statistical Analysis
We performed analyses using Excel (Microsoft®, Redmond, WA) and SAS version 9.4 (SAS Institute, Cary, NC). We created summary statistics by work area location and task. When the values presented in the report are from samples below the LOD they are denoted by a "<" symbol.

Results

Industrial Hygiene Survey Results
Personal and Area Full-shift Air Sampling Results
Table A1 presents the personal and area full-shift air sampling results from our visit in January 2017. We collected five personal full-shift air samples, including four on employees working indoors and one on an employee performing off-site work, and 20 area full-shift air samples over two days. All four personal air samples collected indoors were above the NIOSH REL for diacetyl of 5.0 ppb, and one personal air sample was above the NIOSH REL for 2,3-pentanedione of 9.3 ppb. The samples exceeding the REL for diacetyl were collected on different days. Only one personal sample was above the LOD for 2,3-hexanedione.

For area full-shift air sampling, the grinding area had the highest air concentrations of diacetyl with a range of 12.6 ppb–27.7 ppb. For grinding, the range was 12.1 ppb–28.0 ppb for 2,3-pentanedione and <0.2 ppb–0.7 ppb for 2,3-hexanedione. The roasting area had the second highest air concentration of diacetyl with a range of 5.4 ppb–12.6 ppb. For roasting, the range was 4.9 ppb–11.1 ppb for 2,3-pentanedione and <0.2 ppb for 2,3-hexanedione.

Task-based Air Sampling Results

Table A2 presents the personal task-based air sampling results from our visit in January 2017. We collected 15 personal task-based air samples. An employee who flavored roasted beans for six minutes had an exposure to diacetyl of 67.2 ppb and 2,3-pentanedione of 82.6 ppb. An employee who packaged ground coffee for 12 minutes had an exposure to diacetyl of 53.2 ppb and to 2,3-pentanedione of 56.8 ppb. An employee who ground coffee for 11 minutes had an exposure to diacetyl of 32.0 ppb and to 2,3-pentanedione of 36.4 ppb. Just three of the task-based samples were above the LOD for 2,3-hexanedione, with a maximum concentration of 2.0 ppb.

Source Air Sampling Results

Table A3 presents the source air sampling results using instantaneous evacuated canisters. We sampled at the top of a mixing bucket that contained whole bean coffee with butterscotch flavoring and measured 27.5 ppb for diacetyl, 68.6 ppb for 2,3-pentanedione, and <9.6 ppb for 2,3-hexanedione. We captured two instantaneous evacuated canister source samples during grinding of butterscotch-flavored coffee and found air concentrations of 65.5 ppb and 489 ppb for diacetyl, 61.9 ppb and 604 ppb for 2,3-pentanedione, and 1.9 ppb and 13.7 ppb for 2,3-hexanedione. A sample was taken at the headspace of the butterscotch flavoring bottle that measured <3.8 ppb diacetyl, 1,469 ppb 2,3-pentanedione, and <9.4 ppb 2,3-hexanedione.

Background Pre- and Post-shift Diacetyl and 2,3-Pentanedione Canister Results

Table A4 presents the results of the instantaneous evacuated canister pre- and post-shift background air samples collected in the administration area, production office, and production area during our visit. Both diacetyl and 2,3-pentanedione air concentrations increased over the course of the work day. For the production area, the pre-shift diacetyl concentration was 7.1 ppb, and post-shift air concentration was 21.3 ppb; the pre-shift 2,3-pentanedione air concentration was 5.7 ppb, and post-shift air concentration was 24.7 ppb. The pre- and post-shift levels of 2,3-hexanedione were less than 1 ppb, with the exception of the Production Office post-shift sample that was 5.9 ppb.

Bulk Samples and Headspace Results

Table A5 presents the bulk sample results using headspace analysis. Air concentrations of diacetyl ranged from 1,384 ppb to 7,013 ppb for whole bean coffee. Air concentrations of 2,3-pentanedione ranged from 1,526 ppb to 8,014 ppb for whole bean coffee. The bulk samples for whole bean coffee were collected from the roaster cooling bin immediately after the beans were released from the roaster hopper or from whole bean coffee storage bins. The bulk sample of liquid flavoring had an air concentration of below the LOD for diacetyl and 6,866 ppb for 2,3-pentanedione. Air concentrations from collected bulk samples were below the LOD for 2,3-hexanedione.

Real-time Monitoring: Carbon Dioxide (CO_2), Carbon Monoxide (CO), Temperature, and Relative Humidity (RH)

Table A6 presents the results from real-time monitoring for CO_2, CO, temperature, and RH collected during our visit. Average CO_2 levels within the facility ranged from 928 parts per million (ppm) to 1,217 ppm. Average indoor CO levels ranged from 0.2 ppm to 3.8 ppm.

Average indoor temperature levels ranged from 74.6 degrees Fahrenheit (°F) to 84.3°F. Average indoor RH levels ranged from 20.8% to 32.7%.

Real-time Monitoring: Total Volatile Organic Compounds (TVOC)
Table A7 presents the results from real-time monitoring for TVOCs during our visit. TVOC levels within the facility ranged from <0.1 ppb to 11,907 ppb. The flavoring area of the facility had the highest levels of TVOCs. During TVOC monitoring in the flavoring area, peak TVOC levels occurred when an employee was flavoring coffee.

Personal CO Sampling
Table A8 presents the results from real-time personal monitoring for CO. Four personal CO measurements were collected during our visit. CO minimum and maximum levels ranged from <0.1 ppm to 157 ppm. Average CO levels ranged from 1.6 ppm to 2.7 ppm over the course of the workday. Figure B1 presents CO levels for an employee during flavoring whole bean coffee and grinding flavored coffee.

Repetitive Motion Tasks, Burn Hazards, and Safety Observations
We observed employees manually transferring 70-kilogram bags of green beans from a delivery truck bed to a pallet on a pallet jack. We observed the employee pull the bag to their chest at the edge of the truck and then roll it off into their arms before twisting around to drop the bag onto the pallet. The delivery truck did not have a lift gate to aid in this process. Employees reported that some deliveries came on trucks with lift gates, although the weekly shipment of 11 bags that we observed never had a lift gate on the truck.

Employees scooped green beans out of 70-kilogram bags into small buckets. The roaster held a maximum of 26 pounds of green beans per roasting session. On average, employees scooped approximately 12 scoops of green beans to fill the bucket with 26 pounds of beans. Employees reported there would be a maximum of 13 roasts in a single day (approximately four per hour). After filling the bucket, beans were dumped into the roaster. Employees were observed performing this task on their tiptoes with their arms extended up over their heads. Some employees stood next to the hot exhaust duct of the roaster when pouring green beans into the roaster. Other employees poured the green beans into the roaster from the control panel side of the roaster.

Beans in the roaster weighed approximately 22 pounds after roasting. Employees were observed shaking flavoring buckets containing roasted beans in order to coat them with flavoring, with the bucket above shoulder height. Employees were also observed reaching over their heads to pour the beans into the grinders. We noted that sometimes during the grinding task, the grinders were located near the back of the packaging table, which required the employee to reach further than ideal to operate the grinder. Packaging whole beans or ground coffee required many repetitive motions. Employees needed to bend over to scoop whole beans from buckets on the floor. Ground coffee was scooped from larger bags on the work surface into varying sized packages. After packaging, the bags were heat sealed with a foot-operated crimping device, creating a potential burn hazard.

Regarding small warehouse safety issues, we observed a small rolling table near the roaster control panel that could block the roaster's emergency stop button. We also observed employees placing their hands inside the roaster, and it was reported that in-depth cleaning of the roaster requires employees to have hands and arms inside the roaster.

Medical Survey Results

Four of the five employees present on the day of the medical survey completed the medical questionnaire and breathing tests. All four participants reported working in or entering the production area, ranging from two hours to 38 hours per week. All reported being within an arm's length of roasted coffee in one or more areas of the production process as well as being within an arm's length of the container when flavoring was being added or mixed with roasted coffee.

Respiratory Symptoms, Repetitive Motion Tasks, and Burn Hazards

Some participants reported respiratory symptoms or eye, nose, or sinus symptoms that were caused or aggravated by green beans, burlap bags, or by grinding or flavoring coffee. Some employees reported wheezing or whistling in the chest that was aggravated by green coffee beans. When asked if there were any concerns about repetitive motion injuries at work, some employees mentioned scooping coffee and lifting buckets of green coffee beans to dump into the roaster hopper as potential sources of ergonomic strain. When asked if there were any concerns about burns at work, some employees mentioned the roaster and heat sealers as potential sources of burns, although no known burns had occurred.

Medical Tests

One spirometry test result indicated mild obstruction. Oscillometry and FeNO test results were normal. Because of the small number of participants and the need to protect individuals' privacy, we cannot provide detailed results or shed light on possible work-relatedness, such as health measures by job title or task. We mailed each participant their individual lung function test results with an explanation of the results and recommended each participant provide the information to their personal physician.

Discussion

Diacetyl, 2,3-pentanedione, 2,3-hexanedione, other VOCs, and other chemicals such as CO and CO_2 are naturally produced when coffee beans are roasted, and grinding the roasted coffee beans produces greater surface area for the off-gassing of these chemicals [Anderson et al. 2003; Akiyama et al. 2003; Daglia et al. 2007; Newton 2002; Nishimura et al. 2003; Raffel and Thompson 2013]. In addition, flavorings added to coffee can contain diacetyl or 2,3-pentanedione. Occupational exposure to diacetyl and 2,3-pentanedione can cause loss of lung function and the lung disease obliterative bronchiolitis [NIOSH 2016].

Alpha-Diketones

Personal Air Sampling

Four personal full-shift air samples taken inside the production area of the facility using standard OSHA methods were above the NIOSH REL for diacetyl. The highest personal full-shift exposure to diacetyl was 20.7 ppb collected from a production area employee during the site visit. One personal full-shift air sample taken inside the facility using standard OSHA methods was above the NIOSH REL for 2,3-pentanedione and measured at 24.0 ppb. As described in the quantitative risk assessment from the NIOSH Criteria Document (Tables 5-27 and 5-34) [NIOSH 2016], after a 45-year working lifetime exposure to 10 ppb (a concentration lower than the highest concentration measured at this facility), NIOSH estimated about 3 in 1,000 workers would develop reduced lung function (FEV_1 below the lower limit of normal). NIOSH predicted that around 2 in 10,000 workers exposed to diacetyl at 10 ppb would develop more severe lung function reduction (FEV_1 below 60% predicted, defined as at least moderately severe by the American Thoracic Society [Pellegrino et al. 2005]). After a 45-year working lifetime exposure to 20 ppb (a concentration closer to the highest concentration measured at this facility), NIOSH estimated that about 5 in 1,000 workers would develop reduced lung function (FEV_1 below the lower limit of normal). NIOSH predicted that 5 in 10,000 workers exposed to diacetyl at 20 ppb would develop more severe lung function reduction. NIOSH recommends keeping diacetyl concentrations below 5 ppb, because at this level the risk of reduced lung function after a working lifetime of exposure is below 1 in 1,000 workers. NIOSH recommends taking steps to reduce diacetyl exposures to below the REL of 5 ppb whenever possible.

During our visit, the roaster operator often remained at the roaster control panel during the roasting process. The roasting drum was fully enclosed, and air was exhausted through the roaster exhaust, minimizing exposures indoors. The only time the roasting drum was opened was during the transfer of roasted beans into the cooling drum. The downdraft system on the roaster machine pulled air over the roasted beans and down into the cooling drum to accelerate cooling, which might have decreased the roaster operator's exposure while performing this task.

Area Air Sampling

Area full-shift samples (Table A1) collected from the grinding area had the highest concentrations of diacetyl (27.7 ppb) and 2,3-pentanedione (28.0 ppb), likely because grinding roasted coffee beans produces greater surface area for off-gassing of these chemicals [Anderson et al. 2003; Akiyama et al. 2003; Daglia et al. 2007; Newton 2002; Nishimura et al. 2003; Raffel and Thompson 2013]. The flavoring area air samples collected ranged from 10.0 ppb to 12.1 ppb for diacetyl and 9.7 ppb to 11.0 ppb for 2,3-pentanedione. The roasting area air samples ranged from 5.4 ppb to 12.6 ppb for diacetyl and 4.9 ppb to 11.1 ppb for 2,3-pentanedione. Levels of diacetyl and 2,3-pentandione present in the flavoring and roasting areas of the facility are likely a result of the flavoring liquid, freshly roasted coffee, and grinding coffee. The area air samples collected from the administration area were the lowest in the facility and ranged from 1.8 ppb to 2.0 ppb for diacetyl and from 1.7 ppb to 2.1 ppb for 2,3-pentanedione, indicating little entrainment of air from the production area into the administrative area.

During our visit, we also observed maximum recorded levels of CO at 78.9 ppm and CO_2 at 2,015 ppm at the grinding area (Table A6). However, CO and CO_2 TWAs at the grinding area and throughout the facility did not exceed OELs.

Task-based Exposures

Coffee processing involves multiple tasks that can cause intermittent, elevated exposures to diacetyl and 2,3-pentanedione. Traditional full-shift sampling will not characterize these short-term, peak exposures. Evaluating intermittent and task-based exposures to diacetyl and 2,3-pentanedione is difficult with current validated sampling methods (OSHA Methods 1013/1016). Because tasks are sporadic in coffee processing, with some only lasting a few seconds or minutes, we used instantaneous evacuated canisters to sample tasks that were only a few seconds to minutes long and OSHA Methods 1013/1016 for longer duration tasks. We sampled by task, with varying durations, to understand which tasks might have contributed to higher exposures to diacetyl and 2,3-pentanedione.

Our task-based air sampling revealed that some tasks had higher air concentrations of diacetyl or 2,3-pentanedione than other tasks. Employees would often flavor the roasted coffee beans in an 18-quart bucket and shake the bucket by hand. Using OSHA Methods 1013/1016, we found flavoring coffee tasks resulted in air concentrations ranging from 22.7 ppb to 67.2 ppb for diacetyl and 24.2 ppb to 82.6 ppb for 2,3-pentanedione (Table A2). Using instantaneous evacuated canisters, we also measured 27.5 ppb of diacetyl and 68.6 ppb of 2,3-pentanedione during flavoring by hand (Table A3). Standing over the flavoring bucket while pouring the flavoring and manually shaking the container likely contributed to higher measured alpha-diketones for an employee performing this flavoring task.

Employees would also grind flavored coffee, which likely additionally contributed to higher measured alpha-diketones. Using instantaneous evacuated canisters, we observed that grinding butterscotch-flavored coffee resulted in the highest instantaneous diacetyl (489 ppb) and 2,3-pentanedione (604 ppb) air concentrations (Table A3). Because these instantaneous samples were collected at the grinder discharge, they were not necessarily reflective of employee exposure; however, they indicate a source of alpha-diketones during grinding that could be controlled. These peak exposures to diacetyl and 2,3-pentanedione during flavoring and grinding tasks likely contributed to the higher personal full-shift air sample results for the production area employees.

Bulk Samples

Diacetyl is not found in green beans and forms later in the coffee roasting process [Daglia et al. 2007]. As expected, we found that roasted coffee emits alpha-diketones into the headspace of sealed vessels, indicating that roasted coffee is a considerable source of alpha-diketones in the facility. Bulk samples of roasted whole bean coffee resulted in the highest levels of alpha-diketones from headspace analysis (diacetyl 7,013 ppb and 2,3-pentanedione 8,014 ppb). We also do not know how long the beans were in the storage bins prior to collecting the samples, but generally the time between roasting and packaging is on the order of hours to days. The amount of time roasted beans had off-gassed could be responsible for differences in headspace analysis results.

Ventilation

There was no general ventilation system present in the facility. The bay door was sometimes open during production activities, and this open bay door was the only source of fresh air entering the production area of the building. Installing local exhaust ventilation systems and a dilution ventilation system would help control the airborne concentrations of alpha-diketones.

Local Exhaust Ventilation

Local exhaust ventilation systems capture contaminants when generated and exhausts them before inhalation by employees occurs. Local exhaust ventilation systems generally consist of hoods or enclosures, duct work, or fans. Depending on the contaminant and whether air is recirculated, filters or other air cleaning technologies can be incorporated. When properly designed local exhaust ventilation systems are installed, overall workplace exposure levels can be reduced by removing contaminants at the source.

During our visit, we discussed some simple local exhaust ventilation systems that could be installed in the production space that would likely help reduce overall alpha-diketone exposures in the production space. Elevated concentrations of alpha-diketones were associated with grinding and flavoring activities. Installing localized air capture hoods, or even enclosing hoods, to isolate those processes and remove contaminants before they spread throughout the facility could substantially reduce overall employee exposures. Some consideration should be given to moving those activities closer together and near an exterior wall, which could make the local exhaust system more compact and inexpensive.

General Exhaust or Dilution Ventilation

An adequate supply of outdoor air, typically delivered through a heating, ventilation, and air-conditioning system, is necessary in any occupied space to dilute pollutants that are released by equipment, processes, products, and people. In an ideal environment, good general ventilation provides fresh air into the space and removes contaminated air. General exhaust ventilation allows contaminants to be emitted into the workplace and then dilutes the concentration of the contaminant to acceptable levels. This is generally done by providing fresh outdoor air (or recirculated, filtered air) to the space to provide dilution. Simultaneously, air is exhausted from the space to remove the contaminants.

Installing a small air-handling unit that could provide some constant outdoor air flow would provide more dilution and removal of airborne contaminants from the space. Depending on the system chosen, it could also serve to help heat and/or cool the space throughout the year. It would also allow production operations to occur with the large bay door closed at all times. Regardless of how it is done, consistently supplying the production space with appropriate fresh, outdoor air will help reduce airborne contaminants, but it might still not bring all personal exposures to diacetyl and 2,3-pentanedione below the NIOSH RELs. Installing a dilution ventilation system in conjunction with effective local exhaust ventilation systems would be even more effective.

All decisions on ventilation upgrades should be made as part of an overall plan to improve engineering controls at the facility. A ventilation system expert can help meet all ventilation requirements in the production space and other areas of the building occupied by employees.

Repetitive Motion Injuries, Burns, and Safety

Many of the observed tasks presented risk factors for repetitive strain injuries. Changes to the physical work environment and operating procedures would reduce the strain on the body, reduce the risk of burns, and improve small warehouse safety.

We observed opportunities to improve the ergonomics of certain tasks while working with green beans, during the grinding and flavoring of roasted coffee beans, and regarding storage of items in the supply storage area. Because deliveries of green beans were manually unloaded from trucks at the bay door, to reduce ergonomic strain during this unloading task, we recommend using lift gates for all green bean deliveries and using two employees when moving bags of green beans. Pulling the grinders forward would reduce the need to reach to the back of the table while operating the grinder. During the flavoring task, the 18-quart bucket was held above shoulder height and shaken to mix the flavoring with the coffee beans. To reduce strain on the body, hands should be kept below shoulder level during the flavoring task.

We also observed two areas, specifically the roaster's exhaust duct and the heat sealers, where employees might be at risk for burns. To help prevent potential burns from the roaster exhaust duct, the green beans should be poured into the roaster hopper from the control panel side of the roaster. Similarly, turning off heat sealers after use will help prevent accidental burns.

To improve small warehouse safety, we recommend ensuring the small rolling table near the roaster is not blocking the roaster's emergency stop button. To help avoid potentially hazardous conditions around the roaster, we recommend placing a lock on the roaster control panel and following OSHA's control of hazardous energy (lockout/tagout) standard 29 CFR 1910.147.

Medical Survey

Among the employees who participated in the medical survey, mucous membrane symptoms, specifically eye, nose, and sinus symptoms, were the most commonly reported symptoms. Some employees reported their symptoms were caused or aggravated by green coffee beans, burlap bags, or by grinding or flavoring coffee. Coffee dust is an organic dust, and exposure to coffee dust is known to cause respiratory symptoms and is a known risk factor for occupational asthma [Karr et al. 1978; Zuskin et al. 1979, 1985, 1993; Thomas et al. 1991; Sakwari et al. 2013]. Green coffee dust is thought to be a more potent allergen than roasted coffee dust because roasting destroys some of the allergenic activity [Lehrer et al. 1978]. As discussed in the recommendation section, one way to prevent symptoms related to green coffee dust and burlap might be to make N95 disposable filtering-face piece respirators available for voluntary use when working with burlap bags of green beans. However, because N95s are not protective against alpha-diketones (diacetyl, 2,3-pentanedione, or 2,3-hexanedione), NIOSH-certified organic vapor cartridges would be warranted for flavoring.

Some employees reported upper and lower respiratory symptoms. Upper respiratory disease such as allergic rhinitis (hay fever, nasal allergies) and sinusitis are sometimes associated with lower respiratory symptoms and asthma and might precede the diagnosis of asthma [Shaaban et al. 2008; EAACI Task Force on Occupational Rhinitis et al. 2008; Rondón et al. 2012, 2017; Sahay et al. 2016]. Upper respiratory involvement (e.g., rhinitis, sinusitis) can result in suboptimal control of asthma. Asthma symptoms often improve when away from exposures that trigger symptoms while other lung diseases such as obliterative bronchiolitis or COPD generally do not improve. Spirometry can be used to help detect and follow individuals with asthma and other lung diseases such as obliterative bronchiolitis or COPD. Spirometry can show if air is exhaled from the lungs more slowly than normal (i.e., obstructive abnormality) or if the amount of air exhaled is smaller than normal (i.e., restrictive abnormality). In asthma, there is intermittent airways obstruction which is reversible after treatment with bronchodilator medications (e.g., albuterol). In obliterative bronchiolitis, scar tissue prevents the small airways (bronchioles) from opening up when albuterol is given. In other words, the airways are fixed and not responsive (reversible) to bronchodilator medicine. The obstructed airways prevent rapid emptying of the lung air sacs (alveoli) during exhalation. This explains why the respiratory symptoms of those with occupational obliterative bronchiolitis do not tend to improve when away from work-related exposures; however, avoidance of further exposure can stop progression of the disease [Akpinar-Elci et al. 2004].

Spirometry and impulse oscillometry measure different things. Spirometry assesses airflow and is the breathing test typically used to screen for flavoring-related lung disease. Impulse oscillometry assesses the airways response to a sound or pressure wave and has not commonly been used to screen for flavoring-related lung disease. In general, during the impulse oscillometry test, a small pressure impulse (sound wave) is imposed upon the inspiratory and expiratory airflow during normal tidal breathing. This pressure wave causes a disturbance in the airflow and pressure, and the response of the airways (i.e., change in pressure to change in flow) is a measure of the resistance to airflow in the airways [Desiraju and Agrawal 2016]. Impulse oscillometry might be useful as an indirect measure of airflow obstruction and helpful in individuals not able to perform forced breathing maneuvers that are required during the spirometry test. The impulse oscillometry test has been used for many years to measure changes in the airways of children with lung problems such as asthma and cystic fibrosis [Song et al. 2008; Komarow et al. 2011; Shi et al. 2012; Schulze et al. 2016]. More recently, impulse oscillometry has been used to investigate lung problems in adults exposed to dust or chemicals, such as World Trade Center emergency responders and soldiers returning from deployment overseas [Oppenheimer et al. 2007; Berger et al. 2013; Weinstein et al. 2016]. Over the years, researchers have developed reference (predictive) equations for different populations of children for oscillometry [Malmberg et al. 2002; Park et al. 2011; Lee et al. 2012; de Assumpção et al. 2016]. For adults, there are fewer reference equations available for oscillometry [Vogel and Smidt 1994; Newbury et al. 2008; Schulz et al. 2013]. The predicted values we used for oscillometry measures were based on gender and age according to reference values recommended by the manufacturer. Unlike predictive equations used for spirometry, the impulse oscillometry reference equations we used did not take into account height, race, or smoking status [Vogel and Smidt 1994].

We recommend starting a medical monitoring program because air sampling detected employee exposures to diacetyl and 2,3-pentanedione that exceeded the respective NIOSH RELs, and some participants reported respiratory symptoms. All employees involved in production tasks (e.g., roasting, interacting with open storage bins/containers of roasted coffee, grinding, weighing, flavoring, or packaging coffee) should participate in the workplace medical monitoring program. A medical monitoring program is a means of early identification of employees who might be developing lung disease (e.g., asthma, obliterative bronchiolitis) and can help prioritize interventions to prevent occupational lung disease. The NIOSH medical survey results can serve as a baseline for employees who participated, if they choose to share these results with their healthcare provider. In a workplace with risk of occupational lung disease, prevention of smoking-related lung disease is important and makes the detection of work-related adverse effects easier. The Centers for Disease Control and Prevention offers tools and resources for setting up a smoking cessation program [CDC 2017b].

Conclusions

We identified full-shift employee exposures to diacetyl and 2,3-pentanedione in the production area that exceeded the NIOSH RELs. Overall, full-shift air concentrations of diacetyl and 2,3-pentanedione were consistently higher in the flavoring and grinding areas. The tasks of flavoring roasted coffee beans by hand, grinding flavored roasted coffee beans, and weighing and packaging roasted coffee were associated with higher diacetyl levels, likely due to the close proximity of the employee's breathing zone to the roasted beans and flavoring. CO and CO_2 levels were low throughout most of the facility; the highest CO and CO_2 levels were observed in the production area of the facility, especially at the grinding area. Personal CO exposure increased during flavoring and grinding; however, personal CO levels were below the NIOSH ceiling limit. We observed opportunities to reduce strain on the body during certain tasks, decrease the risk of potential burns, and improve general small warehouse safety. Recommendations are made to reduce employee exposure to these occupational hazards and to protect respiratory health.

Some employees reported mucous membrane symptoms and/or respiratory symptoms. One spirometry test result indicated mild obstruction. We recommend a medical monitoring program to identify any employees who might be developing lung disease (e.g., asthma, obliterative bronchiolitis) and to help management prioritize interventions to prevent occupational lung disease. All employees involved in production tasks (e.g., roasting, interacting with open storage bins/containers of roasted coffee, grinding, weighing, flavoring, or packaging coffee) should participate in the workplace medical monitoring program.

Recommendations

On the basis of our findings, we recommend the actions listed below. Our recommendations are based on an approach known as the hierarchy of controls. This approach groups actions by their likely effectiveness in reducing or removing hazards. In most cases, the preferred approach is to eliminate hazardous materials or processes and install engineering controls to reduce exposure or shield employees.

Engineering Controls

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

1. Work with a qualified ventilation engineer to install local exhaust ventilation at the grinders and around the coffee flavoring activities. Consider consolidating these activities into the same space, preferably near an exterior wall, to make the implementation of effective engineering controls easier.
2. Consult with a ventilation engineer to install a dilution ventilation system that meets current local mechanical codes. This system should consistently supply fresh, outdoor air to the production space. If properly selected, it could also be used to help heat and cool the production space throughout the year. The system should be operated whenever production activities are ongoing, but it could be shut off during unoccupied periods.
3. Conduct follow-up personal air sampling on employees with primary duties in the production area to verify that the modifications have been effective in reducing alpha-diketone exposures to below the recommended exposure limits.

Administrative Controls

Administrative controls are employer-dictated work practices and policies implemented to reduce or prevent hazardous exposures. Their effectiveness depends on employer commitment and employee acceptance. Regular monitoring and reinforcement are necessary to ensure that policies and procedures are followed consistently.

1. Require lift gates for all deliveries of green beans.
2. Use two employees when moving bags of green beans. Communicate throughout the lifting and moving of the bag so that both employees are lifting, lowering, and moving at the same time, avoiding jerking motions.
3. Pull the grinders forward to reduce the need to reach to the back of the table that they are sitting on.
4. Do not flavor roasted beans by hand. Instead, use an automatic mechanism that minimizes employee contact with flavored beans during blending. Until an alternative method of flavoring beans is introduced, to reduce strain on the body during shaking of flavoring buckets, keep hands below shoulder height, and do not shake the flavoring bucket over shoulder level.
5. To prevent excessive bending and reaching, store heavier, more commonly used items on shelves that are between knee and shoulder height.

6. Always pour green beans into the roaster hopper from the control panel side of the roaster to help prevent the possibility of contact with the hot roaster exhaust duct.
7. Turn heat sealers off after packaging tasks are completed.
8. Ensure the small rolling table near the roaster is not blocking the roaster's emergency stop button.
9. Place a lock on the roaster control panel in accordance with OSHA control of hazardous energy (lockout/tagout) standard 29 CFR 1910.147. When an employee is cleaning the roaster, the employee performing the cleaning should keep the key on their person for the duration of the cleaning task.
10. Periodically clean the roaster's exhaust in accordance with manufacturer instructions to remove chaff build up to reduce a fire hazard and to improve the efficiency, energy usage, and roaster performance.
11. Include roaster exhaust checks and any future local exhaust systems in a preventive maintenance schedule to ensure they operate appropriately.
12. Continue to cover bins of roasted beans to reduce the overall emission of alpha-diketones and other chemicals (e.g., CO, CO_2) into the workplace and lower employee exposure.
13. Eliminate the use of compressed air and dry sweeping as much as possible during cleaning. Instead, use a vacuum system with a high-efficiency particle air filter and wet methods whenever possible.
14. Ensure employees understand potential hazards (e.g., diacetyl, 2,3-pentanedione, CO, CO_2, green and roasted coffee dust) in the workplace and how to protect themselves. OSHA's *Hazard Communication Standard*, also known as the "*Right to Know Law*" [29 CFR 1910.1200] requires that employees are informed and trained on potential work hazards and associated safe practices, procedures, and protective measures.
15. Ensure employees are educated to consider the risks of further exposure if they develop lower respiratory symptoms (e.g., cough, shortness of breath, wheezing) that are progressive and severe in degree. Employees should report new, persistent, or worsening symptoms to their personal healthcare providers and to a designated individual at this workplace. Employees with new, persistent, or worsening symptoms should share this report with their healthcare providers.

Personal Protective Equipment

The effectiveness of personal protective equipment in the form of respiratory protection in controlling respiratory exposures depends on avoiding breakdowns in implementation that result in insufficient protection. Proper use of respiratory protection (respirators) requires a comprehensive respiratory protection program and a high level of employee and management involvement and commitment to assure that the right type of respirator is chosen for each hazard, respirators fit users and are maintained in good working order, and respirators are worn when they are needed. Supporting programs such as training, change-out schedules, and medical assessment might be necessary. Respirators should not be the sole method for controlling hazardous inhalation exposures. Rather, respirators should be used until effective engineering and administrative controls are in place.

1. In addition to engineering and administrative controls, respiratory protection is a potential option to further reduce exposures to alpha-diketones (e.g., diacetyl and 2,3-pentanedione). If follow-up air sampling after engineering controls have been installed and administrative controls are implemented indicates levels of diacetyl and 2,3-pentanedione remain above their respective NIOSH REL or STEL, or if a long delay is anticipated before these controls can be put into place, we recommend respiratory protection be used during tasks with elevated exposures. Respirators used to reduce exposures to diacetyl and 2,3-pentanedione should be NIOSH-certified and equipped with organic vapor cartridges. The choice of respirator should be guided by personal exposure sampling for diacetyl and 2,3-pentanedione (NIOSH 2004). For reference, air-purifying half-face respirators have an assigned protection factor (APF) of 10, and air-purifying full-face respirators have an APF of 50. Also, there are powered-air purifying respirators that have APFs of 25, 50, or 1000. A respirator's APF refers to the maximal level of protectiveness a specific respirator design can achieve under laboratory conditions. The OSHA APFs can be found in Table 1 of OSHA Respiratory Protection Standard at https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=12716.

   If respiratory protection is used, a written respiratory protection program should be implemented as required by the OSHA Respiratory Protection Standard (29 CFR 1910.134), including training, fit testing, maintenance, and use requirements.

2. Continue to offer employees the voluntary use of N95 disposable filtering-facepiece respirators when moving burlap bags of green beans, when cleaning the exhaust system of chaff, when emptying the chaff containers, or when cleaning the green bean storage area. N95 respirators should be available in various sizes, and each potential N95 user should receive a copy of Appendix D of the OSHA Respiratory Protection Standard (https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=standards&p_id=9784). Information about Appendix D and voluntary use of respirators can be found on the OSHA website at https://www.osha.gov/video/respiratory_protection/voluntaryuse_transcript.html.

   Please be aware that N95s are not protective against alpha-diketones (diacetyl, 2,3-pentanedione, or 2,3-hexanedione). In cases of dual exposure to dust and alpha-diketones, such as those in flavorings, NIOSH-certified organic vapor cartridges (for the alpha-diketones) and particulate cartridges/filters (for the dust) would be warranted.

Medical Monitoring

The purpose of a medical monitoring program is to help assure the health of employees who have workplace exposures (e.g., diacetyl, 2,3-pentanedione, green coffee beans/dust) known to pose risk for potentially serious health conditions such as asthma or obliterative bronchiolitis.

1. Some coffee processing workers who flavor coffee or have exposure to flavored coffee production using the flavoring chemicals diacetyl and 2,3-pentanedione have developed obliterative bronchiolitis [Bailey et al. 2015]. Headspace analyses of the liquid flavorings used to flavor coffee in this facility identified diacetyl and 2,3-pentandione, and personal air sampling conducted in the production area identified levels in air exceeding the NIOSH REL. In view of this, as detailed in the NIOSH Criteria Document [NIOSH 2016], we recommend that the employer implement a medical monitoring program for all employees who work in or enter production areas for a total of 40 or more hours per year. According to the NIOSH Criteria Document, employees should have baseline evaluations before they are allowed to work in or enter areas where they might be exposed to diacetyl, 2,3-pentanedione, or similar flavoring compounds. The spirometry we conducted in January 2017 could serve as a baseline for survey participants.
2. Employees in the medical monitoring program should be evaluated with a questionnaire (to obtain health and work task information) and spirometry (to assess lung function) every six months due to the potentially rapid development of lung disease. If an employee is identified to have lung disease from exposure to diacetyl, 2,3-pentanedione, or a similar flavoring compound, then all employees who perform similar job tasks or have a similar or greater potential for exposure should be evaluated every three months [NIOSH 2016].

Smoking Cessation Program

In a workplace with risk of occupational lung disease, prevention of smoking-related lung disease is important and makes the detection of work-related adverse effects easier. We recommend implementing a smoking cessation program to assist employees to stop smoking. The Centers for Disease Control and Prevention offers tools and resources for setting up a smoking cessation program [CDC 2017b].

Appendix A: Tables

Table A1. OSHA Methods 1013/1016 personal and area full-shift air sampling results by location, NIOSH survey, January 2017

Analyte	Sample Type	Location	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)	Above REL N
Diacetyl	Personal	Off-site Work Area	1	0 (0%)	<0.2	<0.2	0
Diacetyl	Personal	Production Area	4	4 (100%)	7.4	20.7	4
Diacetyl	Area	Administration	2	2 (100%)	1.8	2.0	N/A
Diacetyl	Area	Flavoring	2	2 (100%)	10.0	12.1	N/A
Diacetyl	Area	Green Bean Storage	2	2 (100%)	9.8	11.6	N/A
Diacetyl	Area	Grinding	6	6 (100%)	12.6	27.7	N/A
Diacetyl	Area	Outside	2	1 (50%)	<0.3	0.5	N/A
Diacetyl	Area	Production Area	2	2 (100%)	8.3	9.5	N/A
Diacetyl	Area	Production Office	2	2 (100%)	10.2	11.7	N/A
Diacetyl	Area	Roasting	2	2 (100%)	5.4	12.6	N/A
2,3-Pentanedione	Personal	Off-site Work Area	1	1 (100%)	0.2	0.2	0
2,3-Pentanedione	Personal	Production Area	4	4 (100%)	7.1	24.0	1
2,3-Pentanedione	Area	Administration	2	2 (100%)	1.7	2.1	N/A
2,3-Pentanedione	Area	Flavoring	2	2 (100%)	9.7	11.0	N/A
2,3-Pentanedione	Area	Green Bean Storage	2	2 (100%)	9.2	10.2	N/A
2,3-Pentanedione	Area	Grinding	6	6 (100%)	12.1	28.0	N/A
2,3-Pentanedione	Area	Outside	2	0 (0%)	<0.3	<0.3	N/A
2,3-Pentanedione	Area	Production Area	2	2 (100%)	7.1	9.2	N/A
2,3-Pentanedione	Area	Production Office	2	2 (100%)	9.7	11.1	N/A
2,3-Pentanedione	Area	Roasting	2	2 (100%)	4.9	11.1	N/A
2,3-Hexanedione	Personal	Off-site Work Area	1	0 (0%)	<0.1	<0.1	—
2,3-Hexanedione	Personal	Production Area	4	1 (25%)	<0.2	0.5	—
2,3-Hexanedione	Area	Administration	2	0 (0%)	<0.2	<0.2	N/A
2,3-Hexanedione	Area	Flavoring	2	0 (0%)	<0.2	<0.2	N/A
2,3-Hexanedione	Area	Green Bean Storage	2	0 (0%)	<0.2	<0.2	N/A
2,3-Hexanedione	Area	Grinding	6	4 (67%)	<0.2	0.7	N/A
2,3-Hexanedione	Area	Outside	2	0 (0%)	<0.2	<0.2	N/A
2,3-Hexanedione	Area	Production Area	2	0 (0%)	<0.2	<0.2	N/A
2,3-Hexanedione	Area	Production Office	2	0 (0%)	<0.2	<0.2	N/A
2,3-Hexanedione	Area	Roasting	2	0 (0%)	<0.2	<0.2	N/A

Note: OSHA=Occupational Safety and Health Administration; NIOSH=National Institute for Occupational Safety and Health; N=number of samples; Above LOD N (%)=number and percentage of samples above the limit of detection (LOD); ppb=parts per billion; < indicates below the LOD; Above REL N=number of samples above the NIOSH recommended exposure limit (REL); N/A indicates that NIOSH RELs are specified for personal air samples and cannot be directly applied to area air samples; "—" indicates there is currently no REL for 2,3-hexanedione.

Table A2. OSHA Methods 1013/1016 personal task-based air sampling results, NIOSH survey, January 2017

Analyte	Sample Type	Task	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)	Mean (minutes) Sample Duration (range)
Diacetyl	Personal	Cleaning Roaster	1	1 (100%)	2.9	2.9	—
Diacetyl	Personal	Flavor coffee	2	2 (100%)	22.7	67.2	10 (6–13)
Diacetyl	Personal	Grind coffee beans	2	2 (100%)	11.9	32.0	9 (7–11)
Diacetyl	Personal	Move roasted coffee	1	1 (100%)	13.3	13.3	—
Diacetyl	Personal	Package coffee	4	4 (100%)	23.0	53.2	13 (10–17)
Diacetyl	Personal	Roast coffee beans	4	4 (100%)	5.8	15.9	12 (7–14)
Diacetyl	Personal	Work with green beans	1	1 (100%)	4.8	4.8	—
2,3-Pentanedione	Personal	Cleaning Roaster	1	1 (100%)	3.8	3.8	—
2,3-Pentanedione	Personal	Flavor coffee	2	2 (100%)	24.2	82.6	10 (6–13)
2,3-Pentanedione	Personal	Grind coffee beans	2	2 (100%)	18.3	36.4	9 (7–11)
2,3-Pentanedione	Personal	Move roasted coffee	1	1 (100%)	13.7	13.7	—
2,3-Pentanedione	Personal	Package coffee	4	4 (100%)	29.0	56.8	13 (10–17)
2,3-Pentanedione	Personal	Roast coffee beans	4	4 (100%)	4.6	19.0	12 (7–14)
2,3-Pentanedione	Personal	Work with green beans	1	1 (100%)	6.0	6.0	—
2,3-Hexanedione	Personal	Cleaning Roaster	1	0 (0%)	<0.7	<0.7	—
2,3-Hexanedione	Personal	Flavor coffee	2	0 (0%)	<0.8	<1.7	10 (6–13)
2,3-Hexanedione	Personal	Grind coffee beans	2	1 (50%)	<=1.3	1.3	9 (7–11)
2,3-Hexanedione	Personal	Move roasted coffee	1	0 (0%)	<0.7	<0.7	—
2,3-Hexanedione	Personal	Package coffee	4	2 (50%)	<0.6	2.0	13 (10–17)
2,3-Hexanedione	Personal	Roast coffee beans	4	0 (0%)	<0.7	<1.5	12 (7–14)
2,3-Hexanedione	Personal	Work with green beans	1	0 (0%)	<1.0	<1.0	—

Note: OSHA=Occupational Safety and Health Administration; NIOSH=National Institute for Occupational Safety and Health; N=number of samples; Above LOD N (%)=number and percentage of samples above the limit of detection (LOD); ppb=parts per billion; < indicates below the LOD; <= indicates less than or equal to the LOD; "—" indicates that only one sample was taken so a mean could not be calculated and a range is not reported.

Table A3. Instantaneous evacuated canister method* source air sampling results, NIOSH survey, January 2017

Source Description	Diacetyl (ppb)	2,3-Pentanedione (ppb)	2,3-Hexanedione (ppb)
Flavoring roasted whole beans with butterscotch flavoring, sampled at top of mixing bucket	27.5	68.6	<9.6
Grinding butterscotch-flavored coffee, sampled at grinder discharge (1)	65.5	61.9	1.9
Grinding butterscotch-flavored coffee, sampled at grinder discharge (2)	489	604	13.7
Headspace of butterscotch flavoring bottle	<3.8	1,469	<9.4

Note: NIOSH=National Institute for Occupational Safety and Health; ppb=parts per billion; < indicates below the limit of detection.
***Sampling duration approximately 30 seconds; source air samples were collected by placing the inlet of the canister sampler at the source.**

Table A4. Instantaneous evacuated canister pre- and post-shift background air sampling results, NIOSH survey, January 2017

Analyte	Sample Type	Sample Location	Pre- or Post-shift	Concentration (ppb)
Diacetyl	Background	Administration	Pre-shift	2.7
Diacetyl	Background	Administration	Post-shift	5.1
Diacetyl	Background	Production Office	Pre-shift	10.3
Diacetyl	Background	Production Office	Post-shift	23.1
Diacetyl	Background	Production Area	Pre-shift	7.1
Diacetyl	Background	Production Area	Post-shift	21.3
2,3-Pentanedione	Background	Administration	Pre-shift	1.6
2,3-Pentanedione	Background	Administration	Post-shift	5.5
2,3-Pentanedione	Background	Production Office	Pre-shift	7.9
2,3-Pentanedione	Background	Production Office	Post-shift	27.2
2,3-Pentanedione	Background	Production Area	Pre-shift	5.7
2,3-Pentanedione	Background	Production Area	Post-shift	24.7
2,3-Hexanedione	Background	Administration	Pre-shift	1.0
2,3-Hexanedione	Background	Administration	Post-shift	1.0
2,3-Hexanedione	Background	Production Office	Pre-shift	1.0
2,3-Hexanedione	Background	Production Office	Post-shift	0.9
2,3-Hexanedione	Background	Production Area	Pre-shift	0.9
2,3-Hexanedione	Background	Production Area	Post-shift	5.9

Note: NIOSH=National Institute for Occupational Safety and Health; ppb=parts per billion.

Table A5. Headspace analysis results* for bulk samples of roasted coffee beans and flavoring, NIOSH survey, January 2017

Bulk Sample Description	Diacetyl (ppb)	2,3-Pentanedione (ppb)	2,3-Hexanedione (ppb)
Whole roasted coffee beans #1	2,965	3,620	<0.6
Whole roasted coffee beans #2	3,886	4,599	<0.6
Whole roasted coffee beans #3	4,391	4,431	<0.6
Whole roasted coffee beans #4	6,966	8,014	<0.6
Whole roasted coffee beans #5	1,704	3,709	<0.6
Whole roasted coffee beans #6	3,582	3,750	<0.6
Whole roasted coffee beans #7	1,384	1,526	<0.6
Whole roasted coffee beans #8	4,455	5,565	<0.6
Whole roasted coffee beans #9	7,013	7,982	<0.6
Whole roasted coffee beans #10	3,842	5,025	<0.6
Butterscotch flavoring	<0.3	6,866	<0.6

Note: NIOSH=National Institute for Occupational Safety and Health; ppb=parts per billion; < indicates below the limit of detection.
***The roasted coffee beans off-gassed for different amounts of time, and this could be responsible for some of the differences in headspace analysis results.**

Table A6. Real-time* area air monitoring for carbon dioxide, carbon monoxide, temperature, and relative humidity, NIOSH survey, January 2017

Area Sample Location	Measurement	Minimum	Maximum	Average
Administrative	CO_2 (ppm)	644.0	1,595.0	928.3
	CO (ppm)	<0.1	1.1	0.2
	Temperature (°F)	71.3	78.4	74.9
	Relative Humidity (%)	21.8	41.4	29.9
Flavoring	CO_2 (ppm)	430.0	1,774.0	1,150.0
	CO (ppm)	<0.1	8.1	2.1
	Temperature (°F)	62.6	88.8	80.0
	Relative Humidity (%)	25.0	48.4	32.7
Green Bean Storage	CO_2 (ppm)	500.0	1,785.0	1,134.0
	CO (ppm)	0.6	6.5	3.5
	Temperature (°F)	69.4	82.7	77.9
	Relative Humidity (%)	24.4	31.6	28.6
Grinding	CO_2 (ppm)	428.0	2,015.0	1,197.9
	CO (ppm)	<0.1	78.9	3.8
	Temperature (°F)	67.4	86.1	79.6
	Relative Humidity (%)	21.3	46.8	30.5
Production Area	CO_2 (ppm)	386.0	1,707.0	1,216.5
	CO (ppm)	<0.1	9.3	3.6
	Temperature (°F)	64.3	82.7	74.6
	Relative Humidity (%)	—	—	—
Roasting	CO_2 (ppm)	400.0	2,041.0	1,099.3
	CO (ppm)	<0.1	2.4	0.3
	Temperature (°F)	67.4	91.3	84.3
	Relative Humidity (%)	16.1	33.7	20.8

Note: NIOSH=National Institute for Occupational Safety and Health; ppm=parts per million; CO_2=carbon dioxide; CO=carbon monoxide; °F=degrees Fahrenheit, "—"=no data.
***Real-time instruments were set to log data at 10-second intervals.**

Table A7. Real-time total volatile organic compound sampling by area, NIOSH survey, January 2017

Area Sample Location	Minimum (ppb)	Maximum (ppb)	Average (ppb)
Flavoring	16	11,907	4,405
Roasting	<0.1	1,911	657
Administrative	<0.1	2,036	456
Production Office	<0.1	4,770	648

Note: NIOSH=National Institute for Occupational Safety and Health; ppb=parts per billion; < indicates below the limit of detection.

Table A8. Real-time* personal air monitoring results for carbon monoxide, NIOSH survey, January 2017

Sample ID	Minimum (ppm)	Maximum (ppm)	Average (ppm)
1	<0.1	19	2.7
2	<0.1	47	1.6
3	<0.1	157	2.6
4	<0.1	55	1.9

Note: NIOSH=National Institute for Occupational Safety and Health; ppm=parts per million; < indicates below the limit of detection.
***Personal CO monitors were set to log data at 10-second intervals.**

Appendix B: Figures

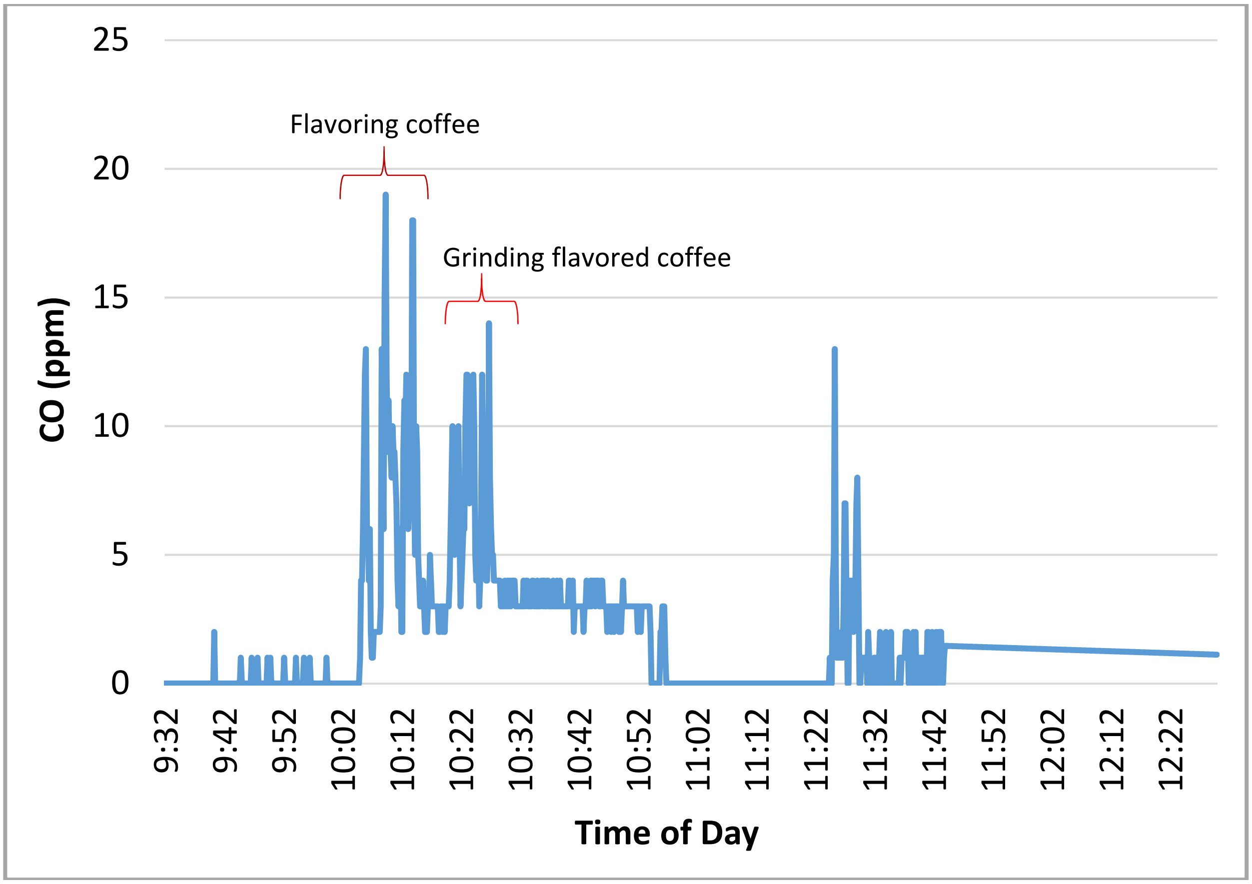

Figure B1. Real-time* personal carbon monoxide air monitoring levels for one employee, NIOSH survey, January 2017. Note: CO=carbon monoxide; ppm=parts per million.
*Personal CO monitor was set to log data at 10-second intervals.

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Keywords: NAICS 311920 (Coffee roasting), Ohio, diacetyl, 2,3-pentanedione, 2,3-hexanedione, coffee, flavorings, carbon monoxide, carbon dioxide, volatile organic compounds (VOCs).

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Acknowledgments

Desktop Publisher: Tia McClelland
Data Analysis Support: Nicole Edwards, Kathleen Fedan, and Brian Tift
Laboratory Support: Dru Burns, Kyle Hatcher, Ryan LeBouf, and Anand Ranpara
Site Visit Team Members: Kristin Cummings, Michael Grant, Alyson Johnson, Ethan Fechter-Leggett, Stephen Martin, Jr., and Brian Tift

Availability of Report

This report is available at http://www.cdc.gov/niosh/hhe/reports/pdfs/2017-0020-3316.pdf. All other Health Hazard Evaluation Reports can be found at http://www2a.cdc.gov/hhe/search.asp

Recommended citation for this report:
NIOSH [2018]. Health hazard evaluation report: Evaluation of exposures and respiratory health at a coffee roasting and flavoring facility. By Fechter-Leggett ED, Johnson AR, Martin SB, Grant MP. Morgantown, WV: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, NIOSH HHE Report No. 2017-0020-3316.

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