State of California—Health and Human Services Agency
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Investigation of Geothermal Gases in the Burns Valley Neighborhood Clearlake, Lake County, California

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Background

In 2012, the Health Officer from Lake County requested assistance from the California Department of Public Health (CDPH), Division of Environmental and Occupational Disease Control, Emergency Preparedness Team (EPT) in addressing concerns related to geothermal gas venting at the Burns Valley Elementary School (BVES), Lake Family Resource Center and surrounding neighborhood in the City of Clearlake. In response, through a collaborative process with the county, CDPH/EPT conducted an investigation of geothermal gases in the Burns Valley neighborhood.

Geothermal venting of hydrogen sulfide (H_2S) and methane (CH_4) gases was detected in the Burns Valley neighborhood in previous investigations. Generally, past investigations were limited and focused in areas around a known vent located at the north end of Robinson Avenue and a few locations at the BVES (Figures 1-2). The purpose of this investigation was to identify areas of concern for vapor intrusion[1] and geothermal venting and to determine whether H_2S is a significant component of indoor air at BVES. The sampling investigation was limited in scope, focusing primarily on measuring H_2S and CH_4, and to a lesser extent carbon dioxide (CO_2), in the BVES and surrounding neighborhood.

Radon is also present in geothermal gases in Lake County. A radon survey conducted in Clearlake in the 1980s found an "anomalously high area" near the BVES [1]. It is our understanding that no radon sampling has been done in the school. CDPH staff contacted the State Radon Officer to inquire about radon data for Lake County. Radon was detected infrequently in historic indoor radon sampling conducted in various areas of the county. We were informed that these data are limited and more testing is needed before drawing any conclusions as to whether there is a low or high potential for radon migration into buildings in Lake County (Personal communication, Willy Jenkins, California Radon Officer, August 23, 2012). This investigation did not include radon testing and thus the question as to whether radon is migrating into indoor air remains unanswered.

[1] Vapor intrusion is the migration of volatile chemicals from the subsurface into overlying buildings.

Summary of Health Effects

While acute health effects associated with exposure to H_2S have been relatively well described, much less is known about the health effects of intermittent and chronic low-level exposures to H_2S, such as that experienced by residents of communities located near sources of H_2S. Exposure to very high concentrations ($\geq$500,000 parts per billion – ppb) of H_2S, even briefly, can result in cessation of breathing, pulmonary edema (fluid filling the lungs), loss of consciousness, and death [2]. Exposure to relatively low levels (~450 ppb) of H_2S for extended periods of time can cause nasal lesions of the olfactory mucosa. In other studies of community members who live near pulp and paper mills, long-term exposure to low levels (mean concentration 2.9 ppb, maximum concentration 40 ppb) of H_2S has been shown to be associated with headaches and eye, nasal, and respiratory symptoms, but data are relatively limited [2]. Odor-related health complaints can occur at concentrations as low as 8 ppb [3].

CH_4 is flammable and explosive and it causes asphyxiation. For a combustible gas such as CH_4 to flash or combust, the presence of CH_4 and oxygen must exist in certain proportions, along with an ignition source. The lowest concentration of a combustible gas or vapor necessary to support its combustion in air is defined as the Lower Explosive Limit (LEL). Below this level, the mixture is too “lean” to burn. The highest concentration of a gas or vapor that will burn in air is defined as the Upper Explosive Limit (UEL). Above this level, the mixture is too “rich” to burn. The range between the LEL and UEL is known as the flammable range.

CH_4 poses a flammable and explosive risk at concentrations between 5% LEL and 15% UEL. As a point of reference, the Department of Toxic Substances Control recommends mitigative measures at schools if concentrations of CH_4 exceed 10% LEL under the building [4].

CO_2 displaces oxygen and thus poses an asphyxiation hazard. As CO_2 levels increase, people start to experience CO_2 intoxication, which may progress to CO_2 poisoning and possibly death. CO_2 intoxication and poisoning produce a variety of effects including, loss of judgment, muscle twitching, headache, nausea, increased heart rate and blood pressure, difficulty breathing, and unconsciousness [5].

Radon is a naturally occurring radioactive, odorless gas. Radon is the second leading cause of lung cancer after smoking [6].

Methods

In June and July 2012, CDPH conducted an investigation at the BVES and in the surrounding neighborhood (Figure 1). Three different types of environmental sampling methods were utilized for the investigation: direct ambient air and indoor air measurements using hand-held instruments, passive indoor air sampling, and soil vapor (gas) sampling.

Ambient Air Measurements

In June 2012, 349 measurements of H_2S and CH_4 were taken throughout the Burns Valley neighborhood and at the BVES. Under the guidance of CDPH staff, a systematic survey of the area was undertaken by a student from the University of California, Berkeley, using a Jerome hydrogen sulfide analyzer and an Eagle combustible gas meter. The Eagle displays measurements of CH_4 in % LEL. In an effort to determine if gases are diffusing from the sub-surface, measurements were taken at approximately 3-6 inches above ground surface, child and adult breathing zones (~30 and 60 inches above ground surface), and in confined spaces, such as water meter vaults. The water meter vaults are a better indicator for the presence of soil gases and the possibility of soil gas migration from the subsurface since the vaults are not affected by wind and weather and gases can therefore build up. Multiple measurements were collected at each location over the course of a week. Measurements collected in the surrounding neighborhood were all taken in the public right-of-way. Sampling locations are provided in Figure 3.

Soil Gas Migration: Soil vapors (gases) migrate into buildings by both diffusion and advection. Diffusion is the mechanism by which soil gas moves from high concentration to low concentration due to a concentration gradient. Advection is the transport mechanism by which soil gas moves due to differences in pressure. Pressure gradients are induced by convection (temperature changes in soil), mechanical equipment in the structure, heating appliances, air handlers and return air ductwork, fireplaces, and weather (changes in barometric pressure, wind, rain). Advective transport is likely to be the most significant in the area very close to a basement or a foundation; soil gas velocities decrease rapidly with increasing distance from the structure. The rate of movement of the vapors into the building is difficult to quantify and dependent on a number of factors (i.e. soil type, chemical properties, building design, and the pressure differential) [7]. Most commonly, vapor intrusion assessments of volatile organic compound contaminant plumes (i.e. chlorinated solvents and petroleum hydrocarbons) involve a known fixed mass of the contaminants, and their spread and concentration can be estimated. In the case of H_2S or CH_4 of volcanic origin there is no known fixed mass at the source. This creates additional barriers in understanding and estimating the concentration and lateral extent of these gases in the subsurface.

Indoor Air Sampling

Indoor air sampling of H_2S was conducted by CDPH in the Lake Family Resource Center and in 26 rooms at the BVES, including classrooms, library, cafeteria, offices, computer lab, and pre-school, using Radiello passive samplers. A total of 31 samples and four duplicates were collected and analyzed. Analyses were conducted by Inter-Mountain Labs.

The Radiello passive samplers were placed for a two-week period, in rooms with both slab-on-grade and raised foundations in BVES. Lake Family Resource Center has a slab-on-grade foundation only. Slab-on-grade foundations typically are at greater risk for vapor intrusion into indoor air than raised foundations.

Ninety three CO_2 measurements were taken in the BVES rooms mentioned above, using direct-reading instrumentation. Four measurements of CH_4 were taken in the basement at the school.

Soil Vapor Sampling

In July 2012, CDPH contracted with EBA Engineering to conduct a soil vapor study in the Burns Valley neighborhood. The purpose of the study was to characterize the levels of H_2S and CH_4 in soil gas beneath the surface in the neighborhood. Soil gas samples were collected at 16 locations from a depth of three feet below the ground surface (Figure 4).

Results

A summary of the results from point measurements collected in the neighborhood and at BVES is provided in Table 1.

Point Measurements (Ambient Air and Confined Spaces/Water Vaults)

The highest levels of H_2S were measured in a hole in the slab of a demolished house on Division Street and inside the base of the stop sign pole at the corner of Olympic Drive and Villa Way (Table 1). A rotten egg odor consistent with H_2S was prevalent in this area. H_2S in ambient air at 30” and 60” above ground did not exceed the California Ambient Air Quality Standard (1-hour) of 30 ppb at any location.

CH_4 levels greater than ≥5% LEL were measured in samples collected from water meter vaults and other confined spaces at the following locations: Robinson Avenue, Uhl Avenue, Evans Avenue, Thomas Avenue, Olive Street, Pine Street, and Olympic Drive. (Figure 3, Table 1). Of particular concern is the presence of CH_4 inside the base of the stop sign on the corner of Olympic Drive and Villa Way, where levels exceed 100% LEL. CH_4 was not detected in any ambient air measurements at any location.

Data generated from direct reading instruments (Jerome H_2S analyzer and Eagle gas meter) have limited interpretive value and should not be used to draw definitive conclusions on the magnitude of impact that geothermal gases may be having on the neighborhood. These data combined with the soil gas data provide a better understanding of the areas where subsurface gases may be of greatest concern.

Indoor Air Sampling

Burns Valley Elementary School

H_2S was detected in roughly half of the Radiello samples at very low concentrations ranging between 0.1 and 0.2 ppb. These values are lower than levels measured outdoors at the school (<1 ppb to 4 ppb) [8].

CO_2 was measured on three days in rooms throughout the BVES. For the majority of the rooms sampled, CO_2 levels were in a range typical for buildings having adequate ventilation. Levels greater than 1,000 parts per million volume (ppm)[2] indicating the need for increased ventilation were measured in the basement, Room 12, Room 14 and in the "old library", with average concentrations of 3,027 ppm, 2,504 ppm, 1,208 ppm and 1,166 ppm, respectively.

CH_4 was measured in the basement at BVES on one day at 0.2% LEL. While CH_4 at this level is not considered flammable or explosive, it suggests the possibility of vapor intrusion since there were no obvious sources of CH_4 in the basement at that time.

Lake Family Resource Center

H_2S was sampled in the Lake Family Resource Center using Radiello passive samplers. Radiellos were placed in three rooms, for a two-week time period. H_2S was measured at

[2] American Society of Heating, Refrigeration and Air Conditioning Engineers: guideline value (1,000 ppm CO_2) indicating the need for increased ventilation.

42.2 ppb, 51.6 ppb, and 58.5 ppb. These levels are consistent with point measurements taken in past sampling efforts and confirm that there is vapor intrusion of H_2S into indoor air at the Lake Family Resource Center.

CDPH compared these levels with the Agency for Toxic Substances and Disease Registry's Intermediate[3] Minimal Risk Level (MRL) of 20 ppb and the Office of Environmental Health Hazard Assessment's Reference Exposure Level (REL) of 8 ppb, for chronic exposure. The level of H_2S present in indoor air at the Lake Family Resource Center exceeds health-based comparison values for intermediate and chronic exposure.

Soil Vapor Sampling

Soil vapor sampling results revealed the presence of H_2S in the subsurface throughout the entire study area, with concentrations ranging from 2 ppb – > 50,000 ppb. The highest levels were seen on Robinson Avenue (> 50,000 ppb), Evans Avenue (15,000 ppb), and in the playfield adjacent to Pine Street (11,000 ppb).

CH_4 was also present throughout the neighborhood with levels exceeding the LEL (≥ 5%) at a number of locations (Figure 4). A comparison of these data with point measurements collected in water vaults correlate relatively well, showing attenuation of H_2S and CH_4 as it migrates and diffuses from the subsurface. CH_4 levels posing a potential explosive risk (≥ 5% LEL) were measured at a number of locations in samples collected from water meter vaults or other confined spaces, indicating the need for public health outreach in the Burns Valley neighborhood, by Lake County (Figure 3, Table 1).

Conclusions

BVES

On the basis of limited data, it does not appear that H_2S is migrating into indoor air in the BVES at levels of health concern. Additional sampling during the winter months would be needed to determine if the movement of subsurface gases is affected by seasonal variation.

CO_2 levels measured in Room 12, Room 14, "old library", and in the basement exceed 1,000 ppm. Staff noted a hole filled with water in the basement floor which was covered

[3] Intermediate MRL represents exposure durations of 14-364 days.

by a piece of wood. The unsealed hole may be providing a conduit for CO_2 migration into the basement. It is the possible that CO_2 may be migrating indoors from the subsurface (vapor intrusion), particularly in the basement. Prolonged exposure to CO_2 at the levels measured during this investigation may result in headache, fatigue, eye and throat irritation.

The CH_4 level measured in the basement is below the LEL of 5%. We would not expect CH_4 to be present in indoor air in the basement without a source. Thus, it is possible that CH_4 is migrating into the basement through the hole in the floor or other cracks and/or conduits.

Burns Valley Neighborhood and Olympic Drive at Villa Way

Ambient air measurements and soil vapor data show the presence of H_2S and CH_4 in the subsurface throughout the investigation area. The highest levels of H_2S were measured at Robinson Avenue, Evans Avenue, the corner of Olympic Drive and Villa Way, and in the play field west of Pine Street. CH_4 was measured at potentially explosive levels on Olive Street, Evans Avenue, Robinson Avenue, in the play field west of Pine Street, and at the corner of Olympic Drive and Villa Way.

Indoor air data collected from the Lake Family Resource Center indicates the presence of H_2S in indoor air at levels exceeding health-based comparison values. Since the facility is closed and no longer occupied, there is no current threat to public health.

Recommendations

BVES

- Increase ventilation in Room 12, Room 14, “old library”, and in the basement to reduce and maintain CO_2 at levels below 1,000 ppm. In addition to increasing ventilation in the aforementioned rooms, seal the hole in the basement floor as it may be providing a conduit for CO_2 and CH_4 migration into the basement.

- Periodic monitoring throughout the year of CO_2 and CH_4 should be conducted in the basement to ensure these gases are not building up to unsafe levels.

- Radon sampling should be conducted in the school, given the potential health risks related to radon exposure.

Lake County Environmental Health Department

- Community members living in the Burns Valley neighborhood should be notified by the county and informed of the findings of this investigation and the hazards associated with H_2S and CH_4, including information about potential construction and/or excavation related hazards.

- The county should increase awareness about radon migration into indoor air and encourage residents of the county to perform radon testing in their homes.

City of Clearlake Department of Public Works

- The City of Clearlake should consult with a professional who has expertise in construction activities in CH_4 environments before excavating in areas where CH_4 has been measured at potentially explosive levels, to ensure worker safety and protection of public health. In addition, actions should be taken to reduce the explosive risk posed by CH_4 venting from the stop sign pole on the corner of Olympic Drive and Villa Way. Employees who read meters in the Burns Valley neighborhood should be alerted to potential hazards associated with CH_4, and instructed not to smoke when in the vicinity of or entering water meter vaults.

References

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8. Lake County Air Quality Management District. Clearlake hydrogen sulfide real time air monitoring September 2011 – May 2012.

Figures and Tables

Figure 1. Investigation Boundary, Burns Valley Neighborhood

☐= Approximate boundary of previous sampling events

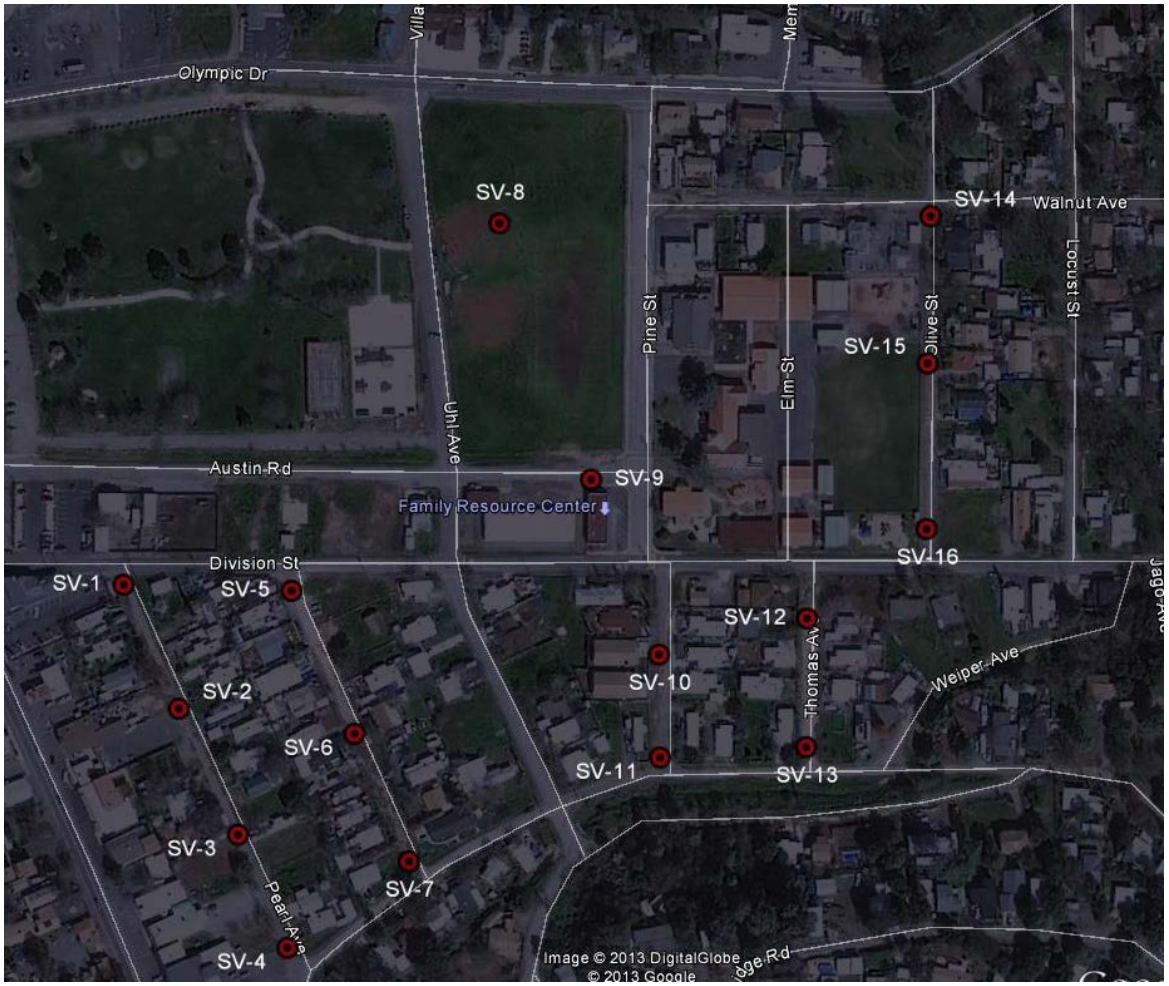
☐=Approximate boundary of CDPH investigation

Figure2.Approximate Location of Known Geothermal Vents in the Burns Valley Neighborhood

Data source: Ecology and the Environment, April 2011.

Figure 3.Sampling Locations and Average Ground Level Concentrations of Hydrogen Sulfide and Methane Measured in the Burns Valley Neighborhood Between June 25-29, 2012

Figure 4. Soil Vapor Sampling Locations and Measured Hydrogen Sulfide and Methane Levels in the Burns Valley Neighborhood



Legend

SV-16: soil vapor probe

H_2S levels (ppb)

SV-1:	3
SV-2:	3
SV-3:	7
SV-4:	10
SV-5:	>50,000
SV6:	29
SV-7:	10
SV-8:	11,000
SV-9:	21
SV-10:	15,000
SV-11:	2,700
SV-12:	2
SV-13	:2
SV-14:	2
SV-15:	3
SV-16:	3

CH_4 levels (%LEL)

SV-1:	0
SV-2:	1
SV-3:	1
SV-4:	1
SV-5:	>100
SV6:	1
SV-7:	0
SV-8:	>100
SV-9:	36
SV-10:	>100
SV-11:	65
SV-12:	1
SV-13:	3
SV-14:	1
SV-15:	65

Table 1. Point Measurements of Hydrogen Sulfide and Methane, Burns Valley Elementary School and Neighborhood June 25 – June 29, 2012

Location	Range of H_2S Levels (ppb)	Location of Max H_2S Level (ppb)	Range of CH_4 Levels (%LEL)	Location of Max CH_4 Level (%LEL)
BVES: basement	ND	ND	ND – 0.2	basement
BVES: irrigation well, water meter near well	1 – 910	1-2 inches (bgs) irrigation well	ND – >100	irrigation well
Lake Family Resource Center	420	indoors	1.6	indoors
Austin Road: corroded fence post along Haverty Field	1 – 4	F2 6" (ags)	ND	ND
Division Street	4,000 – 100,000	F7 under slab of demolished house	>100	F7 under slab of demolished house
Olympic Drive at Villa Way	2,000 – 22,000	F1 1" (bgs) at stop sign	>100	F1 1" (bgs) at stop sign
Pearl Avenue	ND – 2	P1, P2, P3, P4, P7, P8, P9, P10, P15, P16	1 – 10	P5
Robinson Avenue	ND – 260	R4 6" (ags)	ND – 45	R3 (water meter vault)
Uhl Avenue	ND – 32	U3 (water meter vault)	ND – 30	U6
Evans Avenue	1 – 45	E3 (water meter vault)	ND – 20	E3 (water meter vault)
Thomas Avenue	ND – 3	T1	ND	ND
Pine Street	ND – 47	Pi4	ND	ND
Olive Street	ND – 4	O4	ND – >100	O4 (water meter vault)

Table 1. Point Measurements of Hydrogen Sulfide and Methane, Burns Valley Elementary School and Neighborhood June 25 – June 29, 2012

Location	Range of H_2S Levels (ppb)	Location of Max H_2S Level (ppb)	Range of CH_4 Levels (%LEL)	Location of Max CH_4 Level (%LEL)
Locust Street	ND – 4	L13	ND	ND

Refer to Figures 2-3 for location of sampling points.

Note: BVES = Burns Valley Elementary School; ppb = parts per billion; LEL = lower explosive limit; (bgs) = below ground surface; (ags) = above ground surface; ND = not detected