HealthHazard Evaluation Program

Evaluation of Low Frequency Noise, Infrasound, and Health Symptoms at an Administrative Building and Men's Shelter

HHE Report No. 2019-0119-3362

October 2019

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Disclaimer

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Availability of Report

Copies of this report have been sent to the employer and employees at the nonprofit organization and mobile clinic. The state and local health departments and the Occupational Safety and Health Administration Regional Office have also received a copy. This report is not copyrighted and may be freely reproduced.

Recommended Citation

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Introduction

Request

Employer representatives of a nonprofit organization and a mobile health services provider (mobile clinic) as well as county health department officials requested a health hazard evaluation. The request concerned low frequency noise, infrasound, and health symptoms among employees who work at the nonprofit organization's campus. Two events, in February and May 2019, caused particular concern because of the perceived noise intensity and symptoms among some employees, which lead to the campus being vacated.

Workplace

The nonprofit organization and mobile clinic provided services to homeless persons. The campus included an administrative building and a men's shelter, which were located near an inactive landfill with methane flares. The campus and the landfill were owned by the county. The requesters were concerned that sound and vibrations originating from the methane flares could be associated with health effects among employees.

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

Our Approach

In June 2019, we visited the nonprofit organization. For this evaluation, we completed the following activities:

- Measured sound levels and took noise frequency measurements (one-third octave band noise measurements) inside and outside the campus buildings and near the methane flares and motor-operated blowers.
- Interviewed employees who worked in the administrative building and men's shelter about unusual sounds or vibrations, personal health, and their perceptions of the nonprofit organization and the county's response.

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

Our Key Findings

Sound level and noise frequency measurements during the site visit were well below levels likely to cause adverse health effects

- The highest one-third octave band levels when a flare was operating were at 20 hertz. The highest level at this frequency was about 71 decibels in the administrative building, 66 decibels in the men's shelter, and 85 decibels in the parking lot between the methane flare area and the buildings. These were well below the American Conference of Governmental Industrial Hygienists' ceiling limit of 145 decibels for low frequency noise below 80 hertz.

- The highest overall unweighted noise levels (added across all frequencies) were about 73 decibels in the administrative building, 69 decibels in the men's shelter, and 87 decibels in the parking lot. These were well below the American Conference of Governmental Industrial Hygienists' frequency-specific ceiling limit of 150 decibels for low frequency noise below 80 hertz.
- The sound levels during the reported loud noise events in February and May 2019 were higher than those we measured based on employees' descriptions and reported sensory experiences. However, the actual sound levels and frequency characteristics during these events are unknown.
- The low frequency noise (sound at frequencies below 200 hertz) generated by the flares, especially in the frequencies 16 to 25 hertz, influenced sound levels in the buildings. In the administrative building, one-third octave band levels were 12 to 17 decibels higher when a methane flare was operating compared to when flares were not operating.
- The noise levels in the low frequencies were relatively greater than noise levels in higher frequencies, creating an unbalanced noise spectrum.
    - This imbalance between low and high frequencies increases the likelihood of being annoyed by the noise, particularly in the administrative building.
    - The low frequency noise levels we measured were above some European guidelines for low frequency noise and infrasound (sound at frequencies below 20 hertz).

Most interviewed employees reported unusual sounds or vibrations occurring at other times, not just in February and May 2019

- Of the 46 employees interviewed, 37 (80%) reported unusual sounds or vibrations at some point since beginning to work on the campus. Descriptions of the frequency, duration, and intensity of the unusual sounds or vibrations varied.
- By location, 28 (61%) employees reported experiencing unusual sounds or vibrations in the administrative building and 11 (24%) employees reported experiencing them in the men's shelter. This includes two employees (4%) who reported experiencing them in both locations.
- Most employees (89%) who reported experiencing unusual sounds or vibrations in the administrative building stated that they had first occurred before the February 2019 incident. Three of 11 employees (27%) who reported experiencing unusual sounds or vibrations in the men's shelter stated they had first occurred before the May 2019 incident.

Interviewed employees reported different types of symptoms as well as different times when those symptoms first appeared. The symptoms among different employees could have different causes.

- Twenty-four of the 46 (52%) interviewed employees reported experiencing symptoms that they thought were related to unusual sounds or vibrations at the site.
- Nine of the 24 (38%) employees who reported symptoms saw a health care provider about them. One employee reported being hospitalized. Relevant medical records for five (56%) of these employees were available for review.
- Many of the symptoms reported by employees were common, nonspecific, and could have multiple causes. Some of the employees had baseline medical conditions that could be associated with their symptoms.
- In general, information about symptom onset, duration, and timing relative to the incidents was incomplete.
- Some employees reported that their symptoms occurred before the incident in their primary work area. Some symptoms that predated the incident are consistent with symptoms reported in studies about background low frequency noise.
- Some employees reported developing symptoms during or after the February and May 2019 incidents. Auditory symptoms, such as hearing loss, ear pain, tinnitus, and ear pressure, can occur after exposure to loud noise. However, measurements of the actual noise levels or octave band frequency levels during the February and May 2019 incidents are not available.

Over half of the employees did not feel comfortable with returning to the vacated campus

- Over half of the employees (25/44; 57%) reported that they did not feel comfortable returning to the vacated campus.

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

Our Recommendations

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

Benefits of Improving Workplace Health and Safety:

↑ Improved employee health and well-being	↑ Enhanced image and reputation
↑ Better workplace morale	↑ Superior products, processes, and services
↑ Easier employee recruiting and retention	↑ May increase overall cost savings

The recommendations below are based on the findings of our evaluation. For each recommendation, we list a series of actions you can take to address the issue at your workplace. The actions at the beginning of each list are prioritized over the ones listed later. The list order is based on a well-accepted approach called the "hierarchy of controls." The hierarchy of controls groups actions by their likely effectiveness in reducing or removing hazards. In most cases, the preferred approach is to eliminate hazardous materials or processes and install engineering controls to reduce exposure or shield employees. Until such controls are in place, or if they are not effective or practical, administrative measures and personal protective equipment might be needed. Read more about the hierarchy of controls at https://www.cdc.gov/niosh/topics/hierarchy/.

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

Recommendation 1: Reduce low frequency noise generated by the methane flares

Why? Low frequency noise generated by the flares, especially in the frequencies 16 to 25 hertz, is likely related to turbulence during flare operation. Noise at these frequencies influences sound levels in the buildings, leading to an unbalanced noise spectrum (greater noise levels at low frequencies compared to higher frequencies) and a greater likelihood of employees experiencing annoyance because of the low frequency noise.

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

Reduce turbulence generated by the methane flares.

- Optimize the waste methane gas and air mixture to continually maintain a proper ratio and decrease combustion instability or combustion roar.
- Use flare burners designed to generate the least amount of noise.
- Reduce the velocity of waste gas stream, when feasible.

Consult with a noise control engineer about the possible use of building treatments such as double-glazed windows to decrease noise transmission into the building.

Recommendation 2: Encourage employees to report health concerns they think are work-related to their supervisors

Why? Information about symptoms in this evaluation was incomplete. Going forward, the nonprofit organization can periodically review information reported by employees to determine whether further action is needed.

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

Formalize a symptom reporting procedure so that information about health concerns is documented.

Encourage employees with health concerns to seek an evaluation from a healthcare provider with occupational medicine expertise and familiar with the types of exposures employees have and their health effects.

- Resources for locating occupational medicine physicians include the Association of Occupational and Environmental Clinics (http://www.aoec.org) and the American College of Occupational and Environmental Medicine (http://www.acoem.org).

Recommendation 3: Improve communication to all nonprofit organization and mobile clinic employees

Why? Open communication improves employees' sense of control and may help eliminate confusion, misinformation, and rumors related to building concerns.

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

Improve communication by documenting employees' concerns regarding the vacated campus. Discuss what is or is not being done to address the concerns and why, and what is being planned for the future.

- Joint meetings among nonprofit organization and mobile clinic employees, management, and representatives of the county may be the best way to improve communication. This will improve transparency and give all involved the opportunity to discuss their concerns and have their questions answered.

- Employee input and distribution of information (for example, meeting minutes) should be equal across all employees and employer representatives.

Recommendation 4: Take employees' perceptions of risk and willingness to return to work at the vacated campus into serious consideration

Why? If employees return to work in a setting that they believe is unhealthy or unsafe, it will likely have an undesirable impact on turnover, absenteeism, job satisfaction, productivity, and quality of work.

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

Take time to speak with individual employees to understand their concerns about the vacated campus and their willingness to return to work there.

- Consider this information when deciding whether to return to work at the vacated campus.

Supporting Technical Information

Evaluation of Low Frequency Noise, Infrasound, and Health Symptoms at an Administrative Building and Men's Shelter

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Section A: Workplace Information

Workplace

A diagram of the campus is shown in Figure A1. The campus included an administrative building and a men's shelter. The campus was adjacent to a landfill that closed in 1982. Two large methane flares (Figure A2), located within a fenced area across the parking lot from the administrative building, burned off excess methane from the adjacent landfill. Each flare had three automated air intake louvers equally spaced around the perimeter of the cylindrical flare stack. Within each flare stack, four burners were equally spaced in a spoke-like fashion about 5 feet (ft) above ground level. The site had three motor-operated blowers that pulled methane from the landfill at approximately 40 inches of vacuum pressure. Typically, only one flare and one blower operated at any given time.

The methane burning system was computer-controlled and the automated air intake louvers could be adjusted (fully open, partially open, or closed) depending on the concentration of methane pulled from the landfill in order to maintain an optimal flare temperature of 1,650 degrees Fahrenheit. Although the system was designed to adjust quickly as necessary (on the basis of continuing feedback to the computer control system) to consistently keep the flare system within optimal operating parameters, environmental or other factors can potentially disrupt the system. A wall perpendicular to the parking lot was built reportedly to reduce noise transmission to the former methane plant that generated energy. This wall was slightly shorter than the flares.

The administrative building had several wings. The one occupied by the nonprofit organization was L-shaped. The main entrance and several offices faced directly toward the methane flares. A hallway with offices along both sides extended from the main entrance straight toward the back of the building, perpendicular to the flares. The men's shelter building also had several rooms facing the flares, including a main office and examination rooms. A large common room also faced the flares. A city road was located on the opposite side of both buildings.

The nonprofit organization was contracted by the county to provide services for homeless persons. Employees of the mobile clinic served clients at the men's shelter. The county owned the campus, landfill, and flares.

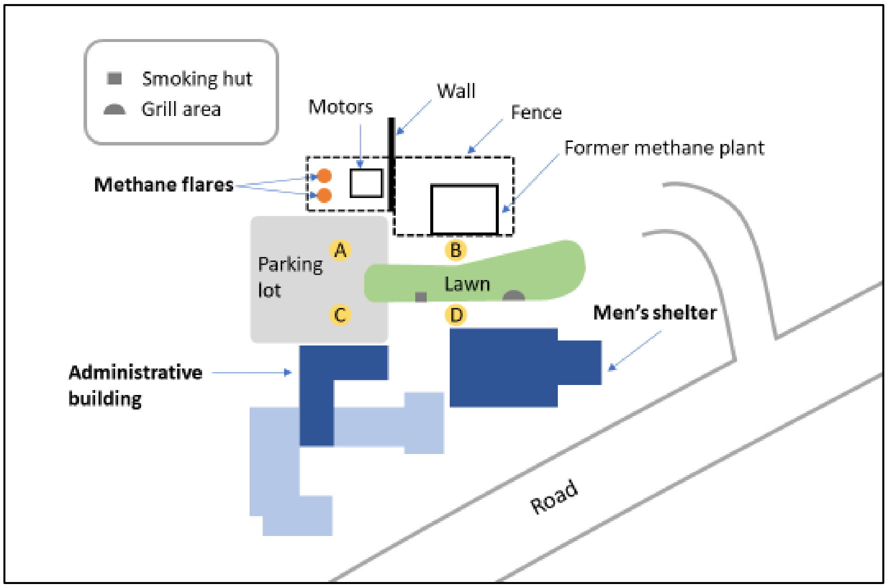

Figure A1. Schematic of the campus and methane flares. Not drawn to scale. Employees worked in the administrative building or the men's shelter. Yellow circles with A–D refer to parking lot locations where we made noise measurements. The closed landfill extends from the top edge of the fenced area to beyond the top of the diagram.

Figure A2. Large methane flares adjacent to the municipal landfill.

Employee Information

At the time of the evaluation, there were 59 nonprofit employees plus 1 volunteer: 31 worked in the administrative building, 26 worked in the men's shelter, and 3 worked for the mobile clinic. Administrative building staff reported working 8–10 hours a day, while men's shelter employees worked 8 hours a day.

History of Issue at Workplace

Request Basis

On February 4, 2019, employees reported unusually loud noise and strong vibrations in the administrative building coming from the direction of the methane flares. During this loud noise event, some employees also reported emotional discomfort and physical symptoms such as vertigo, dizziness, and ear pressure. Prior to this loud noise event, the local area had received substantial heavy rain.

According to staff familiar with flare operation, heavy rainfall conditions can affect the composition of methane and increase the amount of methane released within the landfill. It was likely that the combination of these factors required greater input of air at the flare stack. Because the flare system did not respond and adjust quickly enough to the changing air requirements, an imbalance in the air-to-methane gas ratio occurred, leading to an increase in combustion instability and combustion roar. These conditions led to a subsequent increase in noise. To reduce the likelihood of additional loud noise events, an additional air intake louver was added to each of the flare stacks (for a total of three equally distributed automated louvers around the base of each flare) to bring additional air into the stacks, if needed. Additional adjustments in the computer control systems were also completed to help keep the air-to-gas ratio properly balanced.

As a result of the loud noise event, employees in the administrative building were relocated to an off-campus building within 1 week. On May 17, 2019, loud noise and vibrations were reported at the men's shelter. Some nonprofit organization and mobile clinic employees and shelter clients reported not feeling well during or soon after the incident. On the same day, the men's shelter was relocated to a building normally used for client overflow during colder months.

Other Issues

Some employees reported a strong, persistent odor in the administrative building. The nonprofit organization hired a consultant to evaluate the odor in late 2017. The consultant took an ambient air sample (via a whole air canister) and bulk samples of carpet and wood laminate. Air sampling and headspace analysis of the bulk samples were done to identify volatile organic compounds (VOCs). The VOC concentrations detected in the samples (39 VOCs in the air sample, 32 VOCs in the wood floor laminate headspace sample, and 28 VOCs in the carpet headspace sample) were well below occupational exposure limits. The consultant concluded that the most likely cause of the odor was one of the VOCs identified in the samples, 2-methyl-1,3,butadiene (isoprene), from the duct mastic/sealant used for the heating, ventilation, and air-conditioning ductwork. This VOC is a component of natural and synthetic rubber.

Section B: Methods, Results, and Discussion

Our evaluation objectives were to characterize the following:

- One-third octave band noise frequency levels
- Health symptoms among employees
- Employee perceptions of how the loud noise situations were handled by the nonprofit organization and the county

Methods: Noise Assessment

We gathered information about noise through (1) noise measurements and (2) confidential employee interviews.

Sound Level and One-third Octave Band Measurement

We used a Larson Davis Model 831 integrating sound level meter and sound frequency analyzer and a Model 377B20 ½ inch random incidence microphone for octave band frequency measurements. The sound level meter and microphone met American National Standards Institute (ANSI) S1.4 2014 Type 1 standards and the octave band frequency filter met ANSI S1.11-2004 Class 1 standards. The instrument and microphone were calibrated together before and after each day of measurements using a Larson Davis CAL200 calibrator. We measured one-third octave band noise frequency levels at each one-third octave band center frequency from 6.3 to 20,000 hertz (Hz) (corresponding to frequencies of 5.62–22,400 Hz).

The instrument sampled at a rate of 51,200 Hz (i.e., 51,200 measurements per second) and integrated using linear averaging at 1-second time history intervals. One-third octave band levels were measured using a slow weighting (1,000 millisecond) time constant and the Z-weighting (flat or unweighted) response. During measurements, the instrument was either hand-held or positioned on a tripod at a height of approximately 5 ft above floor or ground level. We took several measurements within rooms inside the administrative building and the men's shelter. We took measurements outside at six locations between the flare areas and the administrative building and men's shelters (identified as Locations A, B, C, and D; grill area; and smoking hut in Figure A1). We also took some measurements offsite along the city road that was behind the administrative building and men's shelter. At each location, most measurements were taken for a duration of approximately 30–45 seconds. Following measurements, the one-third octave band frequency data stored on the instrument were downloaded, exported, and analyzed using Larson Davis G4® software and Microsoft® Excel® for Office 365®.

Confidential Interviews: Perceptions of Noise

We invited all current employees of the nonprofit organization who (1) had been working during the February 2019 incident, May 2019 incident, or both, and (2) were working during our site visit for confidential interviews. We also invited all three mobile clinic employees who provide services at the men's shelter as part of their rotating schedule. We interviewed 46 employees, 43 employees in person and 3 employees by phone. Our convenience sample included 45 current employees and 1 former employee who had been employed during the February 2019 incident.

During the interviews, we discussed work characteristics and demographic information. We also asked about perceptions of sounds or vibrations experienced in the administrative building or men's shelter. We categorized employees as administrative building employees or men's shelter employees based on their self-reported primary work area prior to the relocations. Mobile clinic employees were categorized as men's shelter employees. Administrative building employees were asked about their primary work area within the building. Using a blueprint as a reference, we categorized employees as working primarily in rooms facing the flares based on a reported room number for their office or working in a room with a window facing the methane flares, as reported by employees.

We asked employees whether they heard any unusual sounds or experienced any unusual vibrations since starting to work on the campus. For "yes" responses, we asked employees about when they first heard unusual sounds or felt unusual vibrations in the administrative building or men's shelter. We also asked employees to describe the unusual sounds and vibrations. We grouped unusual sounds and vibrations together for analysis.

We summarized results using descriptive statistics. We compared the proportion of employees working primarily in rooms facing the flares who reported unusual sounds or vibrations to the proportion of all other interviewed employees who reported unusual sounds or vibrations using a two-side Fisher's exact test where $P < 0.05$ was considered to indicate statistical significance. We used R version 3.5.1 to perform statistical analyses.

Other interview topics and results are presented later in this report.

Results: Noise Assessment

Noise Measurement

The primary external sources for noise near the administrative building and men's shelter were the operating methane flare(s) and blower(s). Figure B1 shows the one-third octave band noise levels at an operating flare and at an operating blower. The highest sound levels in the vicinity of the operating methane flare occurred in frequencies below 50 Hz and ranged from 70.8 to 101.2 decibels (dB), depending on frequency and distance from the flares. The highest levels (95.0 to 101.2 dB), measured approximately 2 to 3 ft away from an air intake louver of the flare stack, were at a frequency of 20 Hz. At 12.5 Hz, 16 Hz, and 25 Hz the levels ranged from 84.9 to 93.5 dB. At 10 ft from a flare in operation, the sound level at 20 Hz was 91.2 dB, and at the adjacent frequencies of 12.5 Hz, 16 Hz, and 25 Hz, the sound levels were at or slightly above 80 dB. The highest sound levels generated by an operating blower were in the frequencies from 500 to 6,300 Hz, ranging from 68.6 to 76.2 dB. The measurements near the blower also showed high sound levels in frequencies below 50 Hz, but these were due to the sound generated by the nearby operating methane flare.

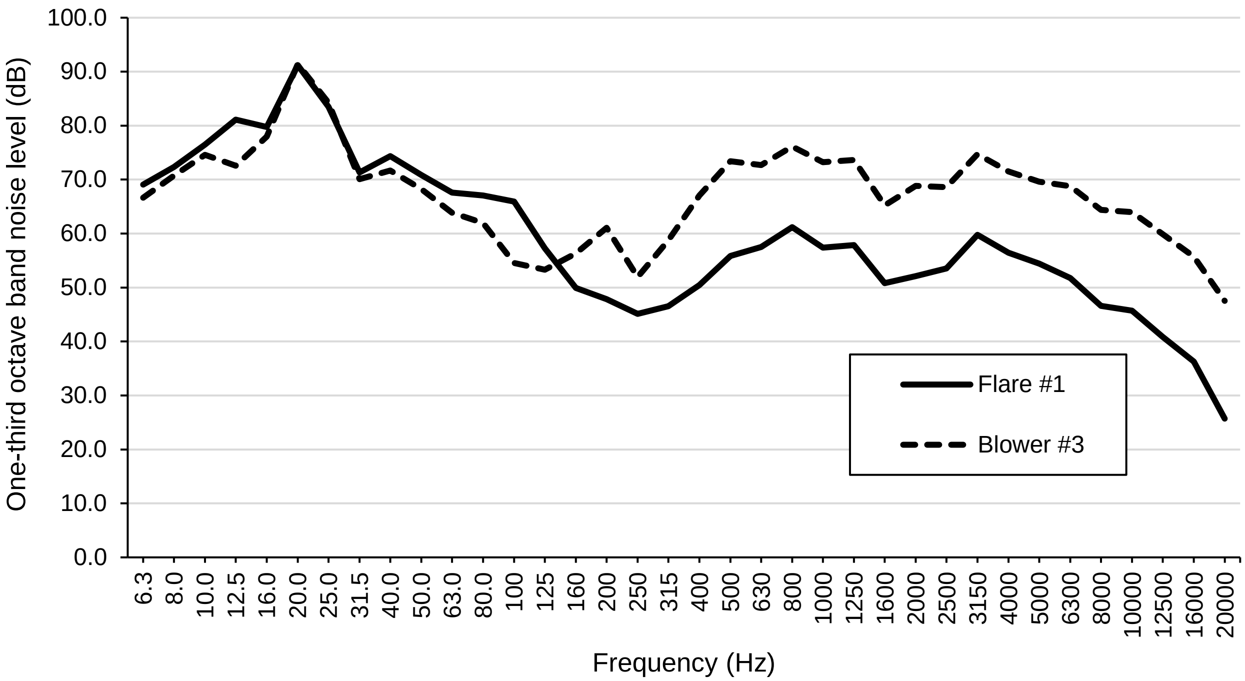

Figure B1. One-third octave band noise levels measured approximately 8 to 10 feet from an operating methane flare and blower.

Table C1 provides the one-third octave band measurement results (up to 80 Hz) and overall sound levels while one of the methane flares was in operation for comparison to occupational infrasound and low frequency noise threshold limit values (TLVs) established by the American Conference of Governmental Industrial Hygienists (ACGIH) [ACGIH 2019]. The highest one-third octave band levels we measured across these frequencies (as well as for frequencies up to 20,000 Hz) at each location was at 20 Hz, except for measurements taken along the city road behind the administrative and men's shelter buildings, where the levels were highest at 63 Hz. One-third octave band noise levels at 20 Hz ranged from 60.5 to 71.4 dB in the administrative building, 60.4 to 65.6 dB in the men's shelter, 75.8 to 84.9 dB at the four outdoor locations in the parking lot, grill area, and smoking hut. These results show that the sound levels we measured were well below the ACGIH frequency-specific TLV ceiling value of 145 dB and the overall TLV ceiling limit of 150 dB.

Because relative sound levels were greater in lower frequencies relative to higher frequencies, Table C2 provides the overall C-weighted decibel (dBC) and A-weighted decibel (dBA) measurements results within the administrative building and men's shelter. The overall C-weighted sound levels ranged from 55.9 to 67.2 dBC in the administrative building and from 58.7 to 62.4 dBC in the men's shelter. A-weighted sound levels ranged from 26.5 to 39.8 dBA in the administrative building and 42.6 to 48.0 dBA in the men's shelter.

During our site visit, the flares were shut down to complete some adjustments to the flare and blower-motor computer control systems. During this shutdown, we took several one-third octave band measurements for comparison to levels when a flare was operating. Within the administrative building we took measurements in eight different rooms. All of the rooms had exterior windows, but five of the rooms faced toward the flares. The other three rooms had windows facing out toward a side or toward the rear (roadside) of the building. The highest one-third octave band noise levels across these eight rooms when the flares were on occurred at 20 Hz, ranging from 62.1 to 71.4 dB. When the flares were off the highest one-third octave band noise levels occurred at 8 Hz, ranging from 50.5 to 59.6 dB. In general, our measurements did not show a substantial difference in the one-third octave band levels for rooms facing the flares versus the rooms not facing the flares. Overall, the levels were slightly higher in the rooms facing the flares across the frequencies of 10 to 100 Hz, but were slightly lower at all other frequencies (and nearly the same from 10,000 to 20,000 Hz)

Figure B2 compares median one-third octave band frequency levels in the administrative building when the flares were on versus when the flares were off. The greatest difference in one-third octave band noise levels between flare on versus flare off conditions occurred across the frequencies of 16 Hz, 20 Hz, and 25 Hz. The differences in the median dB levels at these three one-third octave band frequencies were 17.4 dB at 20 Hz, 15.2 dB at 25 Hz, and 12.2 dB at 16 Hz. At all other frequencies, the median differences between flare on versus flare off conditions ranged from –4.6 to 6.1 dB, with a negative difference indicating that octave band noise levels were higher when the flares were off.

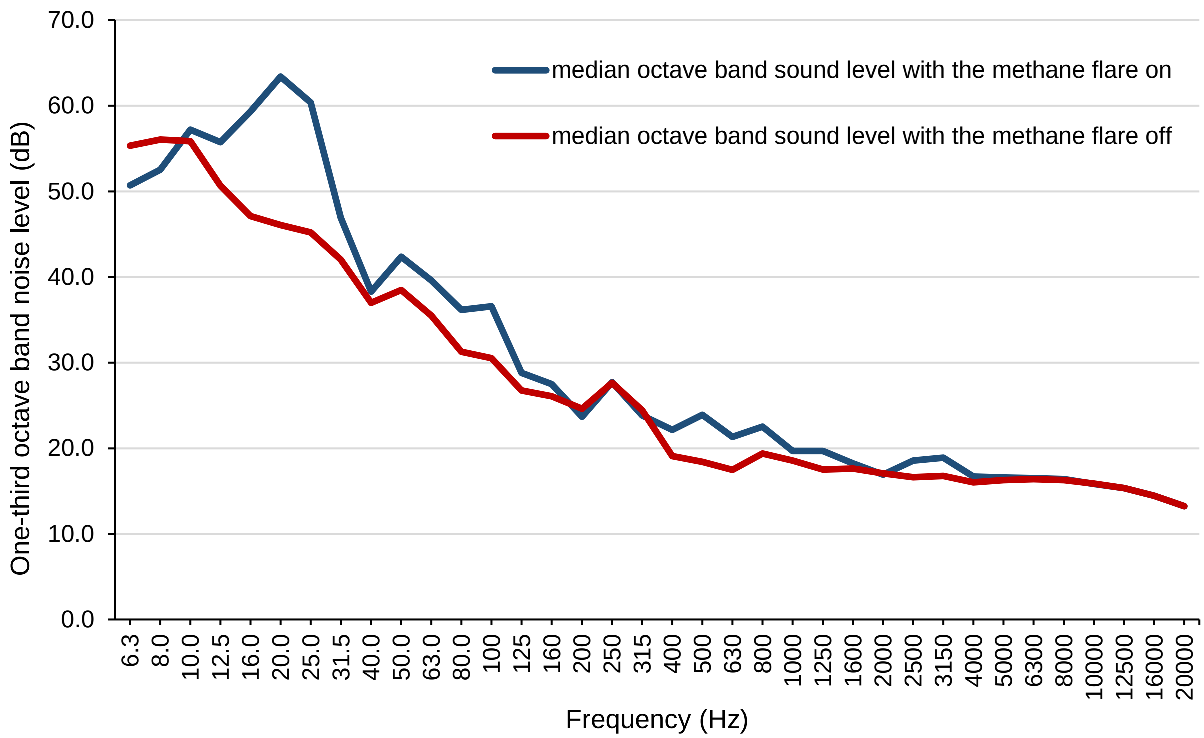

Figure B2. One-third octave band noise levels across eight rooms in the administrative building when a methane flare was on versus when the flare was off.

Figure B3 compares the median one-third octave band frequency levels in the administrative building when a flare was on and off to four different European guidelines suggested for assessing indoor low frequency noise and infrasound following complaints of annoyance. When the flare was on, our measured levels exceeded the Polish guidelines at frequencies of 20 Hz, 25 Hz, and 50 to 250 Hz, and exceeded German and Dutch guidelines at frequencies of 50 to 100 Hz. The highest exceedance was at 250 Hz when compared to Polish guidelines and was at 100 Hz when compared to German and Dutch guidelines. None of the measured levels were above British guidelines. When the flare was off, we similarly found that levels were above German and Dutch guidelines from 63 to 100 Hz and above Polish guidelines from 100 to 250 Hz.

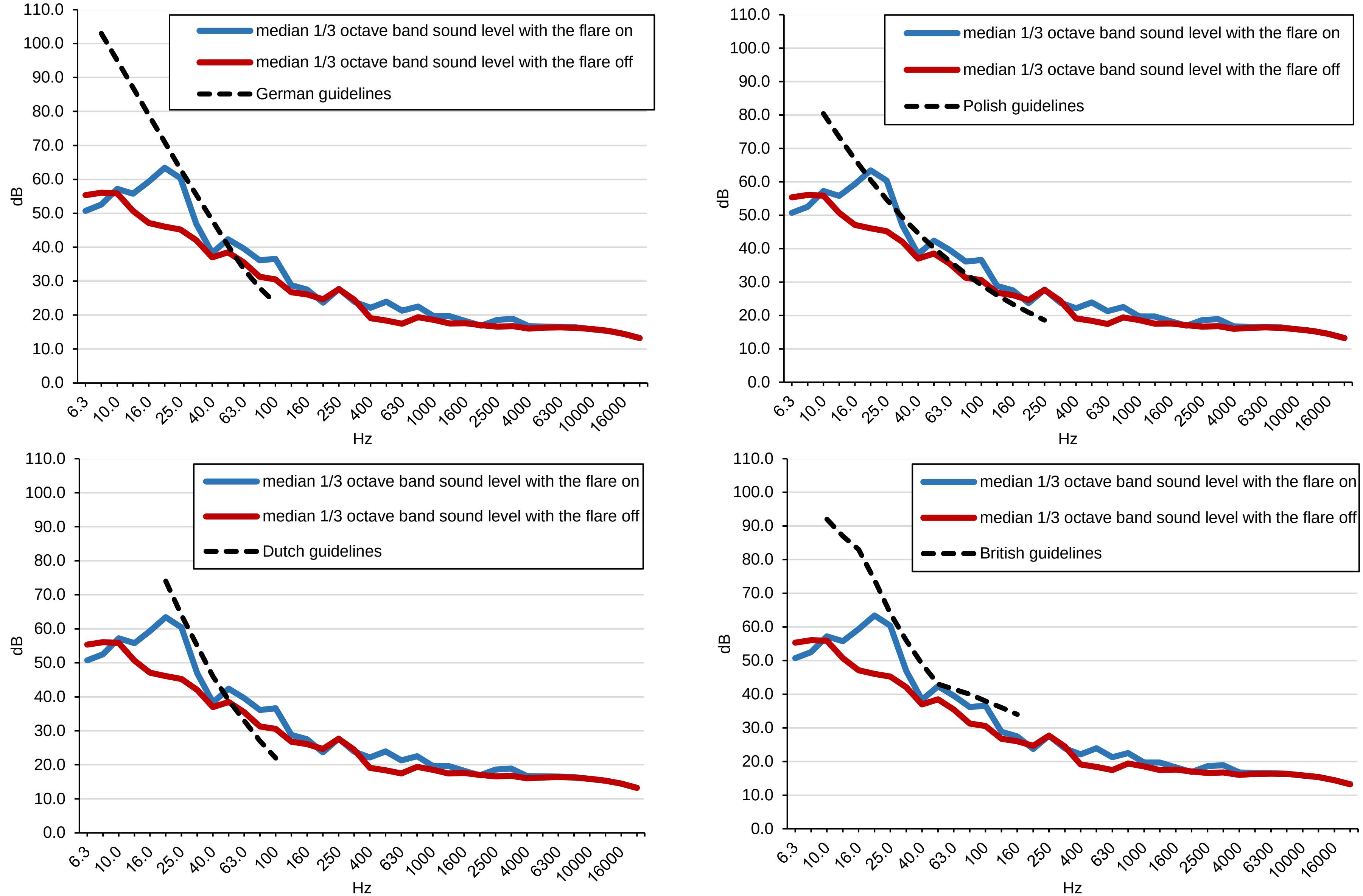

Figure B3. Comparison of median one-third octave band noise levels in the administrative building with a flare on versus off to European low frequency and infrasound guidelines

Confidential Interviews: Perceptions of Noise

Of the 48 employees invited for interviews, 46 employees (96%) participated. Interviewed employees consisted of 44 nonprofit organization employees and 2 mobile clinic employees. The median job tenure was 3 years (range: 5 months–14 years). Nonprofit organization employees worked for a median of 40 hours per week (range: 30–65 hours per week). Mobile clinic employees were on site 2–3 partial days per week. Based on the reported primary work area before the relocations, there were 29 (63%) administrative building employees and 17 (37%) men's shelter employees. Of the 46 interviewed employees, 30 (65%) were female. The median age was 44 years (range: 24–69 years).

Thirty-seven (80%) interviewed employees reported either unusual sounds or vibrations. Descriptions of the frequency, duration, and intensity of unusual sounds or vibrations varied. Some employees described a rumbling, analogous to a large truck driving by, or a jackhammer, that can be heard or felt prior to the incidents. Some employees described vibrating windows or objects or a sensation that the building was shaking.

Regarding the location of sounds or vibrations, 28 (61%) employees reported experiencing them in the administrative building and 11 (24%) employees reported experiencing them in the men's shelter. These numbers included 2 (4%) employees who reported experiencing unusual sounds or vibrations in both locations.

Regarding when unusual sounds or vibrations were first noticed, responses ranged from the beginning of employment to the day of the incident at the location where the incident occurred. Of the 28 employees who reported experiencing unusual sounds or vibrations in the administrative building, 25 (89%) reported that they noticed them occurring before the February 2019 incident. Of the 11 employees who reported experiencing unusual sounds or vibrations in the men's shelter, 3 (27%) reported that they noticed them occurring before the May 2019 incident.

The proportion of employees working primarily in rooms facing the flares who reported unusual sounds or vibrations was similar to the proportion of other interviewed employees who reported unusual sounds or vibrations ($P = 0.69$).

Methods: Employee Health Assessment

We gathered information about employee health through (1) interviews and (2) medical record review. During confidential interviews with 46 employees, we asked about their medical histories. We also asked about the following:

- Symptoms that employees thought were related to unusual sounds or vibrations.
- Medical care sought for symptoms that employees thought were related to unusual sounds or vibrations.

We asked all interviewed employees whether they experienced any symptoms that they thought were related to unusual sounds or vibrations at the site. Employees who answered "yes" or "not sure" were asked additional questions about symptoms. If an employee reported seeking medical care for symptoms, we attempted to obtain relevant medical records.

We summarized descriptive statistics for health information. We grouped tinnitus (sensation of noise or ringing in the ears when there is no sound), ear pain, ear pressure, and hearing loss as auditory symptoms. We grouped vertigo (sensation of movement when there is no movement) and balance problems as vestibular symptoms (i.e., symptoms related to balance or the inner ear). We considered an auditory or vestibular symptom to have a plausible (i.e., possible and medically reasonable) alternative explanation if an employee reported (1) having a history of that symptom, (2) having a medical condition for which that symptom is characteristic, (3) taking an over-the-counter or prescription medication known to induce the symptom, or (4) basing it on medical record review, if available.

To assess the distribution of symptoms across groups, we compared the prevalence of symptoms reported by employees working primarily in rooms facing the flares to the prevalence of symptoms reported by other interviewed employees using a two-sided Fisher's exact test. We also used the exact binomial test to assess whether the percentages of administrative building versus men's shelter employees with a given symptom were similar to the percentages of employees who primarily worked in those two areas.

Statistical significance was set at $P < 0.05$. We used R version 3.5.1 to perform statistical analyses.

Results: Employee Health Assessment

Twenty-four (52%) employees responded "yes" or "unsure" when asked whether they experienced any symptoms that they thought were related to unusual sounds or vibrations at the site (Figure B4). The most common symptom was headache (n = 19), followed by anxiety (n = 14), and lightheadedness (n = 12). Six employees described one or more sources of their anxiety: uncertainty related to the incidents and subsequent relocation (n = 4), whether the campus was safe (n = 2), noise (n = 1), and methane gas (n = 1). Of the 46 interviewed employees, 14 (30%) reported auditory symptoms and 9 (20%) reported vestibular symptoms.

In general, information about symptom onset, duration, and timing relative to the incidents was incomplete. When responses about symptom onset were available, the percentage of employees who reported that symptoms occurred before the incident in their primary area ranged from 0% for ear pain, body vibrations, vision problems, and irritability to 44% for vertigo and 50% for hearing loss.

Of the 24 employees who reported symptoms that they thought were related to unusual sounds or vibrations at the site, 9 (38%) saw a health care provider. One employee reported being hospitalized. Of the nine employees who saw a health care provider, we reviewed the relevant medical records of five (56%) employees who agreed to making them available for review.

Some employees had plausible (i.e., possible and medically reasonable) alternative explanations for auditory or vestibular symptoms. Of the 14 employees who reported auditory symptoms, 2 (14%) had a plausible alternative explanation for their auditory symptoms. Of the 9 employees who reported vestibular symptoms, 3 (33%) had a plausible alternative explanation for their vestibular symptoms.

The proportion of employees working primarily in rooms facing the flares who reported symptoms was similar to the proportion of other interviewed employees who reported symptoms ($P = 0.21$). Similar results were obtained for auditory symptoms ($P = 0.60$) and vestibular symptoms ($P = 0.64$).

The 24 employees who reported symptoms that they thought were related to unusual sounds or vibrations consisted of 19 (79%) administrative building employees and 5 (21%) men's shelter employees. This breakdown was not statistically different from the proportion of administrative building employees (63%) and men's shelter employees (37%) interviewed ($P = 0.13$). Similar results were obtained when comparing each symptom individually.

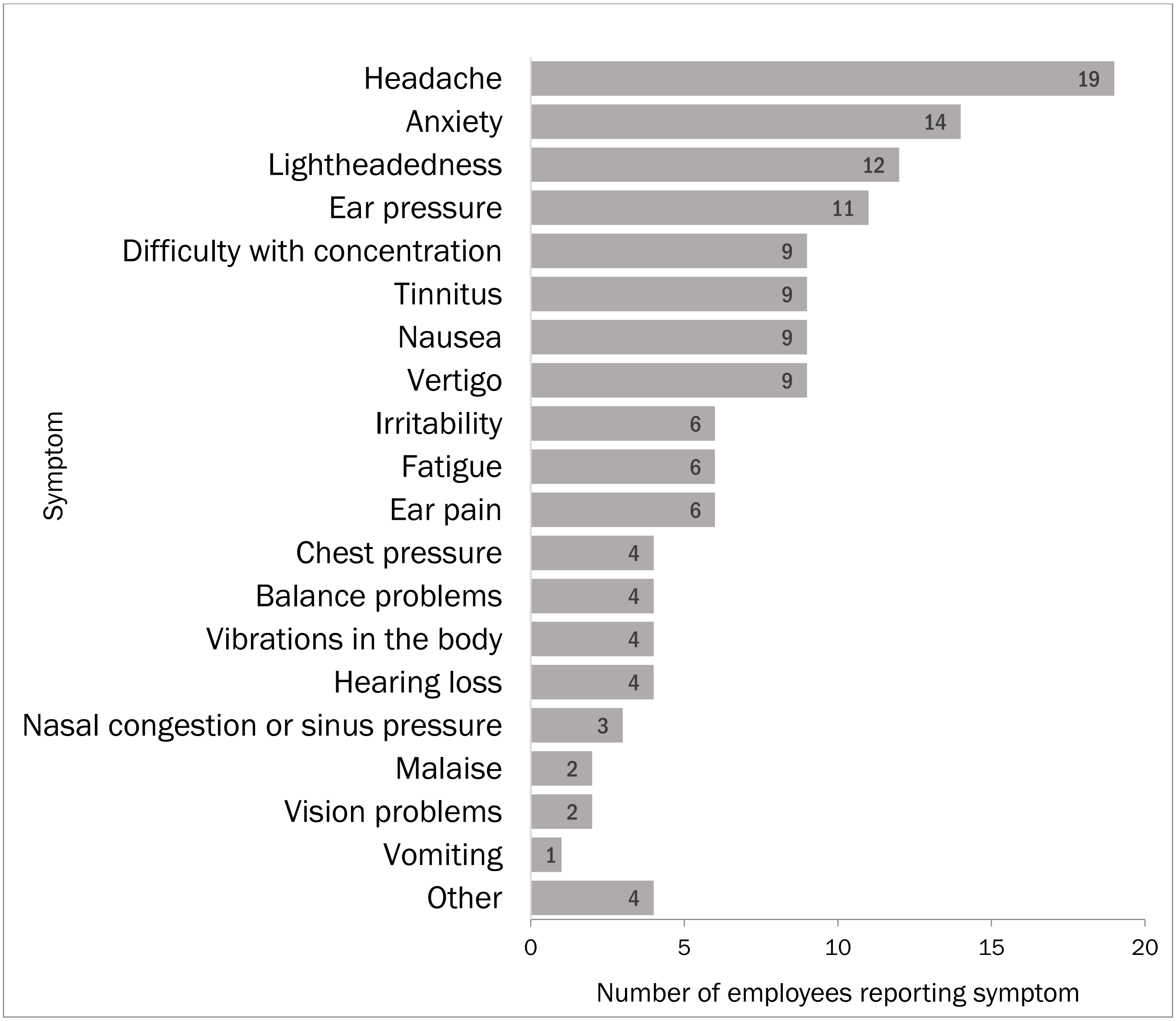

Figure B4. Bar graph showing that among the symptoms reported by employees as being related to unusual sounds or vibrations at work, headache, anxiety, and lightheadedness were the most common.

Methods: Employee Perceptions of the Handling of the Loud Noise Situation

We asked employees several questions about their perceptions and experience of the events that led to their workplace being evacuated/relocated. Employees were asked each question twice, once focusing on the nonprofit organization, and once focusing on the county. These questions included, "Do you have any concerns about how the situation was handled by the nonprofit organization/the county," "Are you satisfied with the nonprofit organization/the county's communication to employees about the situation," and "Do you trust the nonprofit organization/the county to care for your health and safety at work?" Each response was recorded as yes, no, or unsure, and was followed by an open-ended question asking for an explanation of the response. We also asked employees a yes/no question about whether they were comfortable with returning to work at the vacated locations. If the response was "no" or "unsure," it was followed by an open-ended question: "what would be needed for you to feel comfortable returning to work [at the site]?"

Open-ended responses were analyzed to report common themes, which were then tallied to report the number of employees expressing similar concerns. Employees' responses may have been tallied into one or more themes. If fewer than three employees reported a particular concern, it is not reported in order to protect employee confidentiality.

Results: Employee Perceptions of the Handling of the Loud Noise Situation

Table C3 shows the yes/no/unsure responses to questions about employee perceptions of how the situation was handled by the nonprofit organization and the county.

When asked if they had concerns about how the situation was handled by the nonprofit organization, 12 (26%) replied "yes." When interviewed employees were given the opportunity to explain their response, 25 employees provided more detail. Eight (32%) employees replied with a positive comment about how the nonprofit organization handled the situation. The most common concern (n = 7; 28%) was that the men's shelter was not evacuated until months after the administrative building was evacuated. When asked if they had concerns about how the situation was handled by the county, 27 (59%) employees replied "yes." When given the opportunity to explain their response, 32 employees provided more detail. The most common concerns being a perception that the county did not take the situation seriously (n = 10; 31%); a lack of communication about the situation (n = 9; 28%); and the length of time it took to evacuate the men's shelter (n = 7; 22%).

Most interviewed employees (n = 35; 76%) reported that they were satisfied with communication from the nonprofit organization. Twenty-eight employees provided more detail about their response, and a quarter of the responses (n = 7) were positive in nature. The most common concerns reported were being unsure of what plans were moving forward (n = 6; 21%); a perceived lack of transparency from the nonprofit organization (n = 4; 14%); wanting more information about how the situation was being assessed (n = 3; 11%), and a perception that the information was being shared informally (e.g., "office gossip"; n = 3; 11%). Most of the interviewed employees (n = 28; 61%) were not satisfied with communication from the county, and another 14 (30%) were unsure. Thirty-five employees provided more detail about their response, with the most common response (n = 27; 77%) being that there was no communication from the county. The next most frequent response (n = 4; 11%) was that the county was taking too long to share information.

Most of the interviewed employees (n = 42; 91%) reported that they trusted the nonprofit organization to care for their health and safety at work. Twenty-eight employees provided more detail about their response, with the most common responses (n = 21; 75%) being positive in nature (e.g., "they look out for us and are supportive"). One-third (n = 15; 33%) of the interviewed employees reported that they trusted the county to care for their safety and health, while another four (9%) said they were unsure.

Thirty-two employees provided more detail about their response, with the most common responses being that nothing was being done because the situation was not being taken seriously (n = 8; 25%) and the perception that the county does not care about the nonprofit organization (n = 7; 22%). Six (19%) of the comments were positive in nature.

When asked whether they would be comfortable returning to work at the vacated campus, 25 of 44 interviewed employees (57%) said "no," and 19 (43%) said "yes." Thirty-two employees provided a response when asked what it would take to make them comfortable enough to return, with the most common responses being that there is nothing that could be done to alleviate their concerns (n = 12; 38%); if testing is completed that shows the campus is objectively "safe" (n = 9; 28%); or if the problem is "fixed" (n = 8; 25%). Others mentioned they would be comfortable returning if the vibrations stopped (n = 5; 16%) or if the odor in the administrative building was no longer present (n = 5; 16%).

Discussion

Low frequency noise is usually defined as sound occurring at frequencies below 200 Hz. Sound in frequencies below 20 Hz is referred to as infrasound. Although audible sound for humans is generally considered to range from 20 to 20,000 Hz, with the greatest sensitivities across frequencies of 500 to 8,000 Hz, research has shown that sounds below 20 Hz are audible if the sound pressure level is high enough. Watanabe and Moller [1990] showed that hearing thresholds in the infrasound frequencies ranged from 107 dB at 4 Hz to 88 dB at 16 Hz. In contrast, hearing thresholds at 200 Hz are under 20 dB and may be at or near audiometric 0 dB for people with no hearing loss in frequencies from 1,000 to 6,000 Hz.

Low frequency noise and infrasound are omnipresent and rarely, if ever, occur without the concurrent presence of sound in higher frequencies. Infrasound, particularly at frequencies of 1 Hz or less, is generated in nature by volcanos, earthquakes, thunder, waterfalls, waves, and wind. Infrasound levels of up to 110 dB have been measured at wind speeds of approximately 16 miles per hour [Nowacki et al. 2008]. Human activities such as running can generate infrasound levels up to 90 dB, and swimming can generate infrasound up to 140 dB (both at frequencies < 2 Hz) [von Gierke and Parker 1976]. Infrasound levels in cars have been found to range up to 120 dB, and in helicopters or fixed-wing aircraft, infrasound levels can range from 120 to 145 dB [Integrated Laboratory Systems 2001].

In workplaces, sources of infrasound and low frequency noise include ventilation systems, air compressors, turbines, and heavy machinery or equipment. Diesel engines have been shown to generate sound levels of 110 dB across frequencies of 10 to 20 Hz [Integrated Laboratory Systems 2001]. We found no information in the research literature on octave band noise levels generated by methane flares. However, a guidance report on landfill gas flaring for the Scottish Environmental Protection Agency (SEPA) reported that noise generated by combustion in methane flares was predominately found at frequencies around 17 Hz [SEPA 2002].

A literature review by Johnson [1982] assessing hearing damage risk from infrasound did not find evidence of hearing threshold shifts from continuous exposure to infrasound at 140 dB for 30 minutes nor from continuous exposures to levels of 118 dB or less for 24 hours. However, a sense of pressure in the middle ear has been reported to occur at infrasound levels ranging from 127 to 133 dB [Broner 1978]. Subjects in a laboratory study perceived sensations through infrasound vibrations at sound levels of approximately 130 dB at 4 Hz and 110 dB at 20 Hz [Landstrom et al. 1983].

Tsunekawa et al. [1987] reported perception to a lower level of infrasound (50% response to a threshold level of 94 dB at 10 Hz) during a field study evaluating perceptions to exposures occurring underneath a bridge, in an automobile, and near a cooling tower. An early study found that employees exposed for 15 minutes to simulated industrial infrasound at frequencies of 5 Hz and 10 Hz and levels of 100 dB and 135 dB reported symptoms such as fatigue, ear pressure, poor concentration, drowsiness, and perception of vibration in internal organs [Integrated Laboratory Systems 2001]. Research has also reported that symptoms such as headache, sensation of body sway, fatigue, tinnitus, and respiratory difficulties following exposure to infrasound levels ranging from 100 to 120 dB [Storm 2009]. In contrast, a study of 145 long-haul truck drivers exposed infrasound of 115 dB did not find that reported symptoms such as fatigue, vertigo, tinnitus, hearing impairment, headache, abdominal symptoms, or hypertension were statistically significantly more common when analyzed with respect to exposure and hours of work, driving, and rest [Kawano et al. 1991].

The ACGIH TLVs are the only U.S. occupational exposure limits established specifically for low frequency noise and infrasound. TLVs are recommended limits, not enforceable regulatory limits, established to protect against auditory pain and other auditory, respiratory, and cardiac responses. They represent sound exposures to which it is believed that nearly all workers may be exposed without adverse effects that do not involve hearing [ACGIH 2019]. The ACGIH has established two TLVs: (1) a ceiling limit of 145 dB for one-third octave band frequencies from 1 to 80 Hz and (2) a ceiling limit of 150 dB for overall sound pressure levels for frequencies from 1 to 80 Hz. A ceiling limit should not be exceeded at any time. The TLV documentation further notes that low frequency noise exposure across frequencies of 50 to 60 Hz are in the chest resonance range and can cause whole-body vibration which could lead to discomfort and annoyance. ACGIH advises that under these conditions, the sound pressure level may need to be reduced to a level to where these problems are alleviated [ACGIH 2019]. Though only applicable to infrasound exposures for space craft and space stations, the National Air and Space Administration (NASA) has established an exposure limit of 120 dB across the frequency range of 1 to 16 Hz for 24-hour exposure [NASA 1995].

Our one-third octave band noise level measurement results clearly show that the predominant noise frequencies generated by an operating methane flare were at the one-third octave band center frequencies of 20 Hz and secondarily at the adjacent center band frequencies of 16 Hz and 25 Hz. These results were similar to the predominant frequency (17 Hz) reported in a guidance document on landfill gas flaring prepared for SEPA [SEPA 2002]. The wavelength of sound waves is inversely proportional to frequency, with high frequencies having short wavelengths and low frequencies having long wavelengths. Because of the exceptionally long wavelength of low frequency noise (e.g., sound at 20 Hz has a wavelength of almost 56 ft), it is able travel long distances, is difficult to stop with barriers or enclosures because of diffraction and surface propagation, and is minimally attenuated by common building structures.

The predominance of noise from the flares across these low frequencies is a function of the turbulence generated by the combination of methane gas and air-flow through the flare burners, the combustion process (combustion roar and combustion instability), and the effect of the hollow flare stack configuration (resonant acoustic characteristics) as heated air moves upward toward the top of the stack. Combustion roar is related to how much fuel is burned and the rate of burn. Combustion instability is related to an imbalance that occurs when too much air is introduced relative to the waste gas stream, which can periodically disrupt the flame, resulting in generation of low frequency rumbling-type noise [Fleifil et al. 2011]. Noise from combustion roar and combustion instability are characteristically generated at low frequencies, with combustion instability typically at lower frequencies than combustion roar. The factors leading to both combustion roar and combustion instability create turbulence. As turbulence increases, sound levels also tend to increase. Combustion roar and combustion instability can potentially be reduced by optimizing the waste gas and air mixture, using low noise burners or flare tips, and reducing the velocity of the waste gas stream, when feasible.

All of our indoor and outdoor measurements were well below the ACGIH TLV ceiling values for low frequency noise. All of our measurement results were also well below levels reported in the research literature as likely to cause adverse health effects.

While several case studies have reported subjective symptoms such as headaches, feelings of pressure in the head or ears, body vibration, concentration difficulties, or fatigue [Waye 2011] associated with infrasound, many research studies have shown noise-related annoyance is one of the main effects from exposure to infrasound [Andresen and Moller 1984; Broner 1978; Moller 1984; Pawlaczyk-Luszczynska et al. 2009; Waye and Rylander 2001]. In contrast, some researchers have reported that high sound levels in the frequencies of 30 to 80 Hz [Broner and Levanthall 1983; Levanthall 2003] or 25 to 63 Hz [Waye 2011] may have a greater influence on annoyance than high levels of infrasound or at frequencies above these ranges. Waye et al. [2001] reported that annoyance was correlated with subjective estimation of symptoms such as tiredness, dizziness, poor concentration, and sensation of pressure on the head when low frequency noise conditions occurred in the workplace. Although unrelated to workplace exposure, a more recent systematic review and evaluation of observational studies of an adult population living near a source of low frequency noise and infrasound suggests an association between self-reported annoyance and symptoms such as sleep-related problems, difficulty concentrating, and headaches [Baliatsas et al. 2016].

Our comparison of one-third octave band measurements when a flare was operating versus when a flare was not operating showed the influence of noise generated by the flares within the buildings on the campus, particularly across the frequencies 16 to 25 Hz. The levels across these frequencies in the administrative building were 12 to 17 dB higher when the flares were operating compared to when the flares were not operating. The frequency-specific or overall sound levels we measured are not known to cause adverse health effects. However, complaints of annoyance due to low frequency noise tend to be associated with an unbalanced noise spectrum [Broner 2010; Broner and Leventhall 1983], which can occur when sound levels in the low frequencies are higher relative to the sound levels in the higher frequencies.

One method for assessing the potential for the likelihood of annoyance complaints due to low frequency noise is a comparison of overall C-weighted to A-weighted sound pressure levels. C-weighting and A-weighting refer to different metrics for measuring and integrating noise across the frequency spectrum. Because humans do not perceive loudness equally across all frequencies and have diminished perception of loudness at low frequencies, A-weighted sound level measurements approximate equal loudness characteristics of human hearing for pure tones relative to a reference of 40 dB at 1,000 Hz [Earshen 2000]. C-weighting is a measure of noise across all frequencies, similar to linear weighting, except for slight attenuation at frequencies below 50 Hz and above 5,000 Hz. At frequencies above 500 Hz, A- and C-weighting are quite similar. Researchers have suggested that a C-A difference of 20 dB or more is indicative of an unbalanced noise spectrum and potential low frequency noise problems and low frequency noise annoyance complaints [Broner 2010; Broner and Leventhall 1983].

Our results showed that the C-A differences in the administrative building ranged from 17 to 38 dB (median: 29 dB). The C-A differences in the shelter ranged from 12 to 20 dB (median: 16 dB). These results indicate that annoyance may be more likely for occupants of the administrative building than for occupants of the men's shelter. During interviews, 89% of employees who reported experiencing unusual sounds or vibration in the administrative building stated they occurred before the February 2019 incident, whereas 27% of employees who reported experiencing unusual sounds or vibrations in the men's shelter stated they noticed them before the May 2019 incident. It is important to note that during our measurements, the administrative and men's shelter buildings were unoccupied. If these buildings had been fully occupied, it is highly likely that the sound levels, particularly in frequencies above 500 Hz, would have been higher due to the occurrence of conversation (which is generally in the 500 to 2,000 Hz range) and other daily activities. This would likely have the effect of diminishing the C-A differences.

In addition to our comparison of overall C-A differences suggesting that annoyance due to low frequency noise might be likely in the administrative building, we also compared our results to European guidelines for assessing low frequency noise and infrasound in indoor environments (Figure B3). We found that one-third octave band levels when a flare was in operation were below British guidelines (Note: The Swedish guidelines, which cover 31.5 to 200 Hz, are identical to the British guidelines). However, levels were above Polish guidelines at 20 Hz, 25 Hz, and 50–250 Hz. These findings provide additional support to the potential for annoyance from low frequency noise. Interestingly, at some of the low frequencies above 63 Hz we found that levels exceeded German, Dutch, and Polish guidelines, even when the flares were off. Contribution of low frequency noise from nearby city traffic could be a factor in these results.

Our measurements only provide sound level results and noise frequency characteristics during normal operating conditions of the flares at the time of our site visit. During the reported loud noise events, it is possible that the frequency characteristics of the noise may have been similar to those we measured, with the highest levels around 20 Hz and adjacent one-third octave band frequencies. However, the actual sound levels and frequency characteristics are unknown in the absence of measurements using proper instruments. Based on employees' descriptions and reported sensory experiences, sound levels were likely higher during those events than those we measured during the site visit.

Approximately half of the employees we interviewed reported symptoms that they thought were related to unusual sounds or vibrations. It is likely that different subsets of employees have different explanations for their symptoms. First, some employees might have developed symptoms during or after the February and May 2019 incidents, which were described as loud sounds or intense vibrations. Auditory symptoms, such as hearing loss, ear pain, tinnitus, and ear pressure, can occur after exposure to loud noise, such as after a concert. Vestibular symptoms after exposure to low frequency sound or infrasound are less commonly reported in the scientific literature. One study found exposure to noise at 5 Hz and 16 Hz at 95 dB for 5 minutes affected body sway, suggesting that infrasound might affect inner ear function and balance [Takigawa et al. 1988]. Superior semicircular canal dehiscence syndrome is a rare condition in which patients experience vertigo induced by sound or pressure. Patients also have other signs and symptoms such as nystagmus (abnormal eye movements), pulsatile tinnitus, and hearing internal body sounds. Superior semicircular canal dehiscence syndrome is caused by an abnormal thinning or opening in one of the bony canals of the inner ear. While the exact cause of this syndrome is unknown, those who discovered it believe it is congenital; exposure to sound or pressure has not been posited as a cause [Ward et al. 2017]. The interviews and medical records reviewed did not suggest that vestibular symptoms among employees were due to this condition.

Second, some symptoms reported by interviewed employees as predating the incident in their primary area are consistent with symptoms reported in studies about background low frequency noise, such as headache, fatigue, difficulties with concentration, vibrations in the body, and ear pressure in the absence of specific incidents [Pawlaczyk-Luszczynska et al. 2009; Waye 2011]. However, many of these symptoms are also common, nonspecific, and might have multiple causes. Third, some employees with auditory or vestibular symptoms had a plausible alternative explanation for their symptoms based on their medical history. Most employees did not undergo medical evaluation and medical records for some evaluated employees were not available, which might have led to missed opportunities to identify plausible alternative explanations.

Over half (57%) of the interviewed employees reported that they were uncomfortable with returning to work at the vacated campus. Their perceived risk and lack of willingness to return should be considered when the nonprofit organization and county are discussing whether to return to work at the vacated campus. Having employees return to work at a location that they perceive as unsafe may represent a breach of psychological contract, or the implicit agreement that the employer will value and care for the worker in exchange for good work [Morrison and Robinson 1997; Rousseau 1995]. Breach in psychological contract often results in employees feeling violated, and it diminishes trust in an organization. Further, such breaches in psychological contract are associated with undesirable organizational outcomes, such as increased turnover intentions and absenteeism, counterproductive behaviors, decreased willingness to go "above and beyond" one's role to benefit an organization, decreased job satisfaction, and decreased in-role performance [Shen et al. 2019; Zhao et al. 2007].

Limitations

It was not possible during our site visit to characterize sound levels or noise frequency characteristics that occurred at the time of the February and May 2019 incidents. Our measurements were done during normal flare operations and in campus buildings that were unoccupied because employees and shelter clients had been relocated, and no similar loud noise events occurred during the site visit. However, we were able to measure differences and estimate the effects of a methane flare being on and off without background noise. Employees' interview responses were based on self-report and occurred approximately 1–4 months after the incident, which may have resulted in decreased recall. In addition, the incidents might have influenced employees' perceptions of whether symptoms were related to unusual sounds or vibrations. Not all relevant medical records for employees who reported symptoms were available for review. Statistical tests might not have been able to detect significant differences due to the relatively small number of employees.

Conclusions

We found that the overall and one-third octave band noise frequency measurement results during the site visit were well below levels reported in the research literature as likely to cause adverse health effects. The operating flares generated noise primarily in the low frequencies, particularly across the frequencies of 16 to 25 Hz, which influenced frequency-specific sound levels in the nearby buildings. The relatively greater noise levels in low frequencies compared to levels in higher frequencies resulted in a spectrum imbalance that exceeded some European guidelines. This imbalance also increased the likelihood of noise-related annoyance concerns, particularly in the administrative building. Many employees reported symptoms that they thought were related to unusual sounds and vibrations at the workplace, but different explanations for symptoms among different employees were likely. Employees were concerned about communication issues surrounding the incidents, and over half of the employees reported that they were uncomfortable returning to work at the vacated campus.

Section C: Tables

Table C1. Low frequency noise and infrasound levels across one-third octave band frequencies 6.3 to 80 Hz (dB) while flares were operating

Measurement location	6.3 Hz	8.0 Hz	10.0 Hz	12.5 Hz	16.0 Hz	20.0 Hz	25.0 Hz	31.5 Hz	40.0 Hz	50.0 Hz	63.0 Hz	80.0 Hz	Overall sound pressure level
Admin bldg. Room 100	51.5	52.0	52.2	55.4	60.4	62.9	60.5	45.6	36.5	39.5	35.4	35.0	67.0
Admin bldg. Room 101	52.6	53.0	57.5	56.8	59.2	71.4	66.9	47.3	39.1	41.4	40.3	35.5	73.2
Admin bldg. Room 102	50.8	50.1	58.9	62.6	56.4	63.0	60.8	47.0	35.0	41.3	33.1	34.5	68.1
Admin bldg. Room 103	49.6	51.1	57.0	56.2	62.6	65.5	62.9	48.8	41.9	43.6	45.2	39.7	69.3
Admin bldg. Room 105	55.8	56.0	54.4	55.1	56.9	70.0	57.9	50.2	46.6	44.1	44.9	41.5	71.0
Admin bldg. Room 108	55.0	57.9	58.5	55.0	53.8	68.9	59.4	46.5	40.9	40.6	39.5	31.9	70.4
Admin bldg. Room 109	59.7	59.3	59.9	57.6	54.2	63.7	57.9	46.0	40.9	41.2	42.6	36.0	68.2
Admin bldg. Room 110	54.3	57.0	51.5	60.1	53.4	63.0	59.1	42.5	33.7	35.2	36.5	33.1	67.0
Admin bldg. Room 113	54.9	55.8	54.2	51.6	49.6	60.5	51.5	43.7	37.4	37.4	32.3	29.0	63.9
Admin bldg. Room 117	57.1	56.7	53.1	53.4	57.3	60.9	53.9	45.0	38.6	33.8	37.5	37.9	65.4
Admin bldg. Room 118	49.9	51.4	51.3	52.5	48.9	62.1	60.1	44.5	35.7	38.2	33.3	33.1	65.2
Admin bldg. Room 121	50.7	54.6	54.3	50.3	56.2	64.7	58.8	50.3	41.5	42.2	38.7	35.5	67.0
Admin bldg. Room 123	55.9	55.3	58.1	56.1	59.5	63.3	53.8	46.6	44.5	43.4	46.7	47.4	67.2
Shelter bldg. Main room	48.3	52.0	53.8	53.1	50.5	64.6	62.9	52.3	47.8	48.7	46.9	46.1	67.8
Shelter bldg. Socializing room	56.7	56.8	53.7	54.3	54.2	60.4	51.4	48.4	50.3	49.5	46.3	45.6	65.2
Shelter bldg. Check-in desk	52.0	52.2	52.1	53.2	59.5	63.2	60.7	51.6	48.3	47.1	43.3	41.6	67.1
Shelter bldg. Office area	54.0	58.5	60.8	58.2	56.7	65.6	58.4	48.6	44.8	38.4	40.7	36.0	68.9
Shelter bldg. Intake office	47.8	49.7	52.9	54.5	55.2	62.9	58.6	48.3	43.7	37.0	41.1	38.9	65.7
Parking lot - Location A	60.2	62.9	68.9	72.0	76.2	84.9	79.7	68.1	66.8	62.2	63.1	62.9	86.9
Parking lot - Location B	61.3	61.5	61.3	63.2	67.6	76.9	77.1	61.2	59.8	58.3	57.7	54.9	80.6
Parking lot - Location C	62.0	60.4	64.3	69.8	73.8	80.3	75.0	67.6	60.6	61.4	61.2	57.7	82.7
Parking lot - Location D	60.5	62.4	62.1	64.8	68.7	78.1	72.4	63.1	62.4	57.9	58.4	57.4	80.1
Grill area	53.4	55.0	57.8	60.4	64.8	75.8	70.7	60.2	61.2	56.9	57.1	56.1	77.7
Smoking hut	56.0	57.7	63.8	67.4	68.3	81.3	74.1	65.9	63.2	59.1	58.0	55.9	82.6
Blower #2 (6 ft from blower)	65.0	70.6	75.3	76.5	71.8	84.6	80.4	68.3	76.5	72.5	72.6	61.1	87.7
Flare #1 (10 ft from flare)	69.1	72.3	76.5	81.1	79.7	91.2	83.5	71.3	74.4	70.8	67.6	67.1	92.8
At flare control panel	63.2	68.1	74.5	80.2	82.4	94.2	87.7	76.5	74.7	66.6	66.4	53.1	95.6
City road behind shelter	70.4	69.3	71.6	69.4	67.3	71.5	66.2	66.6	65.1	68.1	80.3	71.5	83.0
City road across from public storage business	64.2	62.4	60.4	60.1	60.6	66.0	61.9	61.5	63.0	65.2	69.9	67.3	75.5
ACGIH ceiling limits	145 (frequency dependent)												150 (overall)

Table C2. C-weighted and A-weighted sound level measurement results and their differences in the administrative and shelter buildings

Measurement location	C-weighted sound level (dBC)	A-weighted sound level (dBA)	dBC-dBA difference (dB)
Admin bldg. Room 100	60.4	27.1	33.3
Admin bldg. Room 101	67.2	28.8	38.4
Admin bldg. Room 102	60.7	26.5	34.2
Admin bldg. Room 103	63.1	39.8	23.3
Admin bldg. Room 105	64.6	30.5	34.1
Admin bldg. Room 108	63.7	28.3	35.4
Admin bldg. Room 109	59.9	29.0	30.9
Admin bldg. Room 110	59.7	37.7	22
Admin bldg. Room 113	55.9	39.2	16.7
Admin bldg. Room 117	57.3	36.1	21.2
Admin bldg. Room 118	59.1	31.3	27.8
Admin bldg. Room 121	60.8	31.8	29
Admin bldg. Room 123	59.8	34.6	25.2
Shelter bldg. Main room	62.4	42.6	19.8
Shelter bldg. Socializing room	58.7	43.8	14.9
Shelter bldg. Check-in desk	61.4	45.2	16.2
Shelter bldg. Office area	61.9	45.6	16.3
Shelter bldg. Intake office	60.2	48.0	12.2

Table C3. Employee perceptions of how the loud noise situation was handled by the nonprofit organization and the county (n = 46)

Question	Nonprofit organization Number (%)			County Number (%)		
	Unsure	Yes	No	Unsure	Yes	No
Do you have concerns about how the situation was handled by the ____?	3 (7)	12 (26)	31 (67)	7 (15)	27 (59)	12 (26)
Are you satisfied with ____'s communication to employees about the situation?	1 (2)	35 (76)	10 (22)	14 (30)	4 (9)	28 (61)
Do you trust _____ to care for your health and safety at work?	0 (0)	42 (91)	4 (9)	4 (9)	15 (33)	27 (59)

Section D: References

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