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

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Contents

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

Highlights of this Evaluation

The Health Hazard Evaluation Program of the National Institute for Occupational Safety and Health (NIOSH) received a request from management of a coffee roasting and packaging facility regarding concerns about exposures to diacetyl and 2,3-pentanedione during coffee roasting, grinding, and flavoring.

What We Did

- We visited the coffee roasting, flavoring, and packaging facility during July 26–28, 2016, August 8–12, 2016, and February 3, 2017.
- We collected full-shift (hours), task (minutes), and instantaneous (seconds) air samples to measure concentrations of diacetyl, 2,3-pentanedione, and 2,3-hexanedione over multiple days.
- We collected roasted coffee beans (whole bean and ground) and liquid flavorings to measure their emission potential for diacetyl, 2,3-pentanedione, and 2,3-hexanedione.
- We measured real-time air levels of total volatile organic compounds, carbon monoxide, and carbon dioxide.
- We assessed the ventilation system at the facility.
- We administered a health questionnaire to employees and performed breathing tests.
- We assessed spirometry data from the coffee facility's occupational health provider.

What We Found

- All employees participating in full-shift sampling were exposed to diacetyl at concentrations above the recommended exposure limit of 5.0 parts per billion. The highest measured concentration of 420.9 parts per billion was measured on an employee performing duties in the flavoring and grinding areas.

We evaluated respiratory health and airborne exposures to the alpha-diketones diacetyl, 2,3-pentanedione, and 2,3-hexanedione, total volatile organic compounds, carbon monoxide, and carbon dioxide among employees at a coffee roasting and packaging facility. Some employees in the production area of the facility had full-shift exposures that exceeded the NIOSH recommended exposure limits for diacetyl and 2,3-pentanedione. In addition, air sampling during short-term tasks identified tasks measured over minutes (e.g., flavoring coffee, grinding coffee beans, roasting coffee beans, packaging coffee, and cleaning equipment) that resulted in relatively higher air concentrations of diacetyl and 2,3-pentanedione than other tasks. Air levels of carbon monoxide measured on employees with duties that included flavoring and grinding coffee exceeded the NIOSH ceiling limit of 200 parts per million. Eye and nose symptoms were the most commonly reported symptoms. Wheezing or whistling in the chest was the most common lower respiratory symptom reported. Six participants had abnormal spirometry. One participant with abnormal spirometry and work-related respiratory symptoms was referred to a pulmonologist and received a clinical diagnosis of obliterative bronchiolitis associated with occupational exposure to flavorings. In response to our evaluation, the company installed additional general exhaust ventilation in administrative and production areas, local exhaust ventilation in production areas where sources of high exposures to diacetyl and 2,3-pentanedione were documented, and equipment to monitor pressure differentials between production and administrative spaces. The company also enclosed the grinding area and required workers in production areas to wear air-purifying or powered air-purifying respirators fitted with organic vapor and high-efficiency particulate filter cartridges. A medical surveillance program was instituted.

- Some employees participating in full-shift sampling with job duties in administrative areas and production were also exposed to concentrations above the recommended exposure limit for 2,3-pentanedione of 9.3 parts per billion. The highest measured full-shift concentration of 275.9 parts per billion was measured on an employee performing duties in the flavoring and grinding areas.
- Levels of diacetyl in the air during short-term sampling were highest for tasks involving flavoring coffee (maximum 2,127.7 parts per billion), grinding coffee beans (maximum 80.8 parts per billion), roasting coffee beans (maximum: 54.3 parts per billion), packaging roasted coffee (maximum 59.0 parts per billion), and cleaning equipment (maximum: 48.9 parts per billion).
- Levels of 2,3-pentanedione in the air during short-term sampling were higher for tasks involving flavoring coffee (1,444.7 parts per billion) and grinding coffee beans (maximum: 49.9 parts per billion).
- Time-weighted average carbon monoxide levels were higher when employees were performing tasks in the flavoring room and grinding areas (Range: 13.6 parts per billion to 29.8 parts per billion). Peak air levels of carbon monoxide measured on employees performing tasks in the flavoring room exceeded the NIOSH ceiling limit of 200 parts per million.
- All bulk samples of roasted coffee beans and liquid flavorings emitted diacetyl; all bulk samples of roasted coffee and most bulk samples of liquid flavorings emitted 2,3-pentanedione.
- Nose and eye symptoms were the most commonly reported symptoms. Some employees reported these nose and eye symptoms were caused or aggravated by green bean coffee burlap bags, green bean and roasted coffee dust, flavorings, smoke, and roasting coffee.
- Wheezing or whistling in the chest was the most commonly reported lower respiratory symptom, followed by shortness of breath, breathing trouble, and chest tightness. Some employees reported these lower respiratory symptoms were caused or aggravated by grinding and flavoring, heat, and stress.
- Six (6%) of 99 participants had abnormal spirometry.
- Eight (8%) participants had high exhaled nitric oxide, a marker of allergic airways inflammation.
- One employee with abnormal spirometry and work-related respiratory symptoms was referred to a pulmonologist and received a clinical diagnosis of obliterative bronchiolitis associated with occupational exposure to flavorings.
- Of 53 employees with spirometry testing conducted by NIOSH in 2016 and the coffee facility's occupational health provider in 2017, six (11%) had 15% or more decrease in lung function between tests, which is more than expected because of aging. One employee had 15% or more decrease between two occupational health provider spirometry tests conducted in 2017.

What Has Been Done Since the NIOSH Visit

- Administrative staff were relocated to another building until air levels of diacetyl and 2,3-pentanedione in the administrative spaces were mitigated with additional engineering controls.
- One additional vestibule was constructed in the administrative area to seal doors leading from the office area to the production floor to limit air flow between the production and administrative spaces.
- Pressure gauges were installed in the two vestibule areas to provide a visual indicator that the production area was maintained under negative pressure relative to administrative spaces.
- Ductwork was installed to provide additional fresh air supply to roasting, flavoring, grinding, and packaging areas.
- Ductwork was installed to provide additional exhaust to roasting, flavoring, and grinding areas.
- Local exhaust ventilation was installed in the flavoring room at the flavoring blender.
- The grinding area was enclosed.
- Open transfer points at the roasters were enclosed.
- The use of large ceiling fans was discontinued.
- Follow-up air sampling for diacetyl and 2,3-pentanedione was conducted to assess the effectiveness of engineering controls.
- The employer instituted a medical surveillance program, which included repeating spirometry every six months for participating employees.
- Powered air-purifying respirators were required for employees in the flavoring room and grinding area.
- Respirators fitted with organic vapor and high-efficiency particulate filter cartridges were required for employees in other production areas that did not require powered air-purifying respirators.

What the Employer Can Do

- Ensure employees understand potential hazards (e.g., diacetyl, 2,3-pentanedione, carbon monoxide, carbon dioxide, green and roasted coffee dust) in the workplace and how to protect themselves.
- Ensure all doors between the production and non-production areas are kept closed.
- Limit amount of time non-production employees spend in production area.
- Conduct follow-up air sampling to verify additional modifications have been effective in reducing exposures to below the recommended exposure limits.

- Consider additional engineering controls if follow-up air sampling demonstrates exposures remain above recommended exposure limits for diacetyl or 2,3-pentanedione.
- Install a carbon monoxide monitor near grinders and near the mixer in the flavoring room to alert employees if carbon monoxide levels exceed the NIOSH ceiling limit of 200 parts per million.
- If engineering controls do not reduce personal sampling air levels of diacetyl and 2,3-pentanedione below the NIOSH recommended exposure limits, we recommend that management continue to require employees performing tasks in production areas to wear NIOSH-certified respirators fitted with organic vapor cartridges and particulate filters. The choice of respirator (half-face, full-face, or powered air-purifying respirators) should be guided by the concentrations of diacetyl and 2,3-pentanedione on personal air monitoring.
- If increases to production volumes, modification to current work practices, or changes in ventilation occur, conduct additional air sampling to verify that the modifications have not resulted in alpha-diketone exposures above the NIOSH recommended exposure limits. Install additional engineering controls if they become necessary.
- In areas where more protective respirators (half-face, full-face, or powered air-purifying respirators) are not required, make N95 disposable filtering facepiece respirators available for voluntary use for protection against dust exposure, such as when emptying burlap bags of green beans, cleaning the exhaust system of chaff, emptying the chaff containers, or cleaning the green bean storage area.
- Continue the medical surveillance program for employees who work in production areas of the facility, and encourage the occupational health provider to use spirometry results to evaluate employees' change in lung function over time.
- Encourage employees to report new, worsening, or ongoing respiratory symptoms to their personal healthcare providers and to a designated individual at the workplace.

What Employees Can Do

- Use any local exhaust ventilation as instructed by your employer.
- Follow your employer's rules about mandatory respiratory protection use.
- Whenever possible, avoid spending time in the immediate area during flavoring and grinding.
- If more protective respirators (half-face, full-face, or powered air-purifying respirators) are not required, some employees might wish to use N95 disposable filtering facepiece respirators for some tasks, such as when emptying 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.
- 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 surveillance program.

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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
CFM	Cubic feet per minute
CO	Carbon monoxide
CO2	Carbon dioxide
COHb	Carboxyhemoglobin
COPD	Chronic obstructive pulmonary disease
DR5-R20	The difference between resistance at 5 and 20 Hertz
EF	Exhaust fan
FEV_1	1-second forced expiratory volume
fpm	Feet per minute
Fres	Resonant frequency
FVC	Forced vital capacity
Hz	Hertz
kPa/(L/s)	Kilopascals per liter per second
IDLH	Immediately dangerous to life or health
LPM	Liters per minute
LOD	Limit of detection
LOQ	Limit of quantitation
mg/m^3	Milligrams per cubic meter of air
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
PAPRs	Powered air-purifying respirators
PEL	Permissible exposure limit
ppb	Parts per billion
ppm	Parts per million
QC	Quality control
R5	Resistance at 5 Hertz

R20	Resistance at 20 Hertz
REL	Recommended exposure limit
SMR	Standardized morbidity ratios
RH	Relative humidity
STEL	Short-term exposure limit
TLV®	Threshold limit value
TWA	Time-weighted average
VOC	Volatile organic compound
X5	Reactance at 5 Hertz

Summary

In May 2016, the National Institute for Occupational Safety and Health's (NIOSH) Health Hazard Evaluation Program received a request from management of a coffee roasting and packaging facility regarding concerns about exposures to and health effects from diacetyl and 2,3-pentanedione during coffee roasting, grinding, and flavoring. In July 2016, we conducted an industrial hygiene survey and ventilation assessment at the facility. The industrial hygiene survey consisted of collection of air samples and bulk samples of coffee for analysis of diacetyl, 2,3-pentanedione, and 2,3-hexanedione. Continuous monitoring instruments were used to monitor total volatile organic compounds, carbon monoxide, carbon dioxide, temperature, and relative humidity in specific areas and during tasks. We also measured levels of carbon monoxide in employees' exhaled breath and conducted a ventilation assessment. In August 2016, we conducted a medical evaluation of employees that consisted of a health questionnaire and breathing tests. In February 2017, we returned to conduct an industrial hygiene survey of the finished goods warehouse.

All personal full-shift samples collected during the industrial hygiene survey exceeded the NIOSH recommended exposure limit for diacetyl of 5.0 parts per billion, with a maximum concentration of 420.9 parts per billion. Thirty-six of the 37 full-shift samples exceeded the NIOSH recommended exposure limit for 2,3-pentanedione of 9.3 ppb, with a maximum of 275.9 parts per billion. We identified work tasks that resulted in higher air concentrations of diacetyl and 2,3-pentanedione than other tasks. Specifically, flavoring coffee, grinding roasted coffee beans, roasting coffee beans, packaging roasted coffee, and cleaning equipment were associated with higher diacetyl levels. We observed high instantaneous levels of diacetyl and 2,3-pentanedione during flavoring, grinding, and packaging. Air levels of carbon monoxide collected on employees with duties that included flavoring and grinding coffee exceeded the NIOSH ceiling limit of 200 parts per million. Carbon dioxide levels were low throughout most of the facility.

The most commonly reported symptoms were nose and eye symptoms. Some employees reported these nose and eye symptoms were caused or aggravated by green bean coffee burlap bags, green bean and roasted coffee dust, smoke, flavorings, or roasting coffee. Wheezing or whistling in the chest was the most commonly reported lower respiratory symptom. Some employees reported their lower respiratory symptoms were caused or aggravated by grinding and flavoring, heat, or stress. Six (6%) of 99 participants had abnormal spirometry. Eight (8%) participants had high exhaled nitric oxide, a marker of allergic airways inflammation. Employees who reported grinding or flavoring had higher odds of waking up with chest tightness and episodes of flu-like achiness or achy joints in the last 12 months, and had lower lung function parameters, although these were not statistically significant. One participant with abnormal spirometry and work-related respiratory symptoms was referred to a pulmonologist and subsequently received a clinical diagnosis of obliterative bronchiolitis associated with occupational exposure to flavorings.

In response to our evaluation, the company implemented engineering controls and made administrative changes to reduce employees' exposure to diacetyl and 2,3-pentanedione. The

company installed additional general exhaust ventilation in administrative and production areas, local exhaust ventilation in production areas where sources of high exposures to diacetyl and 2,3-pentanedione were documented, and equipment to monitor pressure differentials between production and administrative spaces. The company also enclosed the grinding area. Personal protective equipment requirements were implemented and included powered air-purifying respirators for employees in the flavoring room and grinding area, and half-face respirators for employees in other areas of the facility until exposures could be reduced and verified by additional air sampling. The company also instituted a medical surveillance program that included repeating spirometry every six months to identify employees who might be developing work-related lung disease (e.g., asthma, flavoring-related lung disease). Of 53 employees who underwent spirometry testing conducted by NIOSH in 2016 and the coffee facility's occupational health provider in 2017, six (11%) had 15% or more decrease in lung function between tests, which is more than expected because of aging. One employee had 15% or more decrease between two occupational health provider spirometry tests conducted in 2017. We recommend follow-up air sampling to confirm the effectiveness of engineering controls and consulting with a ventilation engineer to install additional engineering controls near point sources. Additional engineering controls might be designed to capture diacetyl and 2,3-pentanedione in specific locations at sources where elevated levels of diacetyl and 2,3-pentanedione were measured. We recommend the company continue to train employees about potential workplace hazards, and continue to administer the medical surveillance program.

Introduction

In May 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 packaging facility with concerns about potential health effects from exposure to diacetyl and 2,3-pentanedione during coffee roasting, grinding, and flavoring. In July 2016, we conducted a ventilation assessment and industrial hygiene survey at the facility. We collected area and personal breathing zone air samples for volatile organic compounds (VOCs), including diacetyl, 2,3-pentanedione, and 2,3-hexanedione. We also monitored and recorded carbon monoxide (CO), carbon dioxide (CO_2), and total VOCs. In August 2016, we conducted a medical survey. In February 2017, we collected area air samples in the finished product warehouse.

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) [NIOSH 2016]. 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. 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 that 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 a guideline 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 [FEV_1] 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 (FEV_1 below 60% predicted, defined as least 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 sometimes used as a substitute for diacetyl and produced naturally during coffee roasting. In a study using animals, there was some evidence 2,3-hexanedione might also damage the lungs, but it appeared 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 by a process called off-gassing [Anderson et al. 2003; Hawley et al. 2017]. High exposures to CO and CO_2 can cause headache, dizziness, fatigue, nausea, confusion, 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 use 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.

<u>Occupational Safety and Health Administration (OSHA) [Mandatory]</u>

The U.S. Department of Labor's OSHA permissible exposure limits (PELs) are legal limits 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 2018]. 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 that 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.

<u>American Conference of Governmental Industrial Hygienists (ACGIH) [Recommendations]</u>

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 threshold limit values (TLVs) [ACGIH 2018a]. 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 that 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 2018a]. Additionally, ACGIH provides TLV-Ceiling values that 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 2018b].

<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 that are 15-minute TWA exposures that should not be exceeded at any time during a workday [NIOSH 2010]. Some chemicals have ceiling values that 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 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 2018a]. 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. 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 exposures are maintained below the NIOSH REL for diacetyl [NIOSH 2016].

Table 1. Exposure limits for compounds sampled during the NIOSH survey, July 2016.

Compound	OSHA*	ACGIH		NIOSH		
	PEL	TLV	STEL	REL	STEL	IDLH
Diacetyl	-	10 ppb	20 ppb	5 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; STEL=short-term exposure limit; TLV=threshold limit value; 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.
‡ACGIH does not have a TLV for inhalable or respirable dust but does provide guidelines for inhalable and respirable dust; ACGIH guidelines suggests airborne concentrations be kept below 3 mg/m^3 for respirable particles and 10 mg/m^3 for inhalable particles.
§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 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 among 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 among 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 concerning (range: 4.3 ppb to 166 ppb diacetyl; <5.2 ppb to 199 ppb 2,3-pentanedione) 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 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 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; NIOSH 2018]. It includes asthma attributable to sensitizers, which cause disease through immune (allergic) mechanisms, and asthma attributable 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].

Process Description

In July 2016, the coffee roasting and packaging facility had roughly 120 total employees, with approximately 100 of those employees who worked in production. The employees were not represented by a union. The facility was located in a 65,000 square feet building and had been at this location since 2008. At the coffee roasting and packaging facility, the production area was approximately 53,000 square feet in size. Approximately 11 million to 13 million pounds of coffee was roasted and packaged annually, and roughly 60% of the coffee produced was ground. The facility received and stored approximately 500,000 pounds of green coffee beans on site. Green beans were stored in burlap bags in a designated green bean storage area.

To prepare a batch for roasting, a roaster operator weighed the desired amount of green beans before adding them to the roaster. Two roasters were operating during our visit. Both roasters could hold 400 pounds to 500 pounds of coffee beans. When ready, the roaster operator dropped the green beans into the roaster. The beans were heated to a specific temperature and for a specific time period for the desired roast. Time and temperature varied between different types of roasts. On average, roasts lasted 12 minutes to 15 minutes. Occasionally, the roaster operator would pull a small sample from the roaster to check the color of the beans. At the end of each cycle, the roaster operator emptied the roasted beans into a cooling bin where they were agitated by a rotating arm. The cooling bins at both roasters used a downdraft exhaust system that pulled air downward past the roasted beans to accelerate cooling. The downdraft systems pulled exhaust through the roaster, the afterburners, and then to the outside through a ventilation duct. The roaster operator monitored the roasting equipment throughout the roasting and cooling process. After each roast, the roaster operator would collect a small sample of roasted beans from the cooling bin and use the quality control (QC) grinders to assess the color and quality of the roasted beans. After cooling, the roasted beans were dispensed from the cooling bin by a pneumatic siphon system and pulled into a large metal silo. Multiple roasting batches, up to 1500 pounds could be stored in one silo. The roaster operator then manually moved the silo to a nearby storage area until needed for further processing, including grinding, flavoring, and packaging. The roasters were routinely cleaned to remove accumulated chaff from the exhaust lines. A QC technician periodically brewed roasted coffee in a separate QC room to assess product quality and taste.

For ground coffee, an automated, pneumatic system was used to pull whole beans from the silo into either one of two grinders. Both grinders operated on a continuous process and would grind a full silo of roasted coffee in 45 minutes to 50 minutes. If grinding a full silo of roasted coffee, the grinding operator would set-up the silo and grinder and then walk away to perform other tasks. Ground coffee was sent through an automated system to another silo for storage until needed for further processing (e.g., flavoring or packaging).

For flavored coffee, whole bean or ground coffee was sent to the flavoring room by a pneumatic system that would pull roasted coffee from the silo into the ribbon blender in the flavoring room. The flavoring room attendant would mix a 40-pound pail of liquid flavorings and would manually add liquid flavoring to the ribbon blender while the blender mixed the whole beans or ground coffee with the flavoring. The liquid flavoring was added and mixed over a specified time. Once complete, the flavored coffee was emptied into a silo for storage until needed for packaging.

In the packaging area, orders were completed using eight automated packaging lines. Packaging included form fill and seal machines and single serve pod and bagging machines. Bags were equipped with one-way valves for off-gassing. After packaging, bags and boxes of single-serve pods of coffee were stored in cardboard cases. Electric forklifts were used to move finished products to the finished product area before then being sent to the finished goods warehouse located across the street from the production facility.

A breakroom area and administrative offices were located in the space adjacent to the production floor.

Personal Protective Equipment
Employees were not required to wear a company uniform. Before our visit in July 2016, the state OSHA had visited the facility and conducted air sampling for diacetyl and 2,3-pentanedione. Based on the previous air sampling results, employees working in the roasting, flavoring, and grinding areas were required to wear half-mask or full-mask respirators equipped with organic vapor cartridges. A written respiratory protection program was in place for employees who performed job duties at the roasting, flavoring, and grinding area.

Methods

In July 2016, we conducted our initial visit of the facility. We held an opening meeting with management and employees, collected bulk samples and air samples, and performed a ventilation assessment. At the conclusion of our site visit, we held a closing meeting with management and employees. We returned to the facility in August 2016 to conduct a medical survey, and again in February 2017 to collect air samples in the finished goods warehouse.

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. Measure CO levels in employees' exhaled breath;
5. Assess ventilation systems and their effect on exposure levels;
6. Determine if employees had mucous membrane, respiratory, or systemic symptoms and the proportion of those symptoms that were work-related or aggravated by work;
7. Determine if employees had abnormal lung function tests; and
8. Compare employees' prevalence of respiratory symptoms, diagnoses, and spirometric abnormalities with expected levels based on general population values.

Industrial Hygiene Survey

Sampling Times for Alpha-Diketones

We designed the sampling strategy to assess full-shift exposures and identify tasks and processes that were the greatest contributors to worker exposure to alpha-diketones. Sampling was conducted over multiple days. 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 with 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 personal air samples over several minutes; these samples can provide information about which tasks have relatively higher exposures. To help identify point sources of chemicals, we also performed real-time sampling and collected instantaneous samples over seconds.

Employees who 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 both industrial hygiene surveys over multiple 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 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 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 personal 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 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 from both visits were analyzed using an Agilent 7890/7001 gas chromatograph/mass spectrometer system operated in selected ion monitoring mode for increased sensitivity compared with the traditional flame ionization detector used in OSHA Methods 1013 and 1016 [LeBouf and Simmons 2017].

The limit of detections (LOD) for the alpha-diketone sampling results were the lowest mass that our instruments could detect above background and was a criterion used to determine whether to report a result from a sample. The LODs were 0.010 micrograms per sample (μg/sample) for diacetyl, 0.012 μg/sample for 2,3-pentanedione, and 0.02 μg/sample for 2,3-hexanedione. These equate to 0.3 ppb for diacetyl, 0.3 ppb for 2,3-pentanedione, and 0.5 ppb for 2,3-hexanedione for a typical full-shift air sample but 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 area full-shift air samples and instantaneous task-based and source air samples for VOCs including diacetyl, 2,3-pentanedione, and 2,3-hexanedione using evacuated canisters. The evacuated canister sampling setup consisted of a 450-mL evacuated canister equipped with an instantaneous flow controller designed for a short sampling duration (less than 30 seconds). For task-based air samples, a NIOSH employee placed the inlet of the flow controller by the employee's personal breathing zone as they performed their work task to replicate exposure. For source air samples, a NIOSH employee placed the inlet of the flow control directly at the source of interest.

The canister air samples were analyzed using a pre-concentrator/gas chromatograph/mass spectrometer system [NIOSH 2018b], with the addition of acetaldehyde, acetonitrile, and styrene to the list of quantified compounds. The LODs were 0.78 ppb for diacetyl, 1.08 ppb for 2,3-pentanedione, and 1.92 ppb for 2,3-hexanedione based on a three-times dilution factor. 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 coffees (whole bean) and liquid flavorings. 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) monitors to measure concentrations of total VOCs in the air. The ppbRAE has 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 total VOCs. Areas where higher concentrations of total VOCs are measured help indicate areas where sampling to characterize specific exposures to alpha-diketones might be necessary. 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.

We also continuously measured employee personal exposures to CO using a Dräger Pac® 7000 personal single gas detector (Lübeck, Germany). The Dräger Pac 7000 was placed near the breathing zone of employees and worn by employees while they performed their work duties.

Exhaled CO Measurements

We asked employees to perform a carboxyhemoglobin (COHb) test one or more times throughout their shift to measure CO levels in their exhaled breath. This test helps determine if employees are exposed to elevated levels of CO. Employees were asked to inhale deeply and hold their breath for 15 seconds and then exhale through a mouthpiece into a CO monitor. The device then calculated an estimate of carboxyhemoglobin in blood. We asked participants when they last smoked cigarettes or used tobacco products. Tobacco smoke from cigarettes, cigars, and pipe tobacco contains CO and can cause an increase in exhaled CO. Employees who participated in COHb testing were mailed their individual test results.

Ventilation Assessment

Physical measurements of the facility were taken with a Model DISTO E7100i laser-tape measure (Leica Geosystems AG, Heerbrugg, Switzerland). Differential pressure measurements between adjacent spaces were taken using an Energy Conservatory (Minneapolis, MN)

DG-500 Pressure Gauge. Given the industrial scale of the equipment or protective barriers to the equipment, actual ventilation air flow measurements could not be taken. However, information on the existing ventilation equipment, including the make, model, and specified performance level, was collected so air flow metrics could be determined from published manufacturer literature.

Medical Survey

Participants

We invited all current employees to participate in the medical survey at the workplace on August 8–12, 2016. Participation was voluntary; written informed consent was obtained from each participant before testing. An interpreter was used during the medical survey for non-English speaking employees. 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 (in English and Spanish, if applicable) explaining their breathing test results and recommended each participant provide the information to his/her personal physician.

Questionnaire

We used an interviewer-administered computerized questionnaire to ascertain symptoms and diagnoses, work history at this coffee roasting and packaging 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 2018a]. 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.

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 with 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) FEV_1 (the amount of air the participant can blow out in the first second of exhaling), and 3) the ratio of FEV_1 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 classified the severity of a spirometric abnormality on the basis of the FEV_1 percent predicted as follows: ≥ 70% = mild, 60%–69% = moderate, 50%–59% = moderately severe, 35%–49% = severe, < 35% = 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) resonance 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 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 repeated both tests after the participant received a bronchodilator inhaler medication (i.e., albuterol), which can open the airways in some individuals (e.g., asthmatics). 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
Industrial Hygiene Survey and Ventilation Assessment
We performed analyses using SAS version 9.3 (SAS Institute, Cary, NC). We created summary statistics by work area location, job title, and task. When the values presented in the report are from samples below the LOD they are denoted by a "<" symbol.

NIOSH Medical Survey
We calculated frequencies and standardized morbidity ratios (SMRs) and their associated 95% confidence intervals (CIs) using SAS version 9.3 (SAS Institute, Cary, NC). The SMRs compared prevalences of symptoms and spirometric abnormalities among participants with expected prevalences of a sample of the general population reflected in the NHANES III (1988–1994, symptom data) and NHANES 2007–2012 (symptom data), adjusting for sex, race/ethnicity, age (less than 40 years old or 40 years or greater), and cigarette smoking categories (ever/never). For comparisons with the U.S. population, we used the most recent NHANES survey available for the specific comparisons.

Coffee Facility Occupational Health Provider Spirometry
The coffee roasting, flavoring, and packaging facility consulted an occupational health provider to perform spirometry every six months as part of their medical surveillance program. We assessed the occupational health provider spirometry data collected during March 2017 and October/November 2017 for quality and excessive decline in FEV_1 or FVC between tests for employees who completed more than one spirometry test, which included the NIOSH spirometry data from the August 2016 medical survey. Excessive decline in FEV_1 or FVC was defined as a 15% or more decrease in FEV_1 or FVC between two spirometry tests conducted between August 2016 and November 2017 [Hnizdo et al. 2007]. We mailed participants letters (in English and Spanish, if applicable) regarding their change in FVC and FEV_1 from the NIOSH spirometry testing and the occupational health provider spirometry testing. We recommended participants provide that information to their personal physicians. We reported our findings from the spirometry review to the occupational health provider.

Results

Industrial Hygiene Survey Results

Personal and Area Full-shift Air Sampling Results

Personal and area full-shift air sampling results using OSHA Method 1013/1016 can be seen in Table A1. We collected 37 personal and 119 area full-shift air samples over three days in July 2016, and six additional area full-shift samples in February 2017. All 37 personal full-shift samples collected exceeded the NIOSH REL of 5.0 ppb for diacetyl. Samples above the NIOSH REL for diacetyl included samples collected on employees performing duties in the administrative, flavoring, grinding, finished product storage, green bean storage, packaging, QC lab, and roasting areas. The highest full-shift samples for diacetyl were measured on employees performing duties in the flavoring and grinding areas (three samples; range: 41.1 ppb to 420.9 ppb), and were 8 to 84-fold higher than the NIOSH REL of 5 ppb for diacetyl. Roaster operators had the second highest full-shift exposures (six samples; range: 35.5 ppb to 57.1 ppb). Full-shift samples for diacetyl for employees performing duties at the packaging machines (15 samples) ranged from 29.7 ppb to 48.8 ppb; finished product storage (two samples) ranged from 21.5 ppb to 29.0 ppb; green bean storage (two samples) ranged from 23.9 ppb to 46.1 ppb; and administrative areas (three samples) ranged from 30.8 ppb to 34.9 ppb. Personal full-shift exposures were lowest on employees performing duties in the QC lab (four samples) and ranged from 8.9 ppb to 37.4 ppb.

Similar to the diacetyl results, 36 of the 37 full-shift samples exceeded the NIOSH REL of 9.3 ppb for 2,3-pentanedione. The highest full-shift samples for 2,3-pentanedione were also measured on employees who performed tasks in the flavoring and grinding areas (three samples; range: 21.7 ppb to 275.9 ppb). Roaster operators had the second highest full-shift exposures to 2,3-pentanedione (six samples; range: 19.1 ppb to 34.4 ppb). Full-shift samples for 2,3-pentanedione were similar for employees performing duties at the packaging machines (15 samples; range: 14.4 ppb to 31.0 ppb), finished product storage (two samples; range: 11.5 ppb to 14.7 ppb), green bean storage (two samples; range: 12.2 ppb to 28.3 ppb), and administrative areas (three samples; range: 13.8 ppb to 15.9 ppb). Personal full-shift exposures were lowest on employees performing duties in the QC lab (four samples; range: 4.9 ppb to 17.6 ppb). Three of the four full-shift samples collected on employees in the QC lab were above the NIOSH REL of 9.3 ppb for 2,3-pentanedione.

Some full-shift samples collected on employees performing flavoring and grindings tasks had 2,3-hexanedione levels above the LOD (three samples; range: <0.5 ppb to 11.2 ppb). All other full-shift samples were below the LOD for 2,3-hexanedione.

The highest full-shift TWA area samples were collected in the flavoring room (maximum: 327.2 ppb diacetyl and 772.9 ppb 2,3-pentanedione). The area by the grinders had the second highest levels of diacetyl and 2,3-pentanedione (maximum: 84.2 ppb diacetyl and 45.9 ppb 2,3-pentanedione). Roasting and packaging areas also had high measurements of diacetyl and 2,3-pentanedione. Maximum measurements at the roasters were 57.8 ppb diacetyl and 34.0 ppb 2,3-pentanedione and maximum measurements in the packaging areas were 55.6 ppb diacetyl and 37.4 ppb 2,3-pentanedione. Some area full-shift air samples had measureable levels of 2,3-hexanedione. Full-shift area samples collected in the flavoring room (range: <0.5 ppb to 8.8 ppb), area near the main grinders (range: <0.5 ppb to 1.3 ppb), the roasting area (range: <0.5 ppb to 0.9 ppb), and the silo area (range: <0.4 ppb to 1.0 ppb) had 2,3-hexanedione levels above the LOD.

Of the 125 full-shift area air samples, 120 were above the NIOSH REL for diacetyl. Because area air samples are not personal air samples collected directly on an employee, the NIOSH RELs are not directly applicable to the results for exposure monitoring purposes. However, area air samples can highlight areas with higher exposure risk, and the RELs can be used as points of reference. The following areas had one or more 6-hour air level(s) that exceeded the NIOSH REL for diacetyl: administrative (range: 27.6 ppb to 41.1 ppb), breakroom (range: 16.2 ppb to 41.4 ppb), finished product storage (range: 23.1 ppb to 39.4 ppb), flavoring room (range: 20.3 ppb to 327.3 ppb), green bean storage room (range: 35.2 ppb to 52.2 ppb), grinding (range: 36.9 ppb to 84.2 ppb), all packaging areas sampled (21.0 ppb to 55.6 ppb), production area (range: 27.5 ppb to 43.6 ppb), the QC lab (range: 18.8 ppb to 33.9 ppb), roasting (range: 37.3 ppb to 57.8 ppb), silo area (range: 33.1 ppb to 56.1 ppb), and storage room (range: 36.1 ppb to 49.6 ppb).

Full-shift TWA samples collected in six areas of the finished goods building in February 2017 had diacetyl and 2,3-pentanedione concentrations that were lower than all samples collected in the main production building. Diacetyl concentrations ranged from 2.8 ppb to 5.4 ppb. We note the sample collected in the cabinet shop had a shorter sampling time collection of 4.4 hours. All other samples were collected for six-hours total duration. The office area of the finished goods building where administrative staff were relocated had the lowest measured diacetyl concentration (2.8 ppb). The center operator's desk in the warehouse was also below the NIOSH REL of 5 ppb for diacetyl (4.7 ppb). All other locations in the finished goods warehouse were at, or just above, the NIOSH REL for diacetyl (Table A1; range: 5.0 ppb to 5.4 ppb).

Of the 125 area full-shift air samples, 114 were above the NIOSH REL for 2,3-pentanedione. The following areas had one or more 6-hour air level(s) that exceeded the NIOSH REL for 2,3-pentanedione: administrative (range: 15.8 ppb to 23.9 ppb), breakroom (range: 7.7 ppb to 23.5 ppb), finished product storage (range: 11.8 ppb to 21.1 ppb), flavoring room (range: 11.0 ppb to 772.9 ppb), green bean storage room (range: 19.1 ppb to 29.9 ppb), grinding (range: 16.5 ppb to 45.9 ppb), all packaging areas sampled (14.4 ppb to 37.4 ppb), production area (range: 12.5 ppb to 28.7 ppb), QC lab (range: 10.3 ppb to 18.0 ppb), roasting (range: 19.3 ppb to 34.0 ppb), silo area (range: 18.6 ppb to 32.4 ppb), and storage room (range: 19.0 ppb to 30.3 ppb).

Task-Based Air Sampling Results

Personal task air concentration results can be seen in Tables A2 and A3. We collected 70 personal task-based air samples using OSHA Methods 1013/1016 (Table A2). Task duration ranged from four minutes to 46 minutes. We collected personal task air samples while employees roasted coffee (n = 17), flavored coffee (n = 4), ground coffee (n = 6), moved roasted beans or ground coffee (n=1), packaged coffee (n = 21), cleaned equipment (n = 15), performed a thermal heat of the roaster (n = 5), and performed quality control tasks (n = 1). The highest task-based exposures to diacetyl (four samples; range: 521.3 ppb to 2,172.7 ppb) and 2,3-pentanedione (range: 345.0 ppb to 1,444.7 ppb) were measured while an employee flavored coffee (Table A2). All three 15-minute samples collected while an employee flavored coffee exceeded the NIOSH STEL of 25 ppb for diacetyl and 31 ppb for 2,3-pentanedione. Employees that ground coffee had the second highest exposure to diacetyl (six samples; range: 47.4 ppb to 80.8 ppb) and 2,3-pentanedione (range: 20.7 ppb to 49.9 ppb). All four fifteen-minute samples collected while an employee ground coffee exceeded the NIOSH STEL of 25 ppb for diacetyl and one sample exceeded the NIOSH STEL of 31 ppb for 2,3-pentanedione. Roaster operators also had high task-based exposures to diacetyl (17 samples; range: 28.4 ppb to 54.3 ppb). All four fifteen-minute samples collected while an employee roasted coffee exceeded the NIOSH STEL for diacetyl. One 15-minute sample collected while a roaster operator performed a post-clean thermal heat of roaster exceeded the NIOSH STEL for diacetyl. Packaging tasks also had high levels of exposure to diacetyl (21 samples; range: 3.9 ppb to 59.0 ppb). Seven of the 10 fifteen-minute samples collected while an employee packaged coffee exceeded the NIOSH STEL for diacetyl. Cleaning equipment tasks also exceeded the NIOSH STEL for diacetyl (15 samples; range 11.6 ppb to 48.9 ppb). All 15-minute samples collected while employees cleaned the flavoring mixer, grinders, or packaging machines exceeded the NIOSH STEL for diacetyl.

We collected 44 personal samples near the breathing zone of employees using instantaneous canisters (Table A3). Levels of diacetyl and 2,3-pentanedione observed in the breathing zone of employees using instantaneous canisters were higher than the levels described above. The highest instantaneous levels were measured for flavoring tasks (four samples; range: 1,826 ppb to 2,307 ppb for diacetyl and 991 ppb to 1,509 ppb for 2,3-pentanedione). The second highest levels of diacetyl (instantaneous samples with >100 ppb levels of diacetyl) were observed when a roaster operator pulled a sample of beans from the roaster and used the sample grinder near the roasters to check the quality of the roasted beans (Table A3). An instantaneous sample collected while an employee cleaned the interior of the single serve packaging machine #3 also had greater than 100 ppb of diacetyl (Table A3). 2,3-Hexanedione concentrations were always less than diacetyl and 2,3-pentanedione concentrations and ranged from 1.4 ppb to 157 ppb.

Source Air Sampling Results

Instantaneous evacuated canister concentrations for diacetyl and 2,3-pentanedione can be seen in Table A4. Instantaneous samples were less than 30 seconds in duration. We collected 23 source samples using evacuated canisters. Instantaneous source samples collected by the blender while coffee was being mixed with flavoring had the highest levels of diacetyl and 2,3-pentanedione (two samples; range: 6,732 ppb to 18,744 ppb for diacetyl and 236 ppb to 9,746 ppb for 2,3-pentanedione). The second highest instantaneous source samples for diacetyl and 2,3-pentanedione were collected by the exhaust vent on the backside of single-serve packaging machine #3 (three samples; range: 244 ppb to 346 ppb for diacetyl and 245 ppb to 370 ppb for 2,3-pentanedione). Instantaneous samples collected near the grinders ranged from 61 ppb to 111 ppb for diacetyl and 35.7 ppb to 56.6 ppb for 2,3-pentanedione (Table 4). Instantaneous samples collected inside and outside of the packaging machines' doors had similar levels to those measured at the grinders, and ranged from 31.4 ppb to 104 ppb for diacetyl and 23.8 ppb to 36.1 ppb for 2,3-pentanedione.

Bulk Samples and Headspace Results

All liquid flavoring samples had detectable quantities of diacetyl. Headspace diacetyl concentrations in the 14 liquid flavoring samples we collected ranged from 845 ppb to 10,741 ppb. Of the liquid flavoring samples collected, Butter Rum and Chocolate Caramel Brownie had the highest measured levels of diacetyl. Twelve of the 14 liquid flavoring chemicals had detectable quantities of 2,3-pentanedione. Chocolate Cherry and Hazelnut Cream samples were below the limit of detection for 2,3-pentanedione. Headspace 2,3-pentanedione concentrations in the 12 liquid flavoring samples with detectable quantities ranged from 409 ppb to 6,517 ppb. Of the liquid flavoring samples collected, Caramel Cream and Sea Salt & Caramel had the highest levels of 2,3-pentanedione. All samples were below the LOD for 2,3-hexanedione.

All five bulk samples of roasted coffee had detectable quantities of diacetyl and 2,3-pentanedione. Headspace concentrations of diacetyl ranged from 1,336 ppb to 14,490 ppb and 2,3-pentanedione ranged from 423 ppb to 12,195 ppb. Ground coffee with Butter Rum flavoring had the highest levels of diacetyl and 2,3-pentanedione. All samples were below the LOD for 2,3-hexanedione.

Real-time Monitoring: Carbon Dioxide (CO_2), Carbon Monoxide (CO), and Total Volatile Organic Compounds (TVOCs)

A summary of the real-time CO_2, CO, temperature, and total VOC monitoring results can be seen in Table A6. Levels of CO_2 and CO measured in the flavoring room ranged from 598 ppm to 1,546 ppm for CO_2 and 5.7 ppm to 40.8 ppm for CO. Total VOC measurements in the flavoring room ranged from 1,544 ppb to 104,727 ppb. Levels of CO_2 and CO measured at the brown grinder ranged from 524 ppm to 1,402 ppm for CO_2 and 3.5 ppm to 126.9 ppm for CO. Total VOC levels ranged from 510 ppb to 7,145 ppb at the brown grinder.

Levels of CO_2 and CO at the roasters ranged from 491.0 ppm to 954.0 ppm for CO_2 and 4.6 ppm to 23.6 ppm for CO. Levels of CO_2 and CO measured in packaging at the VFFS box and pallet area ranged from 536 ppm to 635 ppm for CO_2 and 3.4 ppm to 9.9 ppm for CO.

A summary of continuous, real-time, personal measurements of CO can be seen in Table A7. TWA personal CO measurements ranged from 6.7 ppm to 29.8 ppm and were below the NIOSH REL of 35 ppm for CO exposure. All full-shift samples for CO were below their respective NIOSH REL and OSHA PEL for CO. Ranges of full-shift samples for CO were collected on employees performing the duties in the following areas: green bean storage area (11.1 ppm to 11.5 ppm), packaging area (7.4 ppm to 13.8 ppm), roasting area (7.1 ppm to 12.8 ppm), and room and grinding area (13.6 ppm to 29.8 ppm). Additionally, we noted four peak exposures that exceeded the NIOSH ceiling limit for CO of 200 ppm on an employee performing tasks in the flavoring room. The peak exposures occurred when the employee stood over ground coffee in the flavoring room blender and manually added liquid flavoring to the ground coffee in the blender.

Personal Exhaled CO Measurements
Thirty employees who participated in the personal air sampling also provided breath samples for measurement of CO by exhaling into a monitor at various times during the workday. Measurements were typically collected at the beginning of the shift, lunch break, and at the end of the shift. After the participant exhaled into the monitor, the device reported a CO value in ppm and also calculated an estimated COHb percentage. The overall average CO level was 4.0 ppm (range: 0 ppm to 36 ppm), and average COHb was 1.9% (0% to 6.4%). Average CO level in smokers was 8.1 ppm (range: 0 ppm to 21 ppm), and average COHb was 1.8% (range: 0% to 4.0%). All COHb test results in non-smokers were below 6.4% and in smokers were below 4.0%. The highest exhaled CO (36 ppm) and COHb (6.4%) was measured at the beginning of an employee's shift.

Ventilation Assessment Results
The roasting, grinding, packaging and finished goods warehouse space were all supplied fresh, outdoor air through a single RuppAir (Lakeville, MN) RAM 20 Industrial Direct-Fired Horizontal Heater. The RAM 20 unit provided heat to the space during the colder months. An evaporator coil (model 12D45X71; manufacturer was not able to be determined) installed in the supply air duct and connected to a Carrier (Syracuse, NY) model 38APD050 Air-Cooled Condensing Unit allowed the ventilation system to supply cool air to the space during warmer months. Collectively, the system providing outdoor air was capable of delivering around 10,000 cubic feet per minute (cfm) to the facility. The majority of the supply air was introduced through three large supply vents on the eastern end of the packaging space while a small portion of the air was diverted through a separate supply duct and introduced through the western wall of the on-site warehouse space.

Exhaust from the production areas of the facility was provided by a series of rooftop exhaust fans (EFs). A Greenheck (Schofield, WI) model CUBE-121-4 X belt-driven Upblast Centrifugal EF-2 exhausted air from above the grinding area. We did not have equipment to allow accurate measurements of the exhaust fan flow rates, but product literature indicated fan EF-2 exhausted roughly 2,200 cfm from the space. A Greenheck model GB-180-5-X belt-driven Downblast Centrifugal EF-3 exhausted about 2,400 cfm of air from the enclosed flavoring room. Roughly, 1,000 cfm of air was being exhausted from the storage room in the front of the production space by a Greenheck model GB-161-4-X belt-driven Downblast Centrifugal EF-4. Finally, two Greenheck model G-133-VG-7-X direct drive Downblast Centrifugal Exhaust Fans each exhausted about 2,300 cfm of air (4,600 cfm total) from the engineering/maintenance space. In addition to the fresh, outdoor air supplied to the production spaces and exhaust from those spaces, a series of five high-volume ceiling fans were used to facilitate air mixing during our visit.

Differential pressure measurements indicated that proper pressure relationships were maintained throughout most of the facility. The enclosed flavoring room was measured to be under negative pressure (-0.012 inches of water gauge) relative to the main packaging area. This negative pressure meant that less-contaminated air from the production space was pulled into the flavoring room instead of air from the flavoring room escaping into the rest of the production space. The QC Lab (+0.006 inches of water gauge), Operations Manager's Office

(+0.010 inches of water gauge), and main entrance to administrative areas near the employee break room (+0.005 inches of water gauge) were all under positive pressure. Thus, under the conditions when our pressure measurements were taken, air from the administrative areas was pulled into the production space, as desired, instead of air from the production space being pulled into the administrative areas. The administrative spaces of the facility were served by two Lennox (Richardson, TX) rooftop air-handling units. These units were not evaluated during our visit. However, different combinations of operating states for those units (i.e., which are on and off simultaneously) on the administrative side of the facility could make the pressure differentials better or worse.

Medical Survey Results

Demographics

Ninety-nine (83%) of 120 onsite employees participated in the medical survey. The majority of participants were male (66%) and Spanish, Hispanic or Latino (62%), with a mean age of 37 years (range: 18 years–67 years) and average tenure with the company of three years. Nine (9%) participants worked at another coffee roasting and packaging facility or in coffee cafés before working at this facility. Thirty-four (34%) participants were current or former smokers.

Ninety-one (92%) participants reported performing work tasks in the production area for an average of 35 hours per week, ranging from 45 minutes to 45 hours per week. Of these employees, 27 (30%) worked with green beans, 34 (37%) worked in the warehouse, nine (10%) roasted coffee beans, 15 (16%) ground coffee beans, 42 (46%) moved coffee beans or ground coffee, 10 (11%) flavored coffee, 62 (68%) packaged coffee, 50 (55%) cleaned containers of roasted coffee, 28 (31%) performed maintenance on coffee production machines, and 29 (32%) performed quality control activities. Employees reported being within an arm's length of the following exposures: packaging of coffee (76%); an operating production roaster (43%); cooling bins that contained roasted beans while they were cooling (n=39, 39%); an operating production grinder (36%); and flavoring of roasted coffee (22%).

Symptoms and Self-Reported Diagnoses

The prevalence of symptoms over the last year and last four weeks at the time of the survey, and those reported to be better away from work or caused or aggravated by work are listed in Table A8. Nose symptoms were the most commonly reported symptom (n=46, 46%), followed by eye symptoms (n=43, 43%). Of those participants with nose and eye symptoms, 23 participants with nose symptoms and 24 participants with eye symptoms reported those symptoms were better away from work or caused or aggravated by work. Some employees reported these nose and eye symptoms were caused or aggravated by green bean coffee burlap bags, green bean and roasted coffee dust, flavorings, smoke, or roasting coffee.

Wheezing or whistling in the chest was the most commonly reported lower respiratory symptom (n=18, 18%), followed by shortness of breath on level ground or walking up a slight hill (n=17, 17%), breathing trouble (n=17, 17%), and chest tightness (n=17, 17%). Of those participants, four participants with chest wheezing or whistling, five participants with breathing trouble, and 10 participants with chest tightness reported these lower respiratory symptoms were better away from work or caused or aggravated by work. Eleven (65%) of

17 participants with shortness of breath on level ground or walking up a slight hill reported their shortness of breath began after they started employment at this facility. Among those 11 participants, the median tenure was 3.6 years (range: 2.1–6.7 years). Some employees reported these lower respiratory symptoms were caused or aggravated by grinding and flavoring, heat, or stress. Unusual tiredness or fatigue (32%) and flu-like achiness or achy joints (30%) were the most commonly reported systemic symptoms. Of those participants with unusual tiredness and flu-like achiness, 20 participants with unusual tiredness or fatigue and nine participants with flu-like achiness or achy joints reported these systemic symptoms were better away from work or caused or aggravated by work.

Of the 91 employees who performed production tasks, the 15 (16%) who reported grinding or flavoring had 3.7 times the odds of reporting chest tightness in the last 12 months than those employees who did not perform grinding or flavoring (odds ratio: 3.7; 95% confidence interval 1.0–13.4). Employees who reported grinding or flavoring also had 3.4 times the odds of reporting flu-like achiness or achy joints in the last 12 months compared with employees who did not report performing these tasks (odds ratio: 3.4; 95% confidence interval 1.1–10.7).

Eleven (11%) participants reported ever being diagnosed with asthma and three (3%) reported current asthma. One participant reported being diagnosed with asthma after beginning employment at this facility. Eleven (11%) participants reported a diagnosis of hay fever or nasal allergies; two participants were diagnosed with hay fever or nasal allergies after beginning employment at this facility. Six (6%) participants reported a diagnosis of gastroesophageal reflux disease, three participants were diagnosed with gastroesophageal reflux disease after beginning employment at this facility. Five (5%) participants reported a diagnosis of eczema; one participant was diagnosed with eczema after beginning employment at this facility. Four (4%) participants reported a diagnosis of heart disease; three participants were diagnosed with heart disease after beginning employment at this facility. Two (2%) participants reported a diagnosis of chronic bronchitis; one participant was diagnosed with chronic bronchitis after beginning employment at this facility.

Medical Tests

All 99 medical survey participants performed the breathing tests. Six (6%) of 99 participants had abnormal spirometry results, including three with mild restriction, two with moderate mixed patterns, and one with mild obstruction. Two of the three participants with obstruction or mixed patterns had significant improvement after taking a bronchodilator. Thirty-two (32%) participants who performed impulse oscillometry had test results interpreted as abnormal: 17 consistent with small airway abnormality, eight consistent with large airway abnormality, and seven consistent with small and large airway abnormalities. Seventeen (65%) of 26 participants with abnormal impulse oscillometry had significant improvement after taking a bronchodilator. Eight (8%) participants who performed exhaled nitric oxide tests had tests interpreted as elevated. Of the 37 participants with at least one abnormal breathing test, 15 (41%) participants reported nose or eye symptoms that were better away from work or caused or aggravated by work, and five (14%) participants reported one or more lower respiratory symptoms that were better away from work or caused or aggravated by work.

Employees who reported grinding or flavoring had lower mean percent predicted FEV_1 (98.8% versus 101.6%), lower mean percent predicted FVC (98.3 versus 102.0), and lower FEV_1/FVC ratio (0.81 versus 0.82) compared with employees who did not report performing these tasks, although the differences were not statistically significant.

Case Report of Flavoring-related Lung Disease
One participant in our medical survey was referred to a pulmonologist for additional diagnostic testing following the medical survey because of abnormal spirometry, work-related respiratory symptoms, and work history at the coffee packaging and roasting facility. The pulmonologist diagnosed the patient with obliterative bronchiolitis associated with occupational exposure to flavorings and prescribed azithromycin for one year.

NHANES Comparison of Symptoms and Diagnoses
The SMR for ever receiving a physician diagnosis of asthma was elevated at 2.1, although the SMR for current asthma was not elevated (Table A9). Prevalences of chronic bronchitis, shortness of breath, wheeze, cough, phlegm, sinus problems, and nose and eye symptoms were not elevated compared with the general U.S. population, adjusted for age distribution, race/ethnicity, sex, and smoking history. In addition, there was not an excess of restrictive, mixed, or obstructive spirometry abnormalities compared with the general U.S. population, adjusted for age distribution, race/ethnicity, sex, and smoking history (Table A10).

Update since July and August 2016 site visits
Below is a summary of follow-up activities after our initial site visits in July 2016 and August 2016.

December 2016
We shared air sampling results for diacetyl, 2,3-pentanedione, and 2,3-hexanedione in the flavoring room and grinding area in a letter dated December 22, 2016, which included written interim findings and recommendations. We recommended the following:

- Powered air-purifying respirators (PAPRs) should be worn at all times by all individuals working in or passing through the flavoring room and grinding area until additional measures (elimination, engineering controls, or administrative controls) can be applied to reduce the levels of diacetyl and 2,3-pentanedione in these areas. The boundaries of the grinding area should be clearly marked so that employees are aware when they need to use appropriate respiratory protection.
  - PAPRs should be NIOSH-certified with an assigned protection factor (APF) of 1000. The PAPRs should also have NIOSH-certified organic vapor cartridges and high-efficiency particulate cartridges/filters.
  - Ensure the respiratory protection program is in compliance with the OSHA Respiratory Protection Standard, 29 CFR 1910.134. Minnesota OSHA instruction CPL 2-2.120 [http://www.dli.mn.gov/sites/default/files/pdf/wsc_respiratory_protection_0911.pdf] provides guidelines to promote enforcement of the OSHA Respiratory Protection Standard.

An OSHA respiratory protection program includes the following elements:

- ○ written policy;
- ○ change-out schedule for cartridges/filters;
- ○ medical evaluation before use to determine fitness;
- ○ fit testing and training before use and annually; and
- ○ establishment and implementation of procedures for proper respirator use, such as prohibiting use with facial hair when this would impair the seal; ensuring user seal-check and inspection of respirators before each use; ensuring proper cleaning, disinfection, and maintenance of respirators; and ensuring proper storage of respirators to protect respirators from damage, contamination, dust, sunlight, and extreme temperatures. Respirators stored in particularly hot areas (especially during the summer) are at risk for deforming. Check the manufacturer's guidelines on what temperatures are appropriate for storage to allow maximum shelf life. Information about maintenance and care of respirators can be found on OSHA's website at https://www.osha.gov/video/respiratory_protection/maintenance_transcript.html.

- Ensure employees understand potential hazards (e.g., diacetyl and 2,3-pentanedione) 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. Minnesota OSHA has an employer's guide to developing an employee-right-know program at http://www.dli.mn.gov/sites/default/files/pdf/hazcom_ertk_development.pdf.
- Employees should report new, persistent, or worsening symptoms to their personal healthcare provider and, as instructed by their employer, to a designated individual at their workplace. Employees with new, persistent, or worsening symptoms should share this report with their healthcare providers.
- Establish a medical surveillance program to help assure the health of employees who have workplace exposures to health hazards (e.g., diacetyl and 2,3-pentanedione) known to pose risk for potentially serious health conditions or illnesses.
  - ○ Known cases of coffee processing workers diagnosed with obliterative bronchiolitis had exposure to flavored coffee or worked in areas that flavor coffee [Bailey et al. 2015]. The NIOSH Criteria Document [NIOSH 2016] recommends the employer institute a medical surveillance program for all employees who work in or enter areas where flavorings are used. Employees who work in or enter these areas for 40 or more hours per year should be included in the medical surveillance program.
  - ○ According to the NIOSH Criteria Document [NIOSH 2016], employees should have baseline evaluations before they are allowed to work in or enter areas (as described above) where they might be exposed to diacetyl, 2,3-pentanedione, or similar flavoring compounds. The spirometry we conducted in August 2016 could serve as a baseline for survey participants. Employees in the medical surveillance

program should be evaluated with a questionnaire (to obtain health and work task information) and spirometry (to assess lung function) every six months because of 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]. As such, we recommend that employees in the medical surveillance program be evaluated every three months.

January 2017

On January 19, 2017, we held a teleconference with company management to discuss additional sampling results that we received since the first interim letter. We provided a summary of the full-shift TWA concentrations of diacetyl and 2,3-pentanedione measured in various areas and on employees at this facility, and bulk sampling and headspace analysis of coffee and liquid flavorings in a letter dated January 31, 2017. We provided additional written interim findings and recommendations. We recommended the following:

- Consult with a ventilation engineer to modify the current ventilation design such that the production areas are under negative pressure, relative to the administrative areas.
- Ensure air from the production area is not recirculated into the administrative areas.
- Offer medical surveillance to all employees. Employees in the flavoring room and grinding areas should be evaluated every three months; other employees should be evaluated every six months.
- Require employees working in other areas with high diacetyl and 2,3-pentanedione levels to wear respirators fitted with organic vapor and high-efficiency particulate filter cartridges until additional engineering controls can reduce personal exposures below the NIOSH REL for diacetyl and 2,3-pentanedione.
- If engineering controls do not reduce personal sampling air levels of diacetyl and 2,3-pentanedione below the NIOSH RELs, we recommend management continue to require employees performing tasks in those areas to wear NIOSH-certified respirators fitted with organic vapor cartridges and particulate filters. The choice of respirator (half-face, full-face, or powered air-purifying respirator [PAPR]) should be guided by the concentrations of diacetyl and 2,3-pentanedione on personal air monitoring.

On January 26, 2017, we held a teleconference with company management to discuss plans to implement additional engineering, administrative, and personal protective equipment controls. During the teleconference, management asked if we could provide additional detail regarding to diacetyl and 2,3-pentanedione concentrations measured at specific locations and during specific processes, to help guide the design of engineering controls.

February 2017

We held a teleconference with company management on February 2, 2017 to discuss results from our CO measurements in the flavoring room. We discussed additional controls that might be implemented in the flavoring room to mitigate employee exposure to diacetyl, 2,3-pentanedione, and CO. On February 3, 2017, a NIOSH industrial hygienist returned to the facility and collected full-shift area samples in the Finished Goods Warehouse. In a letter dated February 9, 2017, we provided air sampling results from short-term, task-based samples collected on employees, and instantaneous samples collected near specific sources to help management and an industrial hygienist consultant identify sources and processes that contributed to the diacetyl and 2,3-pentanedione concentrations observed at the facility. We also provided full-shift area sample results for diacetyl and 2,3-pentanedione concentrations alongside a detailed area sample location description. We also provided a summary of employee personal CO exposure results in that letter.

In emails dated February 11, 2017, and February 18, 2017, company management informed us the flavoring room blender was enclosed with a lid, and a flavoring spray bar automated system was completed. The automation eliminated manual flavoring of whole bean or ground coffee in the flavoring room. Follow-up sampling for CO was planned. Additionally, the company had hired ventilation and construction contractors to help with installing engineering controls. Employees in the administrative spaces were relocated to an adjacent building while engineering controls were installed in administrative areas in the main building. A ventilation engineer modified the air supply to the administrative spaces to ensure administrative spaces were kept under positive pressure relative to the production areas, and follow-up air sampling showed that air levels of diacetyl in the administrative areas were less than the NIOSH REL of 5.0 ppb.

March 2017–November 2017

In response to our evaluation, the company instituted a medical surveillance program in March 2017. Additionally, the company set-up two air purifying systems in the flavoring and training rooms. In March 2017, the company began construction of an additional vestibule to seal doors leading from the office areas to the production area to mitigate risk of entrainment of air from the production area into the administrative spaces. The company also installed pressure gauges in the vestibule areas to provide a visual indicator the positive air pressure in the office areas relative to the production areas was maintained.

In May 2017, the company received finalized designs for (1) the flavoring room roof exhaust stack; (2) enclosure walls for the grinding room; (3) additional ductwork in the roasting, flavoring, and grinding areas, to provide additional supply air and exhaust in those areas; and (4) additional supply air over the packaging areas. In July 2017, the company consultant performed follow-up air sampling to evaluate the effectiveness of engineering controls. The company also installed garage doors in the grinding area to isolate the grinding area from the packaging area. In September 2017, company management informed us they planned to install custom local exhaust ventilation hoods in the flavoring room and finish installing ductwork for additional supply air in the packaging areas. Additionally, the consultant performed follow-up air sampling in November 2017 to evaluate the effectiveness of engineering controls installed as of November 20, 2017.

The occupational health provider conducted 146 spirometry tests, including 92 during March 2017 and 54 during October/November 2017. Fifty employees had spirometry tests performed in March 2017 and October/November 2017, and 46 had one spirometry test performed March 2017 or October/November 2017. Spirometry quality was evaluated based on the American College of Occupational and Environmental Medicine guidelines on occupational health spirometry [Townsend 2011]. FEV_1 and FVC were graded as follows: A if there were three acceptable trials and the highest two values were within 100 mL; B if there were at least two acceptable trials and the highest two values were within 150 mL; C if there were at least two acceptable trials and the highest values were within 250 mL; D if there was only one acceptable trial; and F is there were no acceptable trials. Of the 146 tests performed by the occupational health provider, 126 (86%) were graded A, B, or C, and 20 (14%) as D. Of the 146 spirometry tests, 121 (83%) were interpreted as normal, 14 (10%) with a restrictive abnormality, nine (6%) with an obstructive abnormality, and two (1%) with low FEV_1, and normal ratio and volume. One employee had an excessive decline in FVC and FEV_1 between tests conducted by the occupational health provider; the result was interpreted as normal in March 2017 with a C grade and mild restrictive abnormality in October/November 2017 with an A grade. This employee also participated in NIOSH spirometry testing in August 2016 with an A grade; the result was interpreted as normal; there was a less than 10% decline in FEV_1 and FVC between the August 2016 and October/November 2017 testing.

Of the 99 employees who completed spirometry during the NIOSH medical survey, 53 had at least one spirometry test completed by the coffee facility's occupational health provider as part of their medical surveillance program. The mean time between spirometry tests was 1.0 year (range: 0.6 year–1.3 years). Of the 53 employees who participated in the NIOSH medical survey in August 2017 and had at least one test conducted by the occupational health provider, six (11%) had an excessive decline in FEV_1 or FVC between the NIOSH spirometry testing and their most recent occupational health provider spirometry test we had. This decrease could be a sign of lung disease. However, this interpretation of a larger than expected decrease in FEV_1 or FVC is based on only two tests. We recommended employees share these results with their personal physician to confirm the result with repeat spirometry testing and possibly other testing. All six with excessive decline in FEV_1 or FVC had spirometry results interpreted as normal during the NIOSH medical survey in August 2017. The occupational health provider spirometry interpretations for these six were interpreted as follows: two as normal, three with a restrictive abnormality, and one with an obstructive abnormality.

Discussion

Diacetyl, 2,3-pentanedione, 2,3-hexanedione, other VOCs, and other compounds such as CO_2 and CO 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].

Overall, the highest area samples for total VOCs, CO, diacetyl, and 2,3-pentanedione were observed in areas where coffee was ground or flavored. We also observed elevated levels of diacetyl and 2,3-pentanedione in all areas of the facility, including administrative areas, possibly because of entrainment of air from the production areas into the administrative spaces. Additionally, large ceiling fans used in multiple areas of the facility could have contributed to air circulation from areas near sources and higher concentrations of diacetyl and 2,3-pentanedione into areas of lower concentrations of diacetyl and 2,3-pentanedione.

Alpha-Diketones

Personal Air Sampling

All 37 personal full-shift samples collected on employees at the facility exceeded the NIOSH REL of 5.0 ppb for diacetyl and 36 of 37 personal full-shift samples exceeded the NIOSH REL of 9.3 ppb for 2,3-pentanedione. The highest full-shift air samples for diacetyl and 2,3-pentanedione were measured on employees performing duties in the flavoring and grinding areas (range: 41.1 ppb to 420.9 for diacetyl and 21.7 ppb to 275.9 ppb for 2,3-pentanedione). The REL should be used as a guideline to indicate when steps should be taken to reduce exposures in the workplace. The risks associated with the levels measured in the facility are higher than NIOSH recommends. As described in the quantitative risk assessment from the NIOSH Criteria Document (Tables 5-27 and 5-29) [NIOSH 2016], after a 45-year working lifetime exposure to 500 ppb (a concentration slightly higher than the highest concentration measured at this facility), NIOSH estimated that about 203 in 1,000 workers would develop reduced lung function (FEV_1 below the lower limit of normal). NIOSH predicted around 28 in 1,000 workers exposed to diacetyl at 500 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 200 ppb (a concentration lower than the highest concentration measured at this facility), NIOSH estimated that about 59 in 1,000 workers would develop reduced lung function (FEV_1 below the lower limit of normal). NIOSH predicted about 6 in 1,000 workers exposed to diacetyl at 200 ppb would develop more severe lung function reduction. The effects of a working lifetime exposure at 421 ppb is closer to 500 ppb than 200 ppb.

Roaster operators had the second highest full-shift exposures (range: 35.5 ppb to 57.1 ppb for diacetyl and 19.1 ppb to 34.4 ppb for 2,3-pentanedione). After a 45-year working lifetime exposure to 50 ppb (a concentration slightly lower than the highest concentration measured on roaster operators), NIOSH estimated about 12 in 1,000 workers would develop reduced lung function (FEV_1 below the lower limit of normal). NIOSH predicted 12 in 10,000 workers exposed to diacetyl at 50 ppb would develop more severe lung function reduction. After a 45-year working lifetime exposure to 100 ppb (a concentration higher than the highest concentration measured on roaster operators), NIOSH estimated about 26 in 1,000 workers would develop reduced lung function (FEV_1 below the lower limit of normal). NIOSH predicted about 3 in 1,000 workers exposed to diacetyl at 100 ppb would develop more severe lung function reduction. The effects of a working lifetime exposure at 57 ppb is closer to 50 ppb than 100 ppb. 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 1000 workers. NIOSH recommends taking steps to reduce diacetyl exposures to below the REL of 5 ppb whenever possible.

Area Air Sampling

All areas sampled in the main production facility had air levels exceeding the NIOSH REL for diacetyl and 2,3-pentanedione, including: administrative areas, breakroom, finished product storage, flavoring room, green bean storage room, grinding, all packaging areas sampled, the production area, the QC lab, roasting, the silo area, and the storage room. Of the 125 full-shift area samples, 120 were above the NIOSH REL for diacetyl and 114 were above the NIOSH REL for 2,3-pentanedione. Areas where coffee was flavored or ground consistently had the highest diacetyl (maximums: 327.3 and 84.2 ppb, respectively) and 2,3-pentanedione (maximums: 772.9 and 45.9 ppb, respectively) air levels. We note that NIOSH RELs are intended to be directly compared with personal measurements; therefore, an area air sample that exceeds a NIOSH REL is only an indication of potential personal exposures.

Full-shift TWA samples collected in six areas of the finished goods building had diacetyl and 2,3-pentanedione concentrations that were lower than all samples collected in the main production building. Diacetyl concentrations ranged from 2.8 ppb to 5.4 ppb. The office area of the finished goods building where administrative staff were relocated after we shared interim results in January 2017 had the lowest measured diacetyl concentration (2.8 ppb). The center operator's desk in the warehouse was also below the NIOSH REL of 5.0 ppb for diacetyl (4.7 ppb). All other locations in the finished goods warehouse were at or just above the NIOSH REL for diacetyl (Table A1; range: 5.0 ppb to 5.4 ppb).

Task-Based Exposures

Coffee processing involves multiple tasks that might cause intermittent exposure to diacetyl and 2,3-pentanedione. Traditional full-shift sampling will not characterize these intermittent, peak exposures. Measured short-term peak exposures contribute to average full-shift exposures and can help identify sources and processes that generate diacetyl and 2,3-pentanedione and that can be targeted with engineering controls. 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 so sporadic in coffee processing, with some only lasting a few seconds or minutes, we used instantaneous evacuated canisters to sample tasks lasting only a few seconds to minutes 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 some tasks had higher air concentrations of diacetyl or 2,3-pentanedione than other tasks. The highest task-based TWA exposures to diacetyl (2,172.7 ppb) and 2,3-pentanedione (1,444.7 ppb) were measured while an employee flavored coffee (Table A2). All three 15-minute samples collected while an employee flavored coffee exceeded the NIOSH STEL of 25 ppb for diacetyl and 31 ppb for 2,3-pentanedione.We also measured higher exposures to diacetyl and 2,3-pentanedieone during grinding (maximum diacetyl: 80.8 ppb; maximum 2,3-pentanedione: 49.9 ppb) and packaging (maximum diacetyl: 59.0 ppb; maximum 2,3-pentanedione: 37.2 ppb). All four 15-minute samples collected while an employee ground coffee exceeded the NIOSH STEL of 25 ppb for diacetyl and one

sample exceeded the NIOSH STEL of 31 ppb for 2,3-pentanedione. Seven of the 10 15-minute samples collected while an employee packaged coffee exceeded the NIOSH STEL for diacetyl. Roaster operators also had high task-based exposures to diacetyl (maximum diacetyl: 54.3 ppb). All four fifteen-minute samples collected while an employee roasted coffee exceeded the NIOSH STEL for diacetyl.

We also measured diacetyl and 2,3-pentanedione using instantaneous sampling, in which sample duration was less than 30 seconds. These instantaneous samples were collected to identify and describe short-duration tasks and point sources of diacetyl and 2,3-pentanedione. The highest instantaneous levels taken at the breathing zone of employees were measured while employees performed flavoring tasks. Instantaneous samples taken at the breathing zone of employees while they flavored coffee were as high as 2,307 ppb for diacetyl, and 1,509 ppb for 2,3-pentanedione. Breathing zone samples taken while employees ground or packaged coffee were also high. Instantaneous samples collected while an employee stood at either grinder ranged from 56.2 ppb to 83.8 ppb diacetyl and 26.5 ppb to 44.0 ppb 2,3-pentanedione. The greater surface area for off-gassing that is produced during grinding could have resulted in the higher air concentrations [Akiyama et al. 2003]. Instantaneous samples collected while employees performed packaging tasks ranged from 25.3 ppb to 124 ppb diacetyl and 15.9 ppb to 44.0 ppb 2,3-pentanedione.

Source Air Sampling

The highest instantaneous source sample for diacetyl (18,744 ppb) and 2,3-pentanedione (9,746 ppb) was measured at the transfer point of the flavoring blender, while almond flavoring was being added to coffee. As can be seen in Table A4, elevated levels of diacetyl (>200 ppb) and 2,3-pentanedione (>200 ppb) were also observed at exhaust vents on packaging machines.

Bulk samples

Diacetyl (2,3-butanedione) and 2,3-pentanedione are sometimes added as ingredients in liquid flavorings for coffee. We observed detectable quantities of diacetyl in the headspace of all 14 liquid flavoring samples collected and 2,3-pentanedione was detected in 12 of the 14 liquid flavoring samples. Our results indicate liquid flavorings might contribute to the high levels of alpha-diketones observed in the flavoring room.

Diacetyl is not found in green coffee beans. Rather, diacetyl is generated later in the coffee roasting process [Daglia et al. 2007]. As expected, we found roasted coffee emits alpha-diketones into the headspace of sealed vessels, indicating roasted coffee is a source of alpha-diketones in the facility. The amount of time since beans were roasted, and amount of time roasted beans off-gassed before the collection of bulk samples could be responsible for differences in headspace analysis results.

Real-time Sampling for CO, CO_2, and VOCs

Our real-time monitoring found the highest overall levels of total CO, CO_2, and VOCs were observed in the flavoring room and grinding area. None of the average area or personal levels of CO exceeded the NIOSH REL (35 ppm) or OSHA PEL (50 ppm). However, a personal sample collected on a flavoring and grinding operator exceeded the NIOSH ceiling (200 ppm) for CO. The NIOSH ceiling limit should not be exceeded at any time. All CO_2 measurements were below the NIOSH REL (5,000 ppm) and OSHA PEL (5,000 ppm).

Ventilation

The administrative spaces and QC laboratory were under positive pressure relative to the production spaces at the time our measurements were taken. Generally, this means air from the administrative areas was pushed into the production space, which should serve to keep airborne contaminants generated on the production side from entering administrative spaces. However, as shown in Table A1, concentrations of alpha-diketones from personal and area sampling demonstrated employees working in administrative areas were exposed to levels over the NIOSH RELs. The operating state of the two air-handling units serving the administrative areas could change the pressure relationship with the production space, potentially allowing air to be pulled into the administrative side from production. Also, the doors from production into the employee break room and QC laboratory areas were frequently used throughout the day, which could allow air from production to mix with air in the administrative areas. The alpha-diketones could potentially have been pulled into the administrative spaces from outdoors if exhaust air from the production space was re-entrained into the fresh air intake of air-handling units serving that space. Since our site visit in July 2016, management took several actions to mitigate employee exposures to diacetyl and 2,3-pentanedione while working in the administrative areas. We commend management's actions. The engineering controls implemented since our initial site visit have reduced exposures in the administrative areas to levels below the NIOSH RELs for diacetyl and 2,3-pentanedione.

In addition to focusing on reducing alpha-diketone exposures on the administrative side of the facility, management also made significant engineering control improvements throughout the production space. The flavoring room blender was fitted with a lid and the grinding room was completely enclosed. Management also consulted with ventilation contractors to increase the height of all roof stacks, install additional air supply and exhaust systems in roasting, flavoring and grinding, and install additional supply air systems in the packaging space. Use of the large ceiling fans was also discontinued. As shown in Table A1, the measured area concentrations of diacetyl and 2,3-pentanedione were consistent throughout the entire production space, and in some areas concentrations were much higher than would otherwise be expected. For instance, the diacetyl concentrations measured in the green bean storage room (where no diacetyl was generated) were nearly the same as the concentrations measured in the roasting area. This was likely because the large ceiling fans mixing air throughout the entire production space, which served to even out worker exposures throughout the space. Generally, it would be expected to observe significantly higher concentrations near processes or tasks that generate alpha-diketones (flavoring, grinding, ground bean storage, etc.) and lower concentrations in areas where alpha-diketones are not generated or released in abundant quantities (green bean storage, finished product storage, etc,). Air sampling with the large ceiling fans off will provide more useful results to identify areas or sources of higher alpha-diketone concentrations that could benefit from additional engineering controls. Although many of the engineering controls implemented since our initial site visit have resulted in reduced levels of alpha-diketones throughout the facility, the concentrations of alpha-diketones throughout the production space remain above the NIOSH RELs. Working with a qualified industrial hygienist to continue assessing worker exposures and with qualified ventilation contractors to implement additional well-designed engineering control systems should continue in a stepwise manner. New engineering control systems could consist of local exhaust at contaminant sources, general exhaust fans through the walls or ceiling, or a combination of both.

General exhaust or dilution ventilation
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. The relationship between supply air and exhaust air flow rates can be used to help maintain appropriate pressure relationships. If more air is supplied than exhausted, the space will generally be under positive pressure, which allows contaminants to migrate from the space to adjacent areas. Conversely, exhausting more air than is supplied, maintains the space under negative pressure which helps contain the contaminants in the areas where they are generated.

During our site visit, only one unit capable of supplying fresh air to the production space was present. A series of five rooftop exhaust fans exhausted air from the production areas. The two roasters also exhausted some air from the space, but the time and amount was variable, depending on which stage of the roast cycle each roaster was performing. Since our visit, management has added or improved dilution ventilation systems throughout the production spaces. The facility's industrial hygiene consultant should be able to provide sampling results to describe the impact those changes had on worker exposures. If alpha-diketone concentrations are still elevated above the NIOSH RELs, consider focusing on local exhaust ventilation systems that target remaining point sources before reverting to additional dilution ventilation solutions. A reputable, qualified ventilation engineer should be consulted to help choose the most efficient and cost-effective engineering control systems moving forward.

Local exhaust ventilation
Local exhaust ventilation systems capture contaminants directly at the source. 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. Using the sampling results from the industrial hygiene contractor, identify areas or point sources contributing to the elevated alpha-diketone concentrations in the production area. Using that information, work with a ventilation engineer to design targeted local exhaust ventilation systems to capture and remove the contaminants from the area. Local exhaust systems generally require moving significantly less air than dilution ventilation systems and should not have a large impact on energy costs associated with heating and cooling outside air. Given the additional dilution ventilation systems management has already installed

throughout the production space, targeting additional engineering controls on key remaining point sources would likely help reduce overall alpha-diketone exposures in a more cost-effective manner than additional dilution ventilation.

Enclosure of specific processes
Relocating processes or specific pieces of equipment to make control implementation easier might also help reduce worker exposures in a cost-effective way. Before our visit, the flavoring operation was already enclosed inside its own room. Since our visit, the grinding area has also been enclosed. Isolating other process areas, such as roasted bean storage (whole bean and ground) and dumping roasted coffee (whole bean or ground) from hoppers into the packaging lines on the mezzanine, could make engineering control solutions easier and more effective at reducing worker exposures.

In general, the current upgraded ventilation configuration in the production area should be evaluated. An evaluation by a qualified ventilation engineer can determine if modifications to existing ventilation components could be made to lower airborne concentrations or whether the installation of new equipment might be necessary. In addition to dilution ventilation, the installation and use of local exhaust ventilation systems to decrease concentrations of diacetyl and 2,3-pentanedione can be explored, and an overall, cost-effective solution can be developed. After making changes to production ventilation, processes, controls, or work practices, additional air sampling should be conducted to determine the effect on exposure conditions within the workplace. Those sampling results can then be used to make decisions on additional control strategies, if any are necessary.

Medical Survey
Overall, nose and eye symptoms were the most commonly reported symptoms. Some employees reported these nose and eye symptoms were caused or aggravated by green bean coffee burlap bags, green bean and roasted coffee dust, flavorings, smoke, and roasting 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].

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. Most (37 of 50; 74%) participants that reported lower respiratory symptoms also reported nasal or sinus problems or physician-diagnosed hay fever or nasal allergies. 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]. To prevent symptoms related to green coffee dust and chaff, make N95 disposable filtering-face piece respirators available for voluntary use when emptying burlap bags of green beans into the storage silos or when emptying the chaff containers or cleaning the green bean storage area. 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, NIOSH-certified organic vapor cartridges (for the alpha-diketones) and particulate cartridges/filters (for the dust) would be warranted.

The number of participants ever diagnosed with asthma by a physician (11%) was significantly higher than expected compared with the U.S. population with an SMR of 2.1; however, 10 (91%) of 11 participants who reported ever being diagnosed with asthma were diagnosed before they started working at this facility. Only three participants reported current asthma, which was not higher than expected compared with the U.S. population. One participant was diagnosed with asthma after beginning work at this coffee roasting and packaging facility. Fifty (51%) participants reported at least one lower respiratory symptom in the last 12 months. Of those, 18 (36%) perceived their lower respiratory symptom[s] improved away from work, or were caused or aggravated by work. Most (60%) participants who reported at least one lower respiratory symptom were never smokers, and only six (12%) were current smokers. Asthma symptoms often improve when away from exposures that trigger symptoms while symptoms of 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 demonstrate if air is exhaled from 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 that 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]. In participating employees from this workplace, three had obstruction or mixed patterns on spirometry; two of these significantly improved with bronchodilation in employees who reported ever being diagnosed with asthma, and one did not improve with bronchodilation in an employee who did not report asthma and who was referred to a pulmonologist and diagnosed with flavoring-related lung disease following the medical survey in August 2016.

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 can be useful as an indirect measure of airflow obstruction and helpful in individuals not able to perform forced breathing maneuvers 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 references 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].

Our findings of upper and lower respiratory symptoms with a work-related pattern in some employees, and abnormalities on breathing tests in 37% of participants indicates a burden of respiratory problems in this workforce. The upper and lower respiratory symptoms that improve away from work are likely related to workplace exposures. The lung function abnormalities we found are not specific to a particular respiratory problem or disease. They could be related to workplace exposures or to other factors. Indeed, some employees had respiratory diagnoses that preceded employment at this facility, but other participants reported developing lower respiratory symptoms since beginning to work at this facility. Employees who reported grinding or flavoring had higher odds of waking up with chest tightness and episodes of flu-like achiness or achy joints in the last 12 months compared with employees who did not report performing these tasks. Employees who reported grinding or flavoring also had lower lung function parameters (percent predicted FEV_1, percent predicted FVC, and FEV_1/FVC ratio), although these did not reach statistical significance. Grinding and flavoring tasks had the highest measured exposures of diacetyl and 2,3-petanedione, and could be associated with the symptoms and lower lung function parameters. 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.

The company instituted a voluntary medical surveillance program in response to our evaluation as a means of early identification of employees who might be developing lung disease (e.g., asthma, obliterative bronchiolitis) and to help prioritize interventions to prevent occupational lung disease. An occupational health provider conducted spirometry testing in March 2017 and October/November 2017. Most (86%) tests were graded A, B, or C and could therefore be interpreted with confidence. Six employees had at least a 15% decline in FEV_1 or FVC between spirometry conducted during the NIOSH medical survey and subsequent contracted medical surveillance program spirometry. In adults, FEV_1 and FVC are expected to decline by approximately 30 mL each year, but a 15% decline in approximately one year is more than expected. Excessive decline in FEV_1 or FVC could be because of work-related lung disease, or other factors such as the spirometry equipment, test subject or technician technique, or non-work-related illness affecting results. It is important to monitor the change in lung function over time in employees participating in the medical surveillance program, and for the employee's healthcare provider to investigate excessive decline in FEV_1 or FVC to address the possibility of work-related lung disease, and rule out work-related lung disease or remove that employee from exposure to potential respiratory hazards at work. If work-related lung disaease is suspected, investigate potentially harmful environmental exposures, including diacetyl and 2,3-pentanedione, in the area of the affected employee(s).

Conclusions

We identified specific work tasks that resulted in air concentrations of diacetyl and 2,3-pentanedione that exceeded the NIOSH RELs for diacetyl and 2,3-pentanedione. The highest full-shift and task-based diacetyl and 2,3-pentanedione exposure measurements were observed on employees that performed flavoring and grinding tasks. The flavoring room had the highest levels of diacetyl, 2,3-pentanedione, 2,3-hexanedione, and CO; however, levels were elevated throughout the facility. CO_2 levels were low throughout most of the facility. However, CO levels measured on a flavoring and grinding operator exceeded the NIOSH ceiling limit of 200 ppm.

We commend the efforts taken to date by management to implement additional engineering, administrative, and personal protective equipment controls designed to mitigate exposure to diacetyl, 2,3-pentanedione, and CO. Consultation with a ventilation engineer could further mitigate potential exposures to alpha-diketones and CO by installing local exhaust ventilation systems at point sources and processes with the highest measurements of exposure and additional general exhaust ventilation in the packaging and roasting areas. Additionally, a separate room with separate ventilation for storing full containers of whole-bean or ground coffee might also further reduce overall concentrations of alpha-diketones in the roasting and packaging area.

Overall, nose and eye symptoms were the most commonly reported symptoms. Some employees reported these nose and eye symptoms were caused or aggravated by green bean coffee burlap bags, green bean and roasted coffee dust, flavorings, smoke, or roasting coffee. Wheezing or whistling in the chest was the most commonly reported lower respiratory symptom, followed by shortness of breath, breathing trouble, and chest tightness. Some employees reported these lower respiratory symptoms were caused or aggravated by grinding and flavoring, heat, and stress. Employees who reported grinding or flavoring had higher odds of waking up with chest tightness and episodes of flu-like achiness or achy joints in the last 12 months, and also had lower lung function parameters, although these were not statistically significant. Six (6%) of 99 participants had abnormal spirometry. Eight (8%) participants had high exhaled nitric oxide, a marker of allergic airways inflammation. One employee with abnormal spirometry and work-related respiratory symptoms was referred to a pulmonologist and diagnosed with obliterative bronchiolitis associated with occupational exposure to flavorings. The company instituted a medical surveillance program and began offering spirometry every six months through an occupational health provider 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.

Recommendations

On the basis of our findings, we recommend the actions listed below. We encourage this coffee roasting and packaging facility to use a labor-management health and safety committee or working group to discuss our recommendations and develop an action plan. 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. Consult with a ventilation engineer to install local exhaust ventilation at point sources with the highest measurements of alpha-diketone exposure. More specifically, consider installing local exhaust ventilation at the packaging machines where ground coffee is packaged if alpha-diketone concentrations remain elevated after other controls have been implemented.
2. Consider storing full containers of flavored or unflavored, whole-bean or ground coffee, in a separate room with separate ventilation if levels of alpha-diketones in the roasting and packaging area remain elevated after other controls have been implemented. Consideration should also be given to enclosing the mezzanine area where coffee is introduced to the packaging lines and ventilating the mezzanine area separately.
3. Consult with a ventilation engineer to determine if additional fresh, outdoor air can be supplied to the roasting and packaging area of the plant. Work with the ventilation engineer to ensure the production area is maintained under negative pressure relative to non-production spaces.
4. Ensure all doors between production and non-production areas are kept closed at all times. An increase in air supplied to the space will need to be offset with an increase in air exhausted from the space. Care should be taken to maintain correct pressure relationships between roasting and packaging area and adjacent spaces. Otherwise, contaminants could be pushed from the roasting and packaging area into adjacent areas and increase worker exposures in non-production locations.

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 policies and procedures are followed consistently.

1. Install a CO monitor and alarm in the flavoring room and near the two main grinders that can alert employees if and when CO levels exceed the NIOSH ceiling of 200 ppm. Employees should evacuate and move to an area of fresh air until the CO level drops below 200 ppm.
2. After engineering controls have been installed, conduct follow-up air sampling to verify modifications have been effective in reducing exposures to below recommended exposure limits.
3. Whenever possible, employees should avoid spending time in the immediate area where coffee is being ground or ground coffee is being packaged.
4. Limit the amount of time non-production employees spend in production areas, to the extent possible.
5. Continue to periodically clean the roaster's exhaust according to manufacturer instructions to remove chaff build up to reduce a fire hazard and to improve efficiency, energy usage, and roaster performance.
6. Ensure employees understand potential hazards (e.g., diacetyl, 2,3-pentanedione, CO, $CO_{2,}$ 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.
7. Ensure employees are educated to consider 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

We note personal protective equipment in the form of respiratory protection is considered the least effective means for controlling hazardous respiratory exposures because breakdowns in implementation can 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 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 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. Until engineering and administrative controls are in place, respiratory protection for

diacetyl and 2,3-pentanedione should continue to be used to reduce exposures to alpha-diketones. Continue to use powered air-purifying respirators (PAPRs) with an APF of at least 100 in the flavoring area and an APF of at least 25 in the grinding area.

2. If follow-up air sampling after engineering controls have been installed indicates levels of diacetyl and 2,3-pentanedione above their respective NIOSH RELs and STELs, we recommend respiratory protection be used during tasks with elevated exposures. If respiratory protection is used, NIOSH-certified respirators should be fitted with organic vapor cartridges to protect against diacetyl and 2,3-pentanedione, and particulate filters to protect against dust particles. The choice of respirator should be guided by personal exposure sampling for diacetyl and 2,3-pentanedione (NIOSH 2004). Respirators have assigned protection factors (APFs). APF refers to the highest level of protection a properly selected respirator can provide. For instance, 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 might be more comfortable for employees than the air-purifying respirators currently in use. The powered-air purifying respirators have APFs of 25, 50, or 1,000. 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.
   Continue to implement the written respiratory protection program as required by the OSHA Respiratory Protection Standard (29 CFR 1910.134), including training, fit testing, maintenance and use requirements for all employees who use respiratory protection.

3. Make N95 disposable filtering-face piece respirators available for voluntary use for protection against green or roasted coffee dust exposure such as when emptying burlap bags of green beans into the storage silos, cleaning the roaster exhaust system of chaff, emptying the chaff containers, or 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 (http://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 N95s are <u>not</u> protective against alpha-diketones (diacetyl, 2,3-pentanedione, or 2,3-hexanedione). In cases of dual exposure to dust and alpha-diketones, NIOSH-certified organic vapor cartridges (for the alpha-diketones) and particulate cartridges/filters (for the dust) would be warranted.

Medical Surveillance

The purpose of a medical surveillance 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. Continue your medical surveillance program for employees who work or assist in

the production area. As detailed in the NIOSH Criteria Document [NIOSH 2016], a medical monitoring program is recommended for all employees who work in the production areas or enter production areas for a total of 40 hours or more per year. According to the NIOSH Criteria Document, employees should have baseline medical evaluations (details below) before they are allowed to work in or enter areas where they might be exposed to diacetyl, 2,3-pentanedione, or similar flavoring compounds.

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 because of potentially rapid development of lung disease. Many engineering controls have been implemented since our visit to reduce alpha-diketones throughout the facility. One employee was diagnosed with obliterative bronchiolitis associated with occupational exposure to flavorings before implementation of the engineering controls and medical surveillance program. If another 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 2018b].

Appendix A: Tables

Table A1. OSHA Methods 1013/1016 full-shift personal and area air sampling results by location, NIOSH surveys, July 2016 and February 2017*

Analyte	Sample Type	Location	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)	Above REL N
Diacetyl	Personal	Administration	3	3 (100%)	30.8	34.9	3
Diacetyl	Personal	Production and Administrative	2	2 (100%)	35.8	36.5	2
Diacetyl	Personal	Green Bean Storage	2	2 (100%)	23.9	46.1	2
Diacetyl	Personal	Flavoring and Grinding	3	3 (100%)	41.1	420.9	3
Diacetyl	Personal	Finished Product Storage	2	2 (100%)	21.5	29.0	2
Diacetyl	Personal	Packaging	15	15 (100%)	29.7	48.8	15
Diacetyl	Personal	QC Lab	4	4 (100%)	8.9	37.4	4
Diacetyl	Personal	Roasting	6	6 (100%)	35.5	57.1	6
Diacetyl	Area	Admin	8	8 (100%)	27.6	41.1	N/A
Diacetyl	Area	Breakroom	4	4 (100%)	16.2	41.4	N/A
Diacetyl	Area	Finished Product Storage	8	8 (100%)	23.1	39.4	N/A
Diacetyl	Area	Flavor Room	8	8 (100%)	20.3	327.3	N/A
Diacetyl	Area	Green Bean Storage Room	4	4 (100%)	35.2	52.2	N/A
Diacetyl	Area	Grinding	12	12 (100%)	36.9	84.2	N/A
Diacetyl	Area	Outside	3	2 (67%)	<0.3	0.5	N/A
Diacetyl	Area	Packaging	40	40 (100%)	21.0	55.6	N/A
Diacetyl	Area	Production Area	4	4 (100%)	27.5	43.6	N/A
Diacetyl	Area	QC Lab	4	4 (100%)	18.8	33.9	N/A
Diacetyl	Area	Roasting	12	12 (100%)	37.3	57.8	N/A
Diacetyl	Area	Silo Area	8	8 (100%)	33.1	56.1	N/A
Diacetyl	Area	Storage Room	4	4 (100%)	36.1	49.6	N/A
Diacetyl	Area	Finished Goods Warehouse*	6	6 (100%)	2.8	5.4	N/A
2,3-Pentanedione	Personal	Administration	3	3 (100%)	13.8	15.9	3
2,3-Pentanedione	Personal	Production and Administrative	2	2 (100%)	17.0	21.7	2
2,3-Pentanedione	Personal	Green Bean Storage	2	2 (100%)	12.2	28.3	2
2,3-Pentanedione	Personal	Flavoring and Grinding	3	3 (100%)	21.7	275.9	3
2,3-Pentanedione	Personal	Finished Product Storage	2	2 (100%)	11.5	14.7	2
2,3-Pentanedione	Personal	Packaging	15	15 (100%)	14.4	31.0	15
2,3-Pentanedione	Personal	QC Lab	4	4 (100%)	4.9	17.6	3
2,3-Pentanedione	Personal	Roasting	6	6 (100%)	19.1	34.4	6
2,3-Pentanedione	Area	Administrative	8	8 (100%)	15.8	23.9	N/A
2,3-Pentanedione	Area	Breakroom	4	4 (100%)	7.7	23.5	N/A
2,3-Pentanedione	Area	Finished Product Storage	8	8 (100%)	11.8	21.1	N/A
2,3-Pentanedione	Area	Flavor Room	8	8 (100%)	11.0	772.9	N/A
2,3-Pentanedione	Area	Green Bean Storage Room	4	4 (100%)	19.1	29.9	N/A
2,3-Pentanedione	Area	Grinding	12	12 (100%)	16.5	45.9	N/A
2,3-Pentanedione	Area	Outside	4	1 (25%)	<0.3	0.5	N/A
2,3-Pentanedione	Area	Packaging	40	40 (100%)	14.4	37.4	N/A
2,3-Pentanedione	Area	Production Area	4	4 (100%)	12.5	28.7	N/A
2,3-Pentanedione	Area	QC Lab	4	4 (100%)	10.3	18.0	N/A
2,3-Pentanedione	Area	Roasting	12	12 (100%)	19.3	34.0	N/A

Table A1 (continued). OSHA Methods 1013/1016 full-shift personal and area air sampling results by location, NIOSH surveys, July 2016 and February 2017*

Analyte	Sample Type	Location	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)	Above REL N
2,3-Pentanedione	Area	Silo Area	8	8 (100%)	18.6	32.4	N/A
2,3-Pentanedione	Area	Storage Room	4	4 (100%)	19.0	30.3	N/A
2,3-Pentanedione	Area	Finished Goods Warehouse*	6	0 (9%)	< 0.3	< 0.3	N/A
2,3-Hexanedione	Personal	Administration	3	0 (0%)	<0.4	<0.5	-
2,3-Hexanedione	Personal	Production and Administrative	2	0 (0%)	<0.5	<0.5	-
2,3-Hexanedione	Personal	Green Bean Storage	2	0 (0%)	<0.5	<0.5	-
2,3-Hexanedione	Personal	Flavoring and Grinding	3	1 (0%)	<0.5	11.2	-
2,3-Hexanedione	Personal	Finished Product Storage	2	0 (0%)	<0.5	<0.5	-
2,3-Hexanedione	Personal	Packaging	15	0 (0%)	<0.4	<0.8	-
2,3-Hexanedione	Personal	QC Lab	4	0 (0%)	<0.5	<0.6	-
2,3-Hexanedione	Personal	Roasting	6	(0%)	<0.4	<0.5	-
2,3-Hexanedione	Area	Admin	8	0 (0%)	<0.5	<0.5	N/A
2,3-Hexanedione	Area	Breakroom	4	0 (0%)	<0.5	<0.5	N/A
2,3-Hexanedione	Area	Finished Product Storage	8	0 (0%)	<0.5	<0.5	N/A
2,3-Hexanedione	Area	Flavor Room	8	4 (50%)	<0.5	8.8	N/A
2,3-Hexanedione	Area	Green Bean Storage Room	4	0 (0%)	<0.5	<0.5	N/A
2,3-Hexanedione	Area	Grinding	12	1 (8%)	<0.5	1.3	N/A
2,3-Hexanedione	Area	Outside	4	0 (0%)	<0.5	<0.5	N/A
2,3-Hexanedione	Area	Packaging	40	0 (0%)	<0.5	<0.6	N/A
2,3-Hexanedione	Area	Production Area	4	0 (0%)	<0.5	<0.5	N/A
2,3-Hexanedione	Area	QC Lab	4	0 (0%)	<0.5	<0.6	N/A
2,3-Hexanedione	Area	Roasting	12	1 (8%)	<0.5	0.9	N/A
2,3-Hexanedione	Area	Silo Area	8	1 (13%)	<0.4	1.0	N/A
2,3-Hexanedione	Area	Storage Room	4	0 (0%)	<0.5	<0.5	N/A
2,3-Hexanedione	Area	Finished Goods Warehouse*	6	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 limit of detection (LOD); < indicates below the LOD; Above REL N=number of samples above the NIOSH recommended exposure limit (REL); ppb=parts per billion; N/A indicates that NIOSH RELs are specified for personal air samples, and area air samples cannot be used for direct comparisons with area samples; "–"indicates that there is currently no REL for 2,3-hexanedione; "Production Area" location includes employees that were cross-trained and performed tasks at different areas.
***Indicates area samples that were collected in February 2017.**

Table A2. OSHA Methods 1013/1016 personal task air sampling results, NIOSH survey, July 2016

Analyte	Task	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)	Mean (range) Sample Duration (minutes)
Diacetyl	Cleaning Flavoring mixer	1	1 (100%)	41.7	41.7	15
Diacetyl	Cleaning Packaging Machine	4	4 (100%)	35.6	43.8	15 (13–15)
Diacetyl	Cleaning Roaster	9	9 (100%)	11.6	48.9	23 (10–46)
Diacetyl	Cleaning Grinders	1	1 (100%)	35.8	35.8	15
Diacetyl	Flavor coffee	4	4 (100%)	521.3	2172.7	15 (15–16)
Diacetyl	Grind coffee beans	6	6 (100%)	47.4	80.8	14 (12–15)
Diacetyl	Move roasted beans or ground coffee	1	1 (100%)	43.3	43.3	4
Diacetyl	Thermal heat of roaster, post-clean (not roasting)	5	5 (100%)	7.8	45.3	15 (13–18)
Diacetyl	Package coffee	21	21 (100%)	3.9	59.0	13 (5–18)
Diacetyl	Quality Control	1	1 (100%)	28.7	28.7	14
Diacetyl	Roast coffee beans	17	17 (100%)	28.4	54.3	16 (0–30)
2,3-Pentanedione	Cleaning Flavoring mixer	1	1 (100%)	23.8	23.8	15
2,3-Pentanedione	Cleaning Packaging Machine	4	4 (100%)	14.8	26.0	15 (13–15)
2,3-Pentanedione	Cleaning Roaster	9	9 (100%)	4.6	23.6	23 (10–46)
2,3-Pentanedione	Cleaning grinders	1	1 (100%)	23.0	23.0	15
2,3-Pentanedione	Flavor coffee	4	4 (100%)	345.0	1444.7	15 (15–16)
2,3-Pentanedione	Grind coffee beans	6	6 (100%)	20.7	49.9	14 (12–15)
2,3-Pentanedione	Move roasted beans or ground coffee	1	1 (100%)	19.2	19.2	4
2,3-Pentanedione	Thermal heat of roaster, post-clean (not roasting)	5	5 (100%)	3.7	20.6	15 (13–18)
2,3-Pentanedione	Package coffee	21	20 (95%)	<1.5	37.2	13 (5–18)
2,3-Pentanedione	Quality Control	1	1 (100%)	15.1	15.1	14
2,3-Pentanedione	Roast coffee beans	17	17 (100%)	15.2	32.8	16 (0–30)
2,3-Hexanedione	Cleaning Flavoring mixer	1	0 (0%)	<0.7	<0.7	15
2,3-Hexanedione	Cleaning Packaging Machine	4	0 (0%)	<0.7	<0.8	15 (13–15)
2,3-Hexanedione	Cleaning Roaster	9	0 (0%)	<0.2	<1.0	23 (10–46)
2,3-Hexanedione	Cleaning grinders	1	0 (0%)	<0.7	<0.7	15
2,3-Hexanedione	Flavor coffee	4	4 (100%)	14.3	62.6	15 (15–16)
2,3-Hexanedione	Grind coffee beans	6	0 (0%)	<0.7	<0.9	14 (12–15)
2,3-Hexanedione	Move roasted beans or ground coffee	1	0 (0%)	<2.7	<2.7	4
2,3-Hexanedione	Thermal heat of roaster, post-clean (not roasting)	5	0 (0%)	<0.6	<0.8	15 (13–18)
2,3-Hexanedione	Package coffee	21	0 (0%)	<0.6	<2.2	13 (5–18)
2,3-Hexanedione	Quality Control	1	0 (0%)	<0.7	<0.7	14
2,3-Hexanedione	Roast coffee beans	17	0 (0%)	<0.3	<0.3	16 (0–30)

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 limit of detection (LOD); < indicates below the LOD.

Table A3. Instantaneous evacuated canister method* air sampling results by task, NIOSH survey, July 2016

Location (Area)	Task Description	Diacetyl (ppb)	2,3-Pentanedione (ppb)	2,3-Hexanedione (ppb)
Flavoring room	Adding liquid almond flavoring into hopper	1826	991	56.6
	Standing over flavoring hopper during mixing of Butter Rum, ground coffee	2307	1509	58.9
	Standing over flavoring hopper during mixing of Butter Rum, ground coffee	2090	1035	41.6
	Standing over flavoring hopper during mixing of almond flavoring with ground coffee	1869	1433	157
Grinding	Standing at control panel of grinder	77.2	42.8	2.5
	Standing by Brown Grinder	56.2	26.5	1.8
	Standing by Grey Grinder	83.8	44.0	4.3
Packaging	Cleaning interior of SS3	124	37.1	9.1
	Cleaning vacuum on SS3	25.3	15.9	2.0
	Packing single serve packets into boxes	76.3	45.4	5.0
	Packing single serve packets into boxes	82.3	42.3	2.5
	Packing single serve packets into boxes	50.9	32.1	4.7
Quality Control (QC) Lab	Grinding small cups of light roast, Honduras for cupping	41.0	26.5	2.1
	Grinding small cups of light roast, Honduras for cupping	44.8	30.5	4.4
	Smelling tryer of QC Roaster (Costa Rican Light Roast)	52.6	30.1	2.6
	Start of QC Roast; Costa Rican Light Roast	33.9	16.8	1.4
Roasting	Transfer of roasted beans to cooling bin	36.3	20.2	1.9
	Transfer of roasted beans to cooling bin	59.6	25.1	3.3
	Transfer of roasted beans to cooling bin	50.2	20.8	2.0
	Transfer of roasted beans to cooling bin	56.8	34.7	2.2
	Transfer of roasted beans to cooling bin	61.0	40.4	2.9
	Transfer of roasted beans to cooling bin	59.7	38.1	2.4
	Transfer of roasted beans to cooling bin	56.1	36.3	5.0
	Transfer of roasted beans to cooling bin	57.4	37.1	2.5
	Transfer of roasted beans to cooling bin	59.8	37.4	3.3
	Transfer of roasted beans to cooling bin	44.6	22.6	3.4
	Transfer of roasted beans to cooling bin	41.8	19.5	2.2
	Pulled sample from cooling bin to QC check with grinder and color analyzer	161	41.4	6.2
	Pulled sample from cooling bin to QC check with grinder and color analyzer	73.1	49.5	8.4

Table A3 (continued). Instantaneous evacuated canister method* air sampling results by task, NIOSH survey, July 2016

Location (Area)	Task Description	Diacetyl (ppb)	2,3-Pentanedione (ppb)	2,3-Hexanedione (ppb)
Roasting	Pulled sample from cooling bin to QC check with grinder and color analyzer	73.4	47.4	3.1
	Pulled sample from cooling bin to QC check with grinder and color analyzer	41.5	19.9	1.9
	Pulled sample from cooling bin to QC check with grinder and color analyzer	48.2	20.8	2.1
	Pulled sample from cooling bin to QC check with grinder and color analyzer	47.0	21.2	2.1
	Pulled sample from cooling bin to QC check with grinder and color analyzer	33.5	21.5	2.0
	Grinding QC sample from cooling bin with sample grinder	66.7	40.3	4.0
	Grinding QC sample from cooling bin with sample grinder	67.0	43.2	3.3
	Grinding QC sample from cooling bin with sample grinder	60.6	32.0	2.5
	Grinding QC sample from cooling bin with sample grinder	56.7	37.7	3.2
	Grinding QC sample from cooling bin with sample grinder	77.6	55.3	4.0
	Grinding QC sample from cooling bin with sample grinder	65.6	46.5	10.8
	Grinding QC sample from cooling bin with sample grinder	51.4	24.6	2.2
	Grinding QC sample from cooling bin with sample grinder	96.8	52.8	5.5
	Grinding QC sample from cooling bin with sample grinder	157	70.4	7.7
	Grinding QC sample from cooling bin with sample grinder	31.5	21.1	2.0

Note: NIOSH=National Institute for Occupational Safety and Health; ppb=parts per billion; < indicates below the limit of detection; QC=quality control.
***Sampling duration approximately 30 seconds; task-based air samples were collected by placing the inlet of the canister sampler in the employee's personal breathing zone as he/she performed work task.**

Table A4. Instantaneous evacuated canister method* air sampling results by source, NIOSH survey, July 2016

Location (Area)	Source	Diacetyl (ppb)	2,3-Pentanedione (ppb)	2,3-Hexanedione (ppb)
Flavoring Room	At transfer point of almond flavoring into flavoring blender	18744	9746	596
	Directly above empty flavoring hopper after ground coffee was flavored with Butter Rum	10419	7929	465
	Directly above full flavoring hopper of ground Butter Rum	6732	236	51.8
	Directly above empty flavoring hopper	408	237	< 0.6
Packaging	Exhaust vent on back side of single serve cup packaging machine #3	346	370	21.3
Flavoring Room	Directly above empty flavoring hopper, about to start a new batch	259	205	11.2
Packaging	Exhaust vent on back side of single serve cup packaging machine #3	252	279	16.9
	Exhaust vent on back side of single serve cup packaging machine #3	244	245	13.4
Grinding	Brown grinder during grinding of Donut Shop coffee	111	56.6	7.3
Packaging	Outside door to single serve cup machine #3, with door closed	104	36.1	3.6
Grinding	At Brown Grinder	101	51.7	3.3
	Transfer point of Brown Grinder feed into opening of transport	97.9	50.3	3.8
	At Grey Grinder	87.0	38.6	2.2
Flavoring Room	At 55 gallon discharge collector from blender	86.7	69.9	5.9
Packaging	Next to door in front of machine filling single serve cups (SS4); door closed	76.6	41.5	< 0.6
	Front of Quad 1 machine filling 10 oz bags with the door closed	71.9	43.7	4.0
	Inside of single serve cup packaging machine #3, door open	71.8	51.0	4.3
	Inside of single serve cup packaging machine #3 (door was opened to check a component)	62.6	42.6	7.7
Grinding	At Brown Grinder	61.0	35.7	2.6
Packaging	Front of machine filling single serve cups (SS3) with the door open	37.8	30.1	5.1
Quality Control Lab	Above brewed Honduras Light Roast during cupping	36.9	19.9	1.5
Packaging	Front of machine filling 10 oz bags with the door closed	34.7	24.9	1.7
	Front of machine filling single serve cups (SS3) with the door closed	31.4	23.8	1.9

Note: NIOSH=National Institute for Occupational Safety and Health; ppb=parts per billion; < indicates below the limit of detection for the instrument used to detect 2,3-hexanedione.
***Sampling duration approximately 30 seconds; source air samples were collected by placing the inlet of the canister sampler near roasted beans.**

Table A5. Headspace analysis results* for bulk samples of roasted coffee beans, NIOSH survey, July 2016

Roasted Coffee Description	Diacetyl (ppb)	2,3-Pentanedione (ppb)	2,3-Hexanedione (ppb)
Butter Rum Ground	11221	12195	<209
Butter Rum Ground	14490	3250	<211
Single Serve Breakfast Blend Ground	4178	1386	<210
Single Serve Donut Shop Ground	1336	423	<210
Sumatra Blend Whole bean	2229	1551	<209
Flavoring Description	**Diacetyl (ppb)**	**2,3-Pentanedione (ppb)**	**2,3-Hexanedione (ppb)**
Amaretto	2155	1009	<208
Butter Rum	10741	837	<209
Caramel Cream	7740	6517	228
Chocolate Caramel Brownie	10157	1204	<208
Chocolate Cherry	845	<118	<210
Chocolate Raspberry	370	409	<209
French Vanilla Almond	3341	2926	<211
French Vanilla Almond	3196	1744	<208
Hazelnut	3049	4069	<207
Hazelnut Cream	3043	<117	<209
Sea Salt & Caramel	3868	5662	<210
Toasted Southern Pecan	3719	1100	<206
Vanilla Nut Cream	4146	2438	<208
Vanilla Hazelnut	2978	3297	<209

Note: NIOSH=National Institute for Occupational Safety and Health; ppb=parts per billion. < indicates below the limit of detection for the instrument used to detect the analyte.
***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. Summary of continuous area air monitoring results for carbon dioxide, carbon monoxide, temperature, and total volatile organic compounds, NIOSH industrial hygiene survey, July 2016

Location	CO_2 (ppm) Mean (Range)	CO (ppm) Mean (Range)	Temperature (°F) Mean (Range)	Total VOC (ppb) Mean (Range)
Flavoring Room, Mezzanine Operator Desk	727.0 (598.0–1546.0)	15.2 (5.7–40.8)	91.3 (86.1–92.7)	10200 (1544–104727)
Brown Grinder	590.5 (524.0–1402.0)	11.0 (3.5-126.9)	85.6 (83.2–87.8)	1092.3 (510–7145)
Roasting, Between Operator Panels	579.1 (491.0–954.0)	12.1 (4.6–23.6)	93.3 (88.1–96.1)	—
Packaging, VFFS Box/Pallet Area	574.9 (536–635)	5.5 (3.4–9.9)	86.9 (85.1–89.6)	—

Note: NIOSH=National Institute for Occupational Safety and Health; CO_2=carbon dioxide; CO=carbon monoxide; ppm=parts per million; °F=degrees Fahrenheit; VOC=volatile organic compounds; "-"indicates the measurement was not recorded.

Table A7. Summary of continuous personal air measurements for carbon monoxide, NIOSH survey, July 2016

Job Title	Work Area	CO (ppm) Mean (range)
Flavoring and Grinding Operator	Flavoring and Grinding	13.6 (2–27)
Flavoring and Grinding Operator	Flavoring and Grinding	29.8 (11–584)
Flavoring and Grinding Operator	Flavoring and Grinding	18.8 (3–71)
Roaster Operator	Roasting	12.4 (9–60)
Roaster Operator	Roasting	7.3 (4–10)
Roaster Operator	Roasting	7.0 (4–10)
Roaster Operator	Roasting	12.8 (6–30)
Roaster Operator	Green Bean Storage Room	11.1 (7–21)
Roaster Operator	Green Bean Storage Room	11.5 (0–28)
Production	Packaging	7.3 (5–10)
Production	Packaging, Single Serve Area	8.2 (5–12)
Production	Packaging	13.8 (0–60)
Chief Marketing Officer	QC Lab	6.7 (3 – 10)

Note: NIOSH=National Institute for Occupational Safety and Health; CO=carbon monoxide; ppm=parts per million; < indicates below the limit of detection for the instrument used to detect carbon monoxide.

Table A8. Prevalence of reported symptoms, NIOSH medical survey, August 2016

Symptom	Experienced in the last 12 months N = 99 Number (%)	Experienced in the last 4 weeks N = 99 Number (%)	Aggravated by work or better away from work
Nose symptoms*	46 (46%)	28 (28%)	23 (23%)
Eye symptoms†	43 (43%)	23 (23%)	24 (24%)
Sinusitis or sinus problems	20 (20%)	9 (9%)	10 (10%)
Problem with ability to smell	12 (12%)	-	-
Phlegm on most days for 3 months	9 (9%)	-	-
Lower respiratory symptoms (reported at least one of the following)	50 (51%)	15 (15%)	18 (18%)
Chest wheezing or whistling	18 (18%)	5 (5%)	4 (4%)
SOB on level ground or walking up a slight a hill	17 (17%)	-	-
Breathing trouble	17 (17%)	8 (8%)	5 (5%)
Awoke with chest tightness	17 (17%)	1 (1%)	10 (10%)
Usual cough‡	11 (11%)	6 (6%)	3 (3%)
Awoke with shortness of breath	10 (10%)	3 (3%)	2 (2%)
Asthma attack	2 (2%)	2 (2%)	2 (2%)
Systemic symptoms (reported at least one of the following)	53 (54%)	28 (28%)	29 (29%)
Unusual tiredness or fatigue	32 (32%)	21 (21%)	20 (20%)
Flu-like achiness or achy joints	30 (30%)	12 (12%)	9 (9%)
Fever or chills	21 (21%)	4 (4%)	9 (9%)

Note: N=number of participants; SOB=shortness of breath; "-"= A four week question was not asked for the symptom.
***Nose symptoms includes one or both of the following: 1) stuffy, itchy, or runny nose or 2) stinging, burning nose.**
†Eye symptoms includes one or both of the following: 1) watery, itchy eyes or 2) stinging, burning eyes.
‡This question did not specifically ask about a cough within the past 12 months; participants were asked, "Do you usually have a cough?" If the participants answered yes to that question, they were then asked, "Have you had a cough at any time in the last 4 weeks?"

Table A9. Adjusted* comparisons of symptoms and self-reported physician diagnosis among NIOSH medical survey participants (N=95) to U.S. adult population August 2016

Health condition	Comparative population†	Observed Number	Expected Number	SMR (95% CI)‡
Watery, itchy eyes last 12 months	NHANES III	40	31.3	1.3 (0.9–1.7)
Stuffy, itchy, or runny nose last 12 months	NHANES III	45	42.6	1.1 (0.8–1.4)
Sinus problems last 12 months	NHANES III	20	23.4	0.9 (0.6–1.3)
Phlegm 3 consecutive month or more	NHANES III	9	5.1	1.7 (0.9–3.3)
Wheeze last 12 months	NHANES 2007-2012	17	11.0	1.5 (<1.0–2.5)
Shortness of breath on exertion	NHANES III	17	15.1	1.1 (0.7–1.8)
Cough 3 consecutive months or more	NHANES III	4	4.3	0.9 (0.4–2.3)
Ever asthma (physician-diagnosed)§	NHANES 2007-2012	**11**	**5.3**	**2.1 (1.2–3.7)**
Current asthma (physician-diagnosed)	NHANES 2007-2012	3	3.3	0.9 (0.3–2.7)
Chronic bronchitis (physician-diagnosed)	NHANES III	1	3.0	0. (0.1–1.9)

Note: NHANES=National Health and Nutrition Examination Survey; SMR= standardized morbidity ratio.
***Adjusted for sex, race/ethnicity, age, and smoking categories.**
†We used the most recent NHANES survey available for each comparison.
‡95% confidence intervals (CIs) that exclude one are statistically significantly different from comparison with US adult population and are shown in bold.
§ Ten (91%) of 11 participants ever diagnosed with asthma were diagnosed before they started working at this coffee roasting and packaging facility.

Table A10. Adjusted* comparisons of spirometric results among NIOSH medical survey participants at a coffee roasting and processing facility to U.S. adult population in NHANES III, August 2016 N=95

Spirometry Result	Observed Number	Expected Number	SMR	95% CI†
Obstruction (no mixed)	1	2.2	0.5	0.1–2.6
Restriction (no mixed)	3	5.8	0.5	0.2–1.5
Mixed only	2	0.8	2.6	0.7–9.5

Note: NIOSH=National Institute for Occupational Safety and Health; NHANES=National Health and Nutrition Examination Survey; SMR=Standardized morbidity ratios.
***Adjusted for gender, race, age, and smoking categories.**
†95% confidence intervals (CIs) that exclude one are statistically significantly different from comparison with US adult population.

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