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INDOOR CARBON DIOXIDE LOADING FOLLOWING A SIMULATED CARBON DIOXIDE PIPELINE RELEASE

Sponsored by: American Petroleum Institute (API), Denbury Inc., E3 Environmental

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Executive Summary

Denbury, Inc. (Denbury) and American Petroleum Institute (API) requested CTEH, LLC (CTEH) to design and conduct a carbon dioxide (CO_2) exposure simulation study. The purpose of the study was to provide data to determine whether shelter-in-place (SIP), versus mandatory evacuation, is a viable option for protecting residents in proximity to a catastrophic CO_2 release from a pipeline or associated infrastructure. A Denbury CO_2 pipeline pump station served as the study site. Two towable camper trailers representing residential structures were placed inside a large, sealed tent into which CO_2 from the pump station pipeline was manually introduced. Thus, the overall scope of this study was to identify the magnitude and repeatability of ratios of indoor-to-outdoor CO_2 and O_2 concentrations in camper trailers after a controlled release from a CO_2 pipeline over a range of toxicologically relevant concentrations.

Real-time instruments that measured and transmitted airborne CO_2 and O_2 concentrations were deployed inside the tent (representing a simulated outdoor area), inside the trailers (representing a residential indoor area). Instruments also measured temperature, relative humidity, and barometric pressure inside and outside of the trailers. A test for indoor CO_2 loading due to human occupants occurred for one trailer. Four study participants occupied one trailer for approximately 90 minutes, resulting in a maximum breathing zone CO_2 concentration of approximately 3,800 ppm. A mathematical model was fitted to measurements of CO_2 leakage from both trailers to calculate air change rates of approximately 0.5 and 0.2 per hour, which would represent relatively tightly sealed residential structures.

The novel CO_2 test system was put through iterative trials to optimize the ability to introduce and control set CO_2 concentrations inside the tent using various CO_2 valve flow rates, ventilation fan placement, and CO_2 supply piping configurations. Four tests were run for approximately four hours to establish relatively constant in-tent CO_2 concentrations of 10,000 ppm, 20,000 ppm, 30,000 ppm, and 40,000 ppm at breathing zone height. A fifth test was attempted to rapidly fill the tent with CO_2 and decrease O_2 concentrations to 15% or less. Indoor and outdoor CO_2 and O_2 concentrations were measured and data logged throughout the test period.

Indoor breathing zone and floor level CO_2 concentrations increased similarly for the 10,000 ppm and 20,000 ppm tests, reaching maximums of less than 10,000 ppm. Floor level and breathing zone CO_2 concentrations in the 30,000 ppm and 40,000 ppm tests increased at different rates, with maximum breathing zone CO_2 concentrations of less than 30,000 ppm. In all 10,000 to 40,000 ppm tests, the indoor breathing zone CO_2 concentrations at two hours were below 5,000 ppm. The O_2 concentration never decreased below 19.5% throughout the 10,000 to 40,000 ppm tests. The ratio of indoor-to-outdoor breathing zone CO_2 concentrations over time increased approximately linearly for the 10,000 ppm and 20,000 ppm tests, but not for the 30,000 ppm and 40,000 ppm tests. The fifth test was aborted early due to a leak in the tent enclosure. However, the rapid increase of the tent CO_2 concentration to approximately 90,000 ppm resulted in a decrease of O_2 to 18.2% within the tent. The minimum indoor O_2 concentration for the 50,000 ppm test was 19.3 % and occurred in the breathing zone of trailer 2 which had windows open during the test.

The study and resulting data described herein present a novel approach to investigate potential residential SIP exposures over time and across various outdoor CO_2 plume densities. The results indicate that SIP for several hours provide reduced CO_2 exposure relative to outdoor concentrations, with breathing zone concentrations remaining below 5,000 ppm for at least two hours into a simulated incident.

Table of Contents

List of Tables

List of Figures

List of Equations

1.0 Introduction and Background

Denbury, Inc. (Denbury) and American Petroleum Institute (API) asked CTEH, LLC (CTEH) to design and conduct a carbon dioxide (CO_2) exposure simulation study. The purpose of the study was to provide data to determine shelter-in-place (SIP), versus mandatory evacuation, is a viable option for protecting residents in proximity to a catastrophic CO_2 release from a pipeline or associated infrastructure. Specifically, CTEH was asked to develop data to help first responders better determine whether evacuation or SIP orders represent the safer of two actions for the public in the event of a major CO_2 release event.

The United States Department of Transportation's Pipeline and Hazardous Materials Safety Administration (PHMSA) Emergency Response Guidebook (ERG)* provides first responders with guidance on best practices, based on scientific evidence, to respond to hazmat transportation accidents within the first 30 minutes of the incident. Current ERG guidance recommends isolation of the spill or leak area for at least 100 m (330 ft) in all directions in the event of a small liquid spill (less than 55 US gallons, approximately 208 liters) and evacuation for at least 100 m (330 ft) in the initial downwind direction for a large spill of inert gases.(USDOT, 2020) However, evacuation orders may introduce other public safety hazards, both physical, logistical, and psychological, especially for people with limited bodily mobility, visual impairment, unaccompanied children, those who may not receive evacuation notices in a timely manner, or those without access to transportation. Physical barriers may present hazards for evacuation such as stairs, road closures, or limited visibility in the case of dense fog. Additionally, changes in weather patterns, incident conditions, and delays in communication, may result in inaccurate or outdated evacuation instructions causing residents to evacuate into, instead of away from, hazardous conditions. The lack of a suitable communicated evacuation route may also leave certain residents without a sufficient path of egress. Therefore, the need for safe SIP options, based on scientifically tested exposure scenarios, is paramount.

The overall scope of this study was to identify the magnitude and repeatability of ratios of indoor-to-outdoor CO_2 and O_2 concentrations in camper trailers placed inside if a sealed tent enclosures during and after controlled CO_2 pipeline stream releases over a range of toxicologically relevant concentrations. Secondary study goals were to identify durations of time in which indoor levels of CO_2 and O_2 remain at levels below levels identified by scientific bodies as health hazardous, compared to outdoor levels. The data from this study may be used to inform decisions to either evacuate members of the public or have them SIP during and following a CO_2 pipeline release in a residential community. Specific study aims included the determination of infiltration and exfiltration rates of CO_2 into a residential dwelling and whether these rates are concentration dependent.

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* *ERG. 2020. Guide 120 Gases – Inert. United States Department of Transportation. Pipeline and Hazardous Materials Safety Administration.*

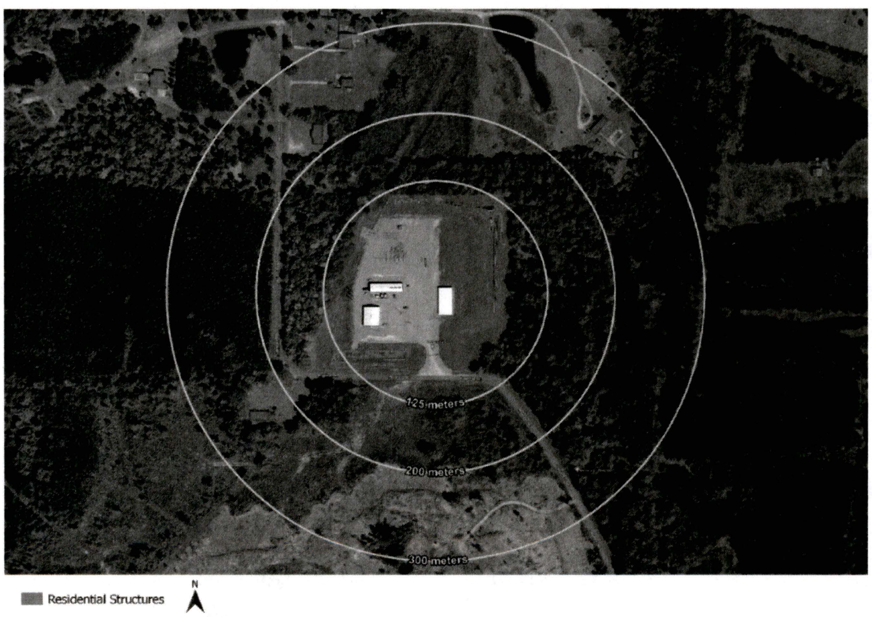
2.0 Materials and Methods

This report describes the results from a simulation study conducted on December 6 to 8, 2022 in Brookhaven, Mississippi. The study was conducted under the safety supervision of a Denbury Site Safety Officer working in conjunction with a CTEH Certified Industrial Hygienist and Certified Safety Professional serving as the Study Safety Officer. Details of the study hazards, safety measures, and Health and Safety Plan (HASP) may be found in Appendix A.

2.1 Study Area

The study was conducted at the Denbury CO_2 pipeline pump station located at 332 Rogers Lane Northeast, Brookhaven, Mississippi. Use of this location allowed for controlled release of pipelined CO_2 within a secure, fenced-enclosed area (Figure 2.1). The study tent enclosure, described below, was erected in a large gravel space approximately 50 meters from the nearest on-site building.

Figure 2.1 Brookhaven Study Location



2.2 Tent Enclosure Design

The CO2 exposures were performed inside a tent enclosure comprised of two large party-style tents sealed together. Each of the two connected tents were 40 ft long x 20 ft wide x 8 ft high with 13 ft roof peaks, providing a total exposure volume of 16,800 ft3. The tents were constructed of a metal frame with a fire-retardant exterior material (e.g., fire-retardant polyethylene sheeting). The enclosure was constructed and sufficiently sealed with polyethylene sheeting taped to the exterior tent walls to reduce gas leakage as well as the time required to raise the CO2 concentration within the enclosure to test-specific target levels. Weighted sandbags were used to hold the bottom of the tent close to the ground surface and tape was used on the exterior walls to seal pinpoint holes. Six electric fans were placed at each of the four corners and the North and South sides of centerline within the tent enclosure to facilitate rapid mixing of the CO_2 to a uniform concentration.

The tent enclosure was designed to facilitate ventilation of the interior between each test using fans to reduce interior CO_2 and H_2S concentrations to an amount safe for entry into the enclosure and diminish test reset time. Resealable openings on opposite sides of the tent enclosure were opened during clearance phases of the study and electric and pneumatic fan ventilation was used between tests to return concentrations of CO_2 within the enclosure and trailers to ambient (approximately 400 ppm).

2.3 Camping Trailer Designs

Two unmodified camping trailers (2018 Keystone Hideout and a Keystone Bullet Ultra Lite) were placed inside the tent enclosure approximately 6 feet apart. The trailers served as surrogates for residential structures within which occupants would SIP in the event of a nearby CO_2 release. Trailer configurations inside the tent enclosure and dimensions are shown in **Error! Reference source not found.** and **Error! Reference source not found.**. The trailer frames were approximately 27 inches to 29 inches above the ground surface which is similar to the height above ground surface of a typical manufactured home. According to the U.S. Department of Housing and Urban Development, ground level must be at least 18 inches below the wood floor joists (USDHUD, 2007, Chapter 5).

Figure 2.2 Trailer Positions within Tent Enclosure (Top View)

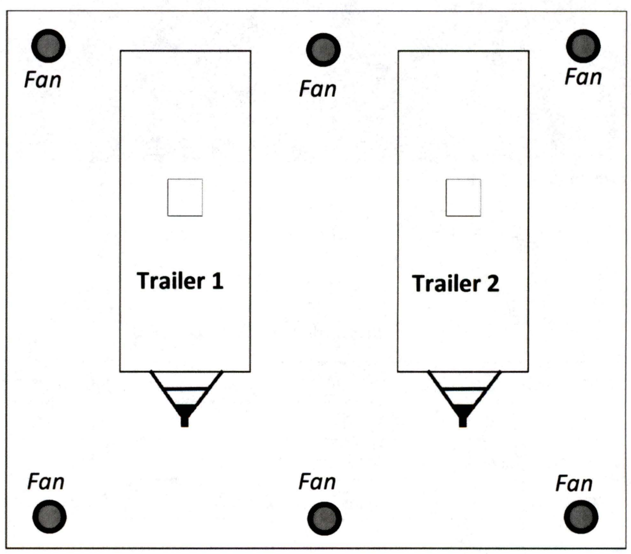


Table 2.1 Tailer Dimensions

	Space	Length (ft)	Width (ft)	Height (ft)	Volume (ft^3)
Trailer 1	Main interior	26	7.7	6.4	1,281
	Slide-out section	11	3.2	5.6	197
Trailer 2	Main interior	26	7.8	6.4	1,298

Slide-out section	12	3.0	5.6	202

In a typical home, there are many differences in structural design, building materials, and materials quality that may impact the permeability of indoor and outdoor air. Camper trailers were selected for use in this study as surrogates for residential dwellings due to their mobility and ability to fit within the tent enclosure. The passive air turnover rate for the camper trailers calculated in Section 2.9 may be used to compare findings presented herein with single story building structures with different air turnover rates.

2.4 CO_2 Source Description

A gas mixture (dry CO_2) provided by Denbury was supplied to a sealed tent enclosure via pipe from a manually actuated manifold (Figure 2.3). The supply of CO_2 (

Table 2.2) was introduced to the tent using a choke and valve manifold capable of providing a flowrate between 69 to 12,222 cubic feet per minute (cfm). A certificate of analysis for the gas mixture was provided by Denbury and is shown in Appendix D.

Figure 2.3 CO_2 Manifold and Pipe Inlet to Tent Enclosure.

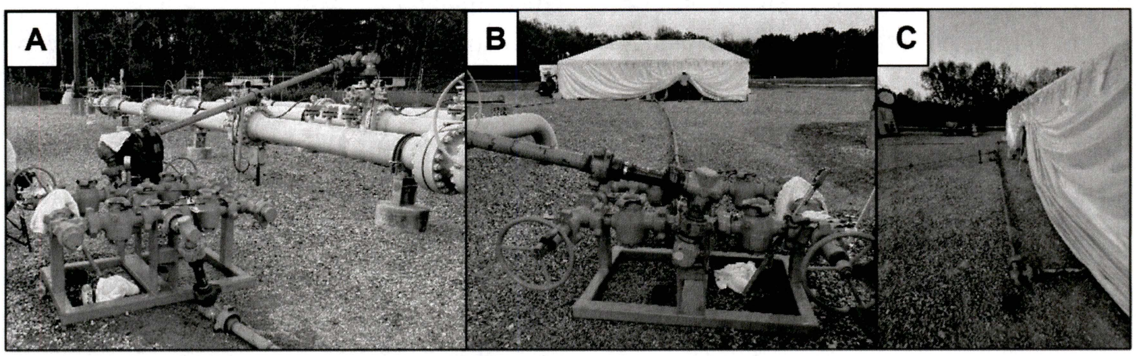


Photo A: CO_2 manifold showing tie-in to primary CO2 pipeline.
Photo B: CO_2 manifold showing leading pipeline to tent enclosure.
Photo C: Pipeline inlet to the front and back of the trailers inside of the tent enclosure.

Table 2.2 Supplied Gas Mixture

Carbon Dioxide (CO_2)	≥ 99.3%	≥ 993,000 ppm
Hydrogen Sulfide (H_2S)	< 0.001 %	< 10 ppm
Methane (CH_4)	0.30%	3,000 ppm
Nitrogen (N_2)	0.30%	3,000 ppm

The gas supply manifold was connected to the enclosure using ground-level two-inch carbon steel piping. Outside the tent enclosure, the supply pipe was bifurcated at ground level and ran parallel gas streams to opposite sides of the tent perpendicular to the trailers. Two-inch diameter riser pipes up to heights of approximately 3 ft were installed into the supply piping perpendicular to pipe length such that CO_2 gas exited vertically toward the tent ceiling. The gas supply at the supply manifold was turned on and off as needed to maintain, as much as practicable, a CO_2 concentration within ±500 ppm of each test's target

CO_2 concentration at the breathing zone height within the tent. The ability to control test target levels was determined prior to running each study test. To allow for safe emergency shutoff, the valve was positioned in a location where it could be safely operated during study events.

Figure 2.4. CO_2 Pipe Outlets Inside of the Tent Enclosure During Setup.

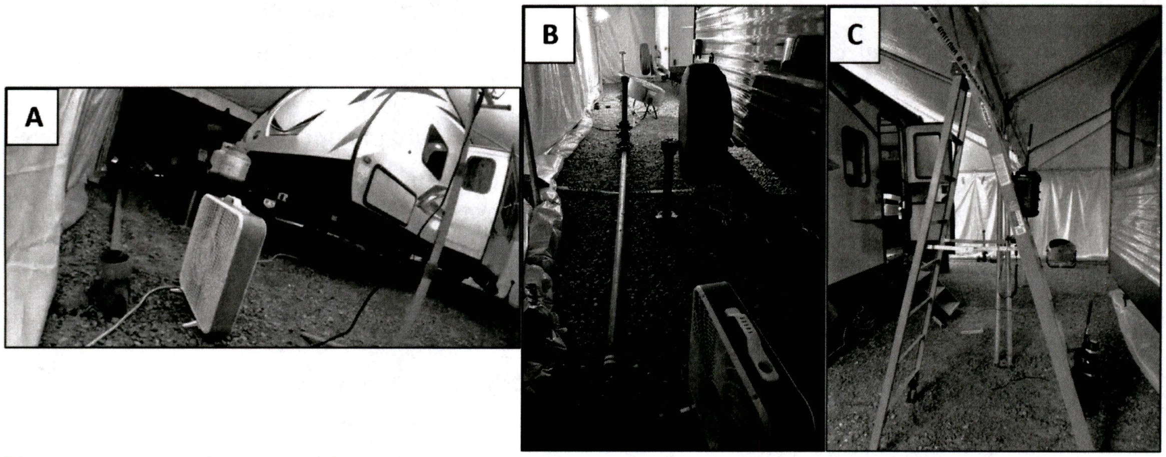


Photo A: CO_2 pipe outlets near the front (South) of the trailers.
Photo B: CO_2 pipe outlets near the front (North) of the trailers.
Photo C: Air monitoring station in between the two trailers at ground level and in the breathing zone.

2.5 Monitoring Equipment and Placement

2.5.1 Remote Telemetering/Datalogging Equipment

Data was logged directly to equipment or transmitted to remote machines approximately one to twenty second intervals. All remote data telemetering was transmitted over radio channels.

Remote telemetering and datalogging equipment consisted of Honeywell AreaRAE Pros and/or Honeywell MultiRAE Pros equipped with nondispersive infrared (NDIR)* CO_2 and O_2 electrochemical sensors were placed within the tent and trailers. For site safety monitoring purposes, an AreaRAE was located halfway between the enclosure exterior and the staging area and four AreaRAEs with sensors for VOC, CO_2, O_2, H_2S and %LEL measurement were located at the property fence line corners.

Sensors for The CO_2 sensors had a measuring range of 0 ppm to 50,000 ppm. Each morning prior to study commencement and between each study scenario, a two-point calibration was conducted for each chemical sensor using calibration gases. Carbon dioxide sensors were calibrated with 5,000 ppm CO_2 and O_2 sensors were calibrated with 20.9% O_2.

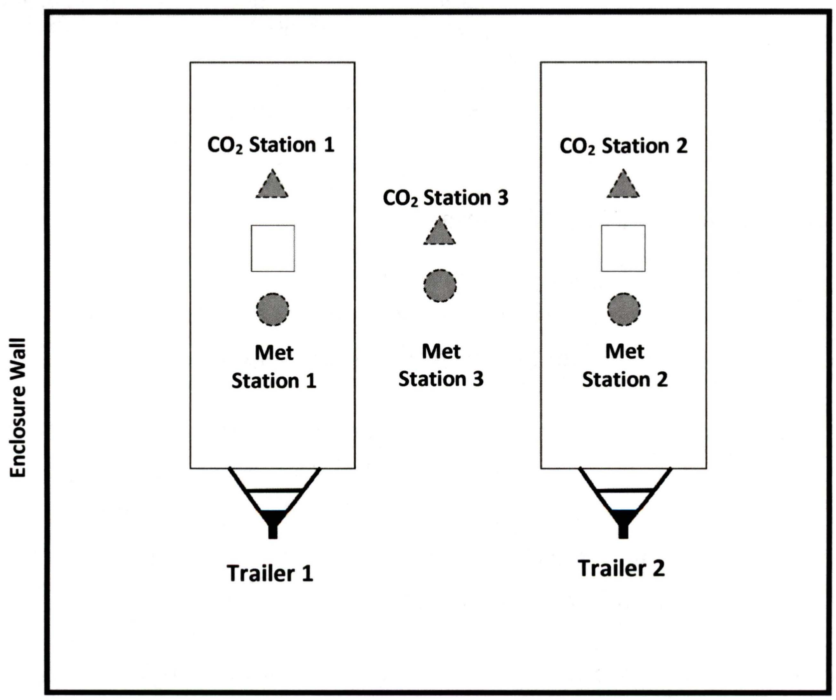
Temperature, relative humidity, and atmospheric pressure were recorded using AreaRAE meteorological sensors as these parameters had the potential to impact the behavior of the gas in the tent enclosure,

** Honeywell NDIR carbon dioxide (CO_2) Non-Dispersive Infrared (NDIR) sensor part number C03-0961-000. See Tech Notes TN-114 and TN-169 in in Appendix E for additional sensor information.*

including infiltration into the trailers and mixing within the trailers. These parameters were measured at one location (denoted in **Error! Reference source not found.** and Figure 2.6 as a Met station) within each trailer and at one location within the tent enclosure.

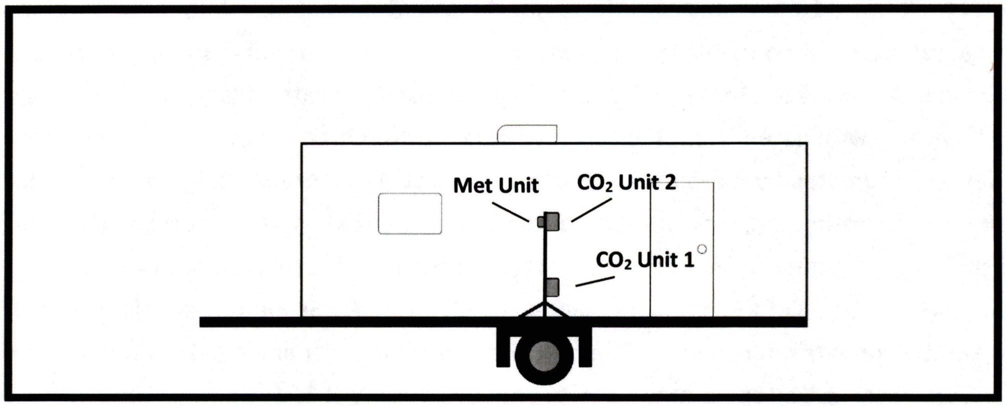
For the exposure simulation tests, gas monitoring was conducted at four monitoring stations: one station inside of each trailer, one station on each trailer exterior roof, and one station placed between the two trailers (**Error! Reference source not found.** and Figure 2.6). For interior trailer monitoring stations, one instrument was placed at a height of approximately 2-feet above ground/floor level (to simulate infant/toddler exposures) and one instrument at a breathing zone height of approximately 63-inches to 69-inches above ground/floor level (to simulate standing adult exposures). The monitoring station located between the trailers within the tent enclosure had one instrument placed at similar ground and breathing zone heights. Data from monitoring stations inside the tent and on trailer roofs were used to inform mixing of the CO_2 atmosphere as each test progressed.

Figure 2.5 Remote/Data Logging Monitoring Locations (Top View)



Met stations consist of instruments capable of measuring temperature, relative humidity, and ambient pressure.

Figure 2.6 Trailer Interior Remote Data/Logging Monitoring Locations (Side View)



Met stations consist of instruments capable of measuring temperature, relative humidity, and ambient pressure. Monitoring stations within both trailers and the enclosure were deployed.

2.6 Test System Performance Optimization

The tent enclosure /CO_2 pipeline exposure system used in this study was a novel experimental system. Therefore, several trials were conducted to optimize the system so that the in-tent CO_2 concentration was as uniform as possible from ground to roof, the desired target CO_2 level could be rapidly achieved and maintained over a 4-hour test period, and the tent and trailers could be safely and rapidly ventilated with fresh air at the conclusion of each test iteration. The following steps were performed to optimize the test system:

1. Background CO_2 and O_2 levels were monitored for 15 minutes.

2. One or two persons with handheld instruments roamed the tent exterior to identify tent leaks or on-site gas deposition hotspots.

3. CO_2 gas was introduced into the tent enclosure for a pre-calculated duration and shut off flow; exterior roamers began looking for leaks and noting exterior gas concentrations.

4. To maintain tent concentrations of ±500 ppm of target concentrations, CO_2 concentration decreases (from tent leakage) were observed and iteration combinations of manual input of supply manifold CO_2, tent sealing, and fan location movements were performed.

2.7 Estimation of Occupant CO_2 Loading of Trailer Interior

Occupant CO_2 loading of Trailer 1 was monitored to estimate the proportion of indoor CO_2 contributed by trailer occupants. Four adult study participants occupied Trailer 1 for approximately 1.5-hrs sitting, standing, walking, and talking, while CO_2 concentrations were measured at breathing zone height.

2.8 Estimation of Trailer Air Change Rates

The camper trailers used in this study were similar in build and size but may differ in their indoor/outdoor air exchange rates compared to residential homes or other types of modular homes designed for permanent occupancy. Knowledge of these differences may be useful in extrapolating indoor CO_2 profiles observed in this study with potential profiles in other types of dwellings. The Air Changes per Hour (ACH) of each trailer was estimated by measuring the loss of indoor CO_2 over time using well established mathematical models for estimating concentration decay in a well-mixed space using the Python language. To accomplish this, overnight CO_2 measurements were recorded with doors and windows closed for trailer 1 following the conclusion of the occupant loading test described in Section 2.8 and following the conclusion of the 40,000 ppm test for trailer 2. The concentration of a gas at any point in time during which it is being lost from a well-mixed space may be calculated by Equation 2.1.

Equation 2.1 Gas Concentration Loss from a Well Mixed Space

$$C_r = (C_0 - C_{in})e^{\left(\frac{-Q(t-t_0)}{V}\right)} + C_{in}$$

Q = Air exchange flow rate between indoors and outdoors in $m^3\ min^{-1}$.
C_r = CO_2 concentration inside the trailer at time t in mg m^{-3}.
C_{in} = CO_2 concentration in air outside the trailer in mg m^{-3}.
C_0 = The initial CO_2 concentration inside the trailer at start of the decay phase in mg m^{-3}.
V = Volume of the trailer in m^3.
t = Time of the measured CO_2 concentration in minutes.
t_0 = Time at the start of the decay phase in minutes.

Solving Equation 2.1 for the air exchange flow rate (Q, m^3/minute) between indoors and outdoors results in Equation 2.2.

Equation 2.2 Indoor/Outdoor Air Exchange Flow Rate

$$Q = -\left(\frac{ln\left(\frac{C_r - C_{in}}{C_0 - C_{in}}\right)V}{t - t_0}\right)$$

Q = Air exchange flow rate between indoors and outdoors in $m^3\ min^{-1}$.
C_r = CO_2 concentration inside the trailer at time t in mg m^{-3}.
C_{in} = CO_2 concentration in air outside the trailer in mg m^{-3}.
C_0 = The initial CO_2 concentration inside the trailer at start of the decay phase in mg m^{-3}.
V = Volume of the trailer in m^3.
t = Time of the measured CO_2 concentration in minutes.
t_0 = Time at the start of the decay phase in minutes.

The air exchange flow rate (Q) was derived separately for each trailer from each CO_2 concentration (C_r)measured overnight inside the trailers and known values for the initial CO_2 concentration inside the trailers, the CO_2 concentration outside the trailers (C_{in}), and the volume (V) of the trailers using Equation 2.2. The underlying probability distribution of the flowrates was then identified using the Kolmogorov-Smirnov test* and the descriptive parameters of the identified distribution were used in subsequent calculations. Equation 2.1 was then fit† to the measured CO_2 concentration inside the trailer using least squares regression with constants C_0 and C_{in}. The volume of the trailer (V) was permitted to vary by 10% and the air exchange flow rate (Q) was permitted to vary between the 90% upper and lower confidence limits of the identified underlying distribution. The air exchange flow rate (Q) for the fitted equation was then used to determine the ACH using Equation 2.3.

Equation 2.3 Air Changes per Hour

$$ACH = \frac{Q \ x \ 60}{V}$$

ACH = Air Changes per Hour
Q = Air exchange flow rate in m^3 min^{-1}.
V = Volume of the trailer in m^3.

2.9 Study Tests

Four study tests were conducted to explore indoor CO_2 and O_2 changes in response to 4-hour outdoor CO_2 environments of up to the National Institute for Occupational Safety and Health (NIOSH) immediately dangerous to life and health (IDLH) level of 40,000 ppm (**Error! Reference source not found.**). To provide comparable results for each study event, both trailers had doors, vents, and windows fully closed, except for Test #5, which was conducted with windows open on Trailer 2. No active ventilation of trailers occurred during any other planned study tests.

Figure 2.7 CO_2 Study Tests

	CO_2 Concentration (ppm)
Test 1	10,000
Test 2	20,000
Test 3	30,000
Test 4	40,000
Test 5	≥50,000

Test 5 (CO2 ≥ 50,000 ppm) was conducted to understand the extent of indoor and outdoor O2 depletion during a "catastrophic release" in which the CO2 supply was allowed to fill the tent non-stop until the tent

* *See Python scipy.stats.kstest for additional details.*
† *See Python scipy.optimize.curve_fit for additional details.*

internal O2 level fell to 15%. Due to the high-CO2 in-tent levels expected to be generated in Test #5, a safety-based test abort trigger was employed: If tent wall leakage exceeded 20,000 ppm CO_2 in any one spot, the test would be aborted and the tent immediately ventilated into a pre-determined, fan-directed direction away from the study participants.

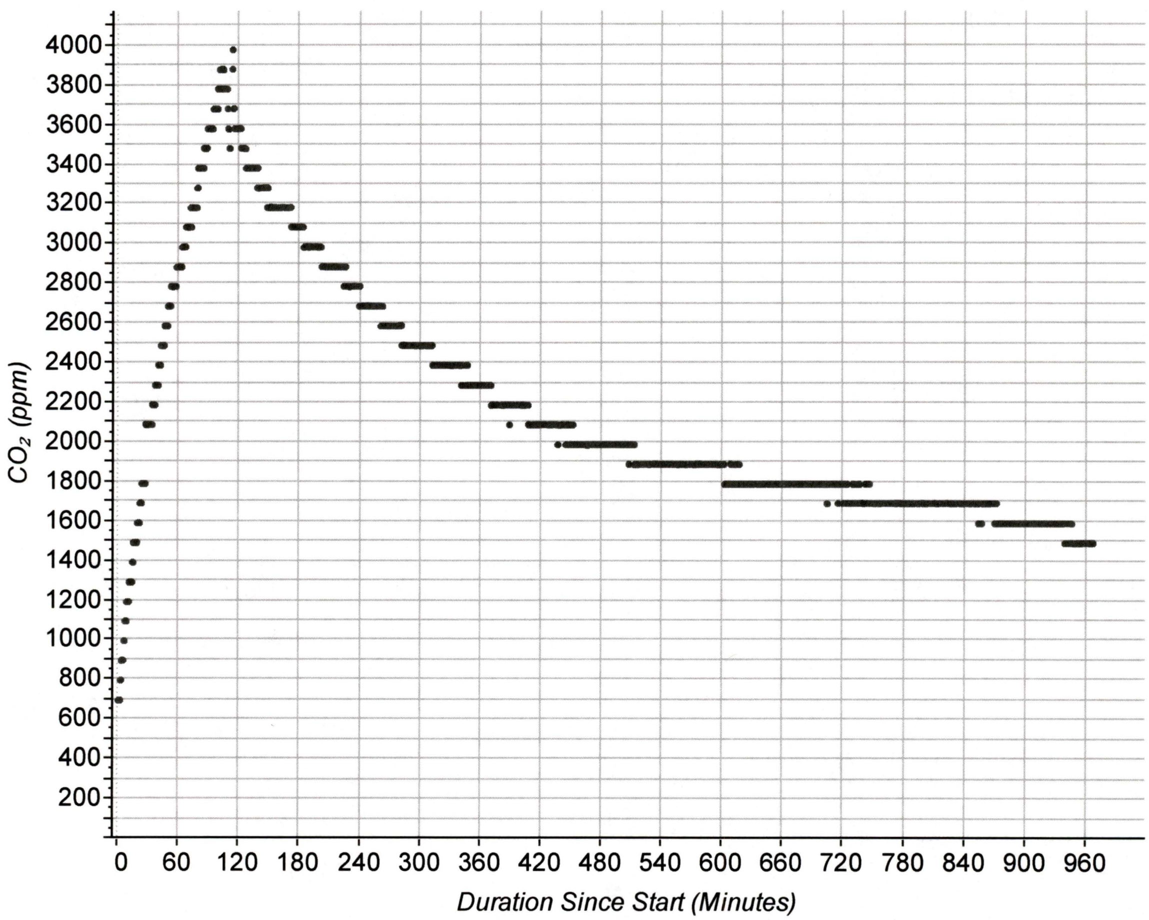
Active ventilation was used between each study event to purge CO_2 concentrations to ≤ 400 ppm CO_2 by exhausting trailer and tent interior to the tent exterior. Windows/doors were opened. Fans were located at the doorway of each trailer to facilitate return of trailer interior CO_2 andO_2 concentrations back to pre-test ambient conditions.

3.0 Results

3.1 Occupant CO_2 Loading and Trailer Air Change Rate Estimation

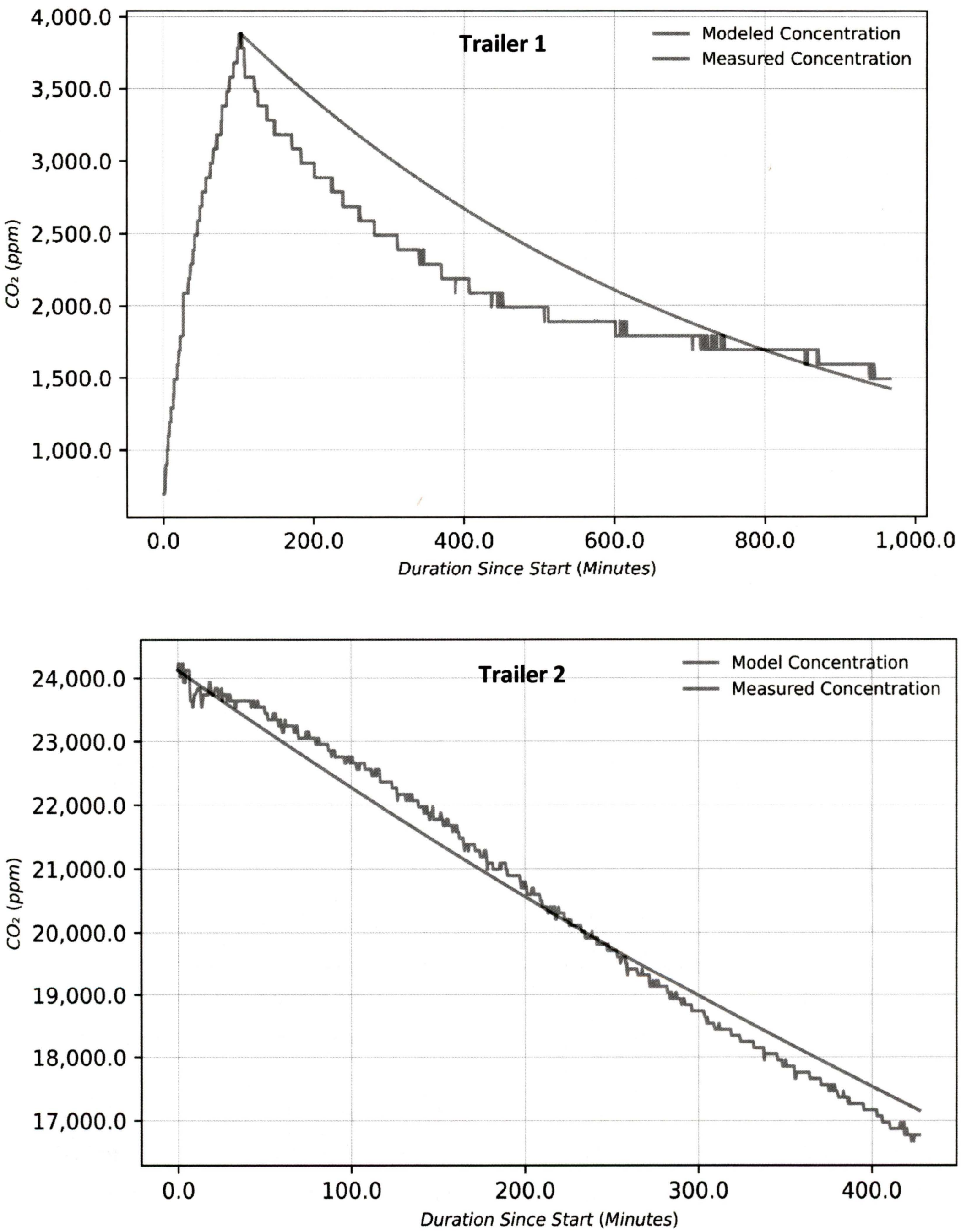
CO_2 concentrations reached 3,878 ppm during this time (Figure 3.1). Assuming the CO_2 exhalation of each study participant represented that of an average adult, this CO_2 loading level of approximately 4,000 ppm would be generally representative of the loading level produced by four adults over 90 minutes for a closed structure of approximately 1,700 ft^3 (approximately 48 m^3). A correction for the volume occupied by furniture inside each trailer was estimated to be 353 ft^3 (approximately 10 m^3).

Figure 3.1 CO_2 Loading and Clearance Profile Following Trailer 1 Occupancy



The data for CO_2 loss from Trailer 1 occupant CO_2 loading test, as well as data for CO_2 loss following the 40,000 ppm test in Trailer 2, were used to calculate air change rates. The measured and modeled CO_2 are shown in Figure 3.2. The modeled profile was created using the mean air exchange flow rates determined from **Error! Reference source not found.** to identify a predicted concentration in each trailer using the standard form for concentration decay in a well-mixed space model (Equation 2.1). The estimated air exchange flow rates from **Error! Reference source not found.** were then used to calculate ACH rates of approximately 0.2 ACH in Trailer 1 and 0.048 ACH in Trailer 2. Thus, Trailer 1 was about 4-times leakier than Trailer 2. For comparison, a typical unventilated home is estimated to have an ACH of 1 to 2 (Reichman et al., 2017).

Figure 3.2 Trailer 1 (Top) Trailer 2 (Bottom) Model-Predicted Air Change Rates



3.2 Tent and Trailer CO_2 and O_2 Time Profiles

Each of four study tests of 4-hour durations were performed, with increasing tent interior concentrations of CO_2 ranging from 10,000 to 40,000 ppm. A study test of concentration > 50,000 ppm was also attempted but aborted prior to reaching 50,000 ppm interior tent concentration due tent leakage exceeding the safety abort trigger condition.

During the 10,000, 20,000, 30,000, and 40,000 ppm tests, overall average CO_2 concentrations were maintained inside the tent within approximately 500 ppm of the target concentrations (Table 2, Figure 3.3 and Figure 3.4).

Table 2. Target and Actual Measured CO_2 Level in Tent Breathing Zone

Target CO2 Concentrations (ppm)	Measured Average Ground CO_2 Concentrations (ppm)	Measured Average Breathing Zone CO_2 Concentrations (ppm)	Measured Average Rooftop CO_2 Concentrations (ppm)	Measured Overall Average CO_2 Concentrations (ppm)
10,000	10,891	10,613	10,576	10,664
20,000	20,861	20,724	19,531	20,168
30,000	29,991	30,484	28,272	29,266
40,000	41,250	40,426	38,242	39,543

As tent breathing zone CO_2 levels fell to about 500 ppm below target concentration, study participants added a 2- to 8-second "puff" of CO_2 from the supply manifold, resulting in a transient CO_2 level that was slightly higher than the target level. This behavior is evident in Figure 3.3 and Figure 3.4 from the multiple peaks and troughs in the CO_2 graphs, with each peak representing a "puff". Ground level and rooftop CO_2 levels were similar to breathing zone levels, indicating rapid and uniform mixing of CO_2 in the tent enclosure. Oxygen levels in the tent decreased with increasing CO_2 levels, with the tent rooftop monitors measuring the lowest O_2 levels. The lowest O_2 levels observed remained above 19.5% in ground and breathing zone measurements (CO2 and O_2 concentrations were measured at the interior trailer floor and at breathing zone levels throughout the tests (**Error! Not a valid bookmark self-reference.** and Figure 3.6). The CO_2 concentrations on the trailer floor and in the breathing zone increased with similar patterns and concentrations over time during the 10,000 and 20,000 ppm study tests. In contrast, the 30,000 and 40,000 ppm test trailer floor CO_2 concentrations rose more rapidly than that of the breathing zone, indicating an initial stratification of CO_2 by height. In both tests, floor level CO_2 increased rapidly, then began to decrease, at which time the rate of increase at the breathing zone level began to rise. The reason is not clear for this rapid increase in breathing zone concentration followed by a decrease in floor level CO_2 in these higher tent concentration tests. Some interior trailer atmospheric property or some feature of changing CO_2 ingress becomes apparent in the 30,000 and 40,000 ppm trailers, resulting in height-specific differences in CO2 loading followed by a marked reduction in floor level CO_2. The lowering of CO_2 levels at the floor height of both trailers in the high ppm tests indicated an upset of low-lying CO_2, forcing it toward the breathing zone height after which it reached a new floor-level equilibration. It is not known whether this phenomenon is specific to the test trailers, or would be observed in other residential homes. The O_2 concentration never fell below 19.5% throughout all study tests from 10,000 to 40,000 ppm.

Figure 3.5). The reason for rooftop deficits of O_2 concentrations is uncertain.

Figure 3.3 Tent CO_2 and O_2 Concentration Time Course During 10,000 and 20,000 ppm Tests

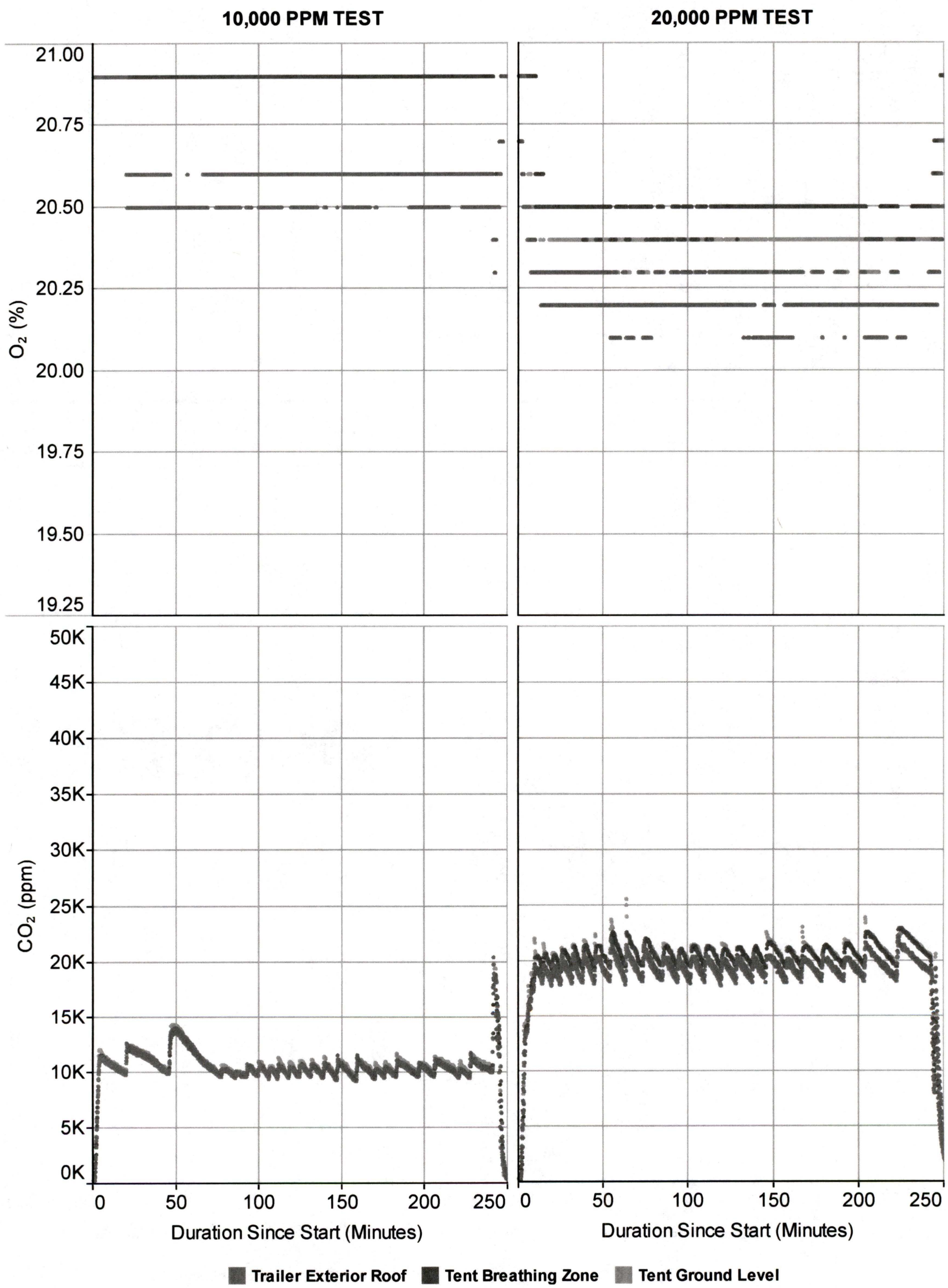
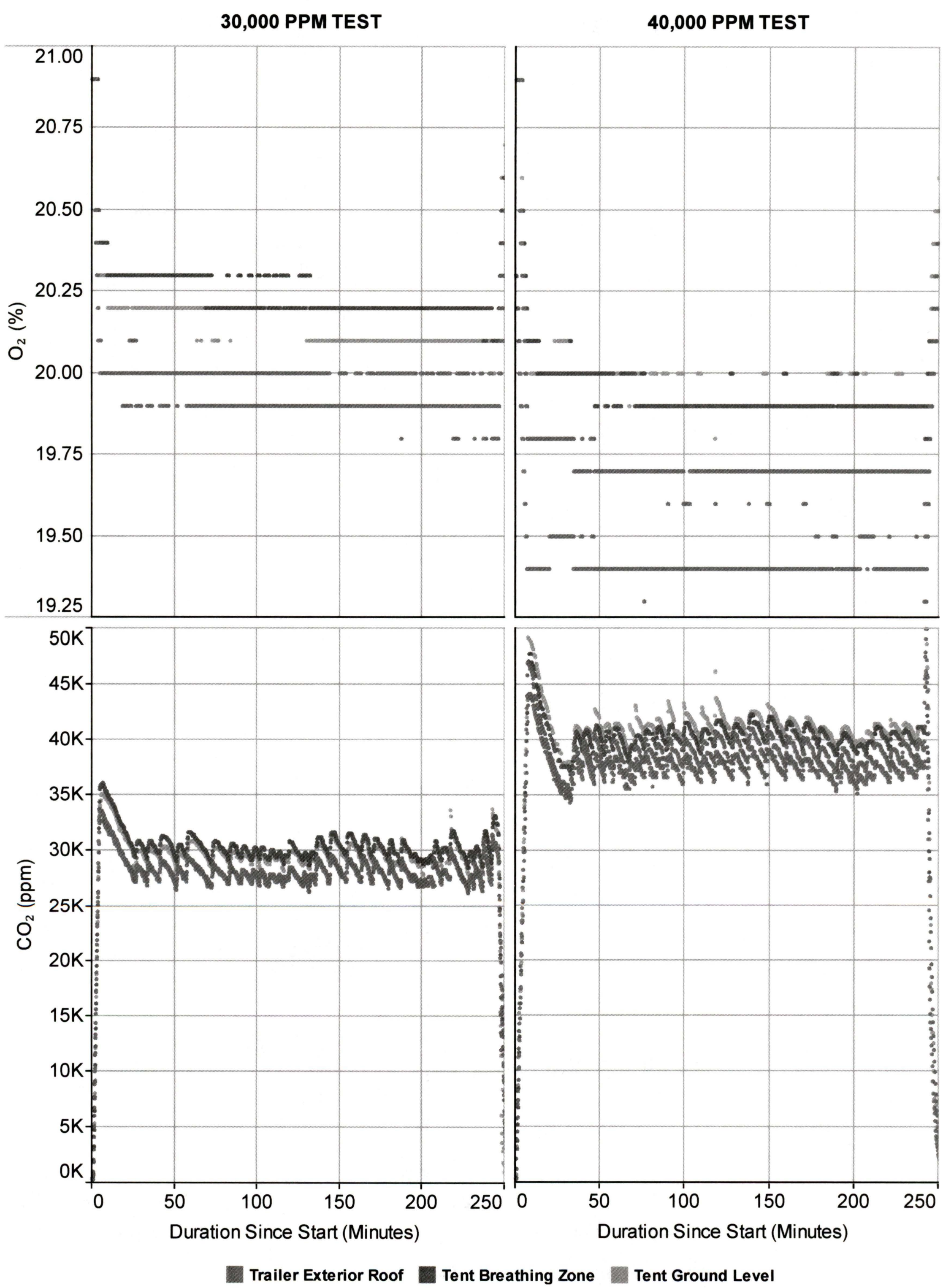


Figure 3.4 Tent CO_2 and O_2 Concentration Time Course During 30,000 and 40,000 ppm Tests



CO_2 and O_2 concentrations were measured at the interior trailer floor and at breathing zone levels throughout the tests (**Error! Not a valid bookmark self-reference.** and Figure 3.6). The CO_2 concentrations on the trailer floor and in the breathing zone increased with similar patterns and concentrations over time during the 10,000 and 20,000 ppm study tests. In contrast, the 30,000 and 40,000 ppm test trailer floor CO_2 concentrations rose more rapidly than that of the breathing zone, indicating an initial stratification of CO_2 by height. In both tests, floor level CO_2 increased rapidly, then began to decrease, at which time the rate of increase at the breathing zone level began to rise. The reason is not clear for this rapid increase in breathing zone concentration followed by a decrease in floor level CO_2 in these higher tent concentration tests. Some interior trailer atmospheric property or some feature of changing CO_2 ingress becomes apparent in the 30,000 and 40,000 ppm trailers, resulting in height-specific differences in CO2 loading followed by a marked reduction in floor level CO_2. The lowering of CO_2 levels at the floor height of both trailers in the high ppm tests indicated an upset of low-lying CO_2, forcing it toward the breathing zone height after which it reached a new floor-level equilibration. It is not known whether this phenomenon is specific to the test trailers, or would be observed in other residential homes. The O_2 concentration never fell below 19.5% throughout all study tests from 10,000 to 40,000 ppm.

Figure 3.5 Trailer Floor and Breathing Zone CO_2 and O_2 Concentration for 10,000 and 20,000 ppm Tests

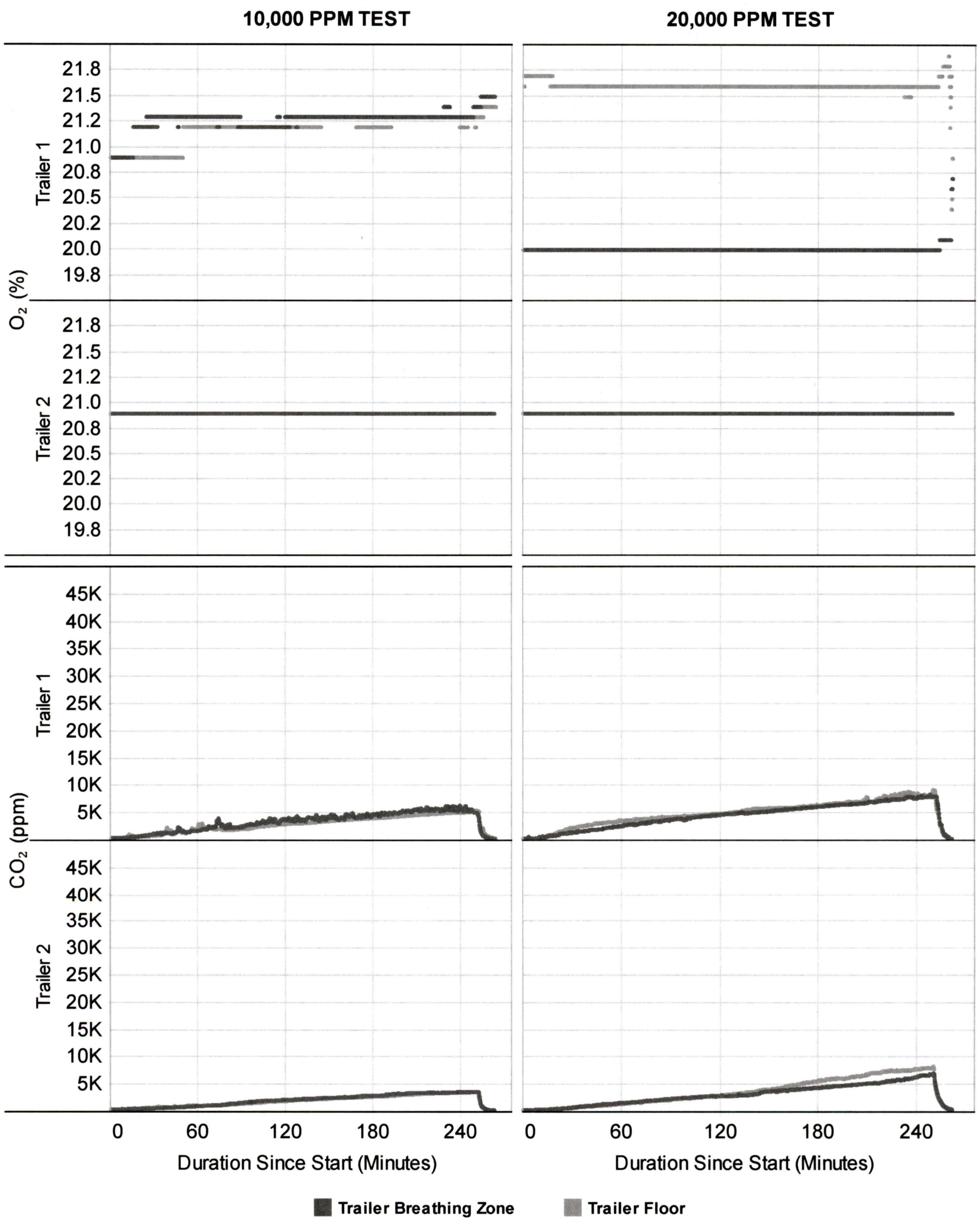
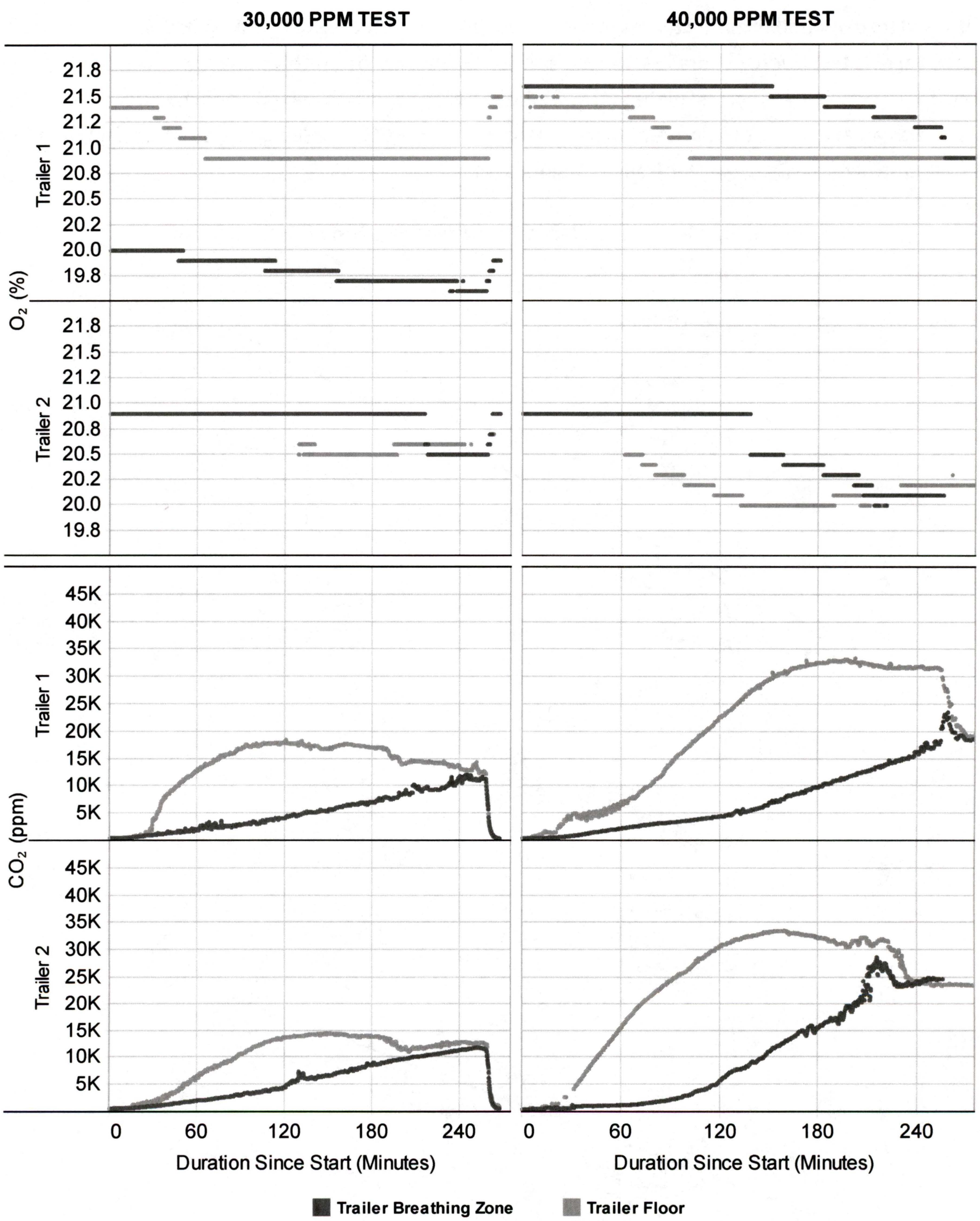


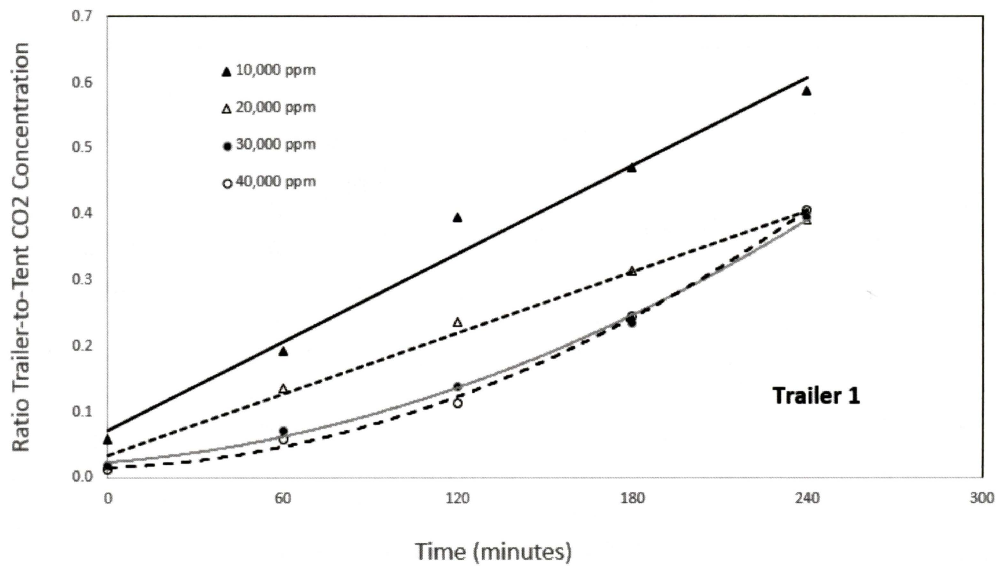
Figure 3.6 Trailer Floor and Breathing Zone O2 Concentration for 30,000 and 40,000 ppm Tests

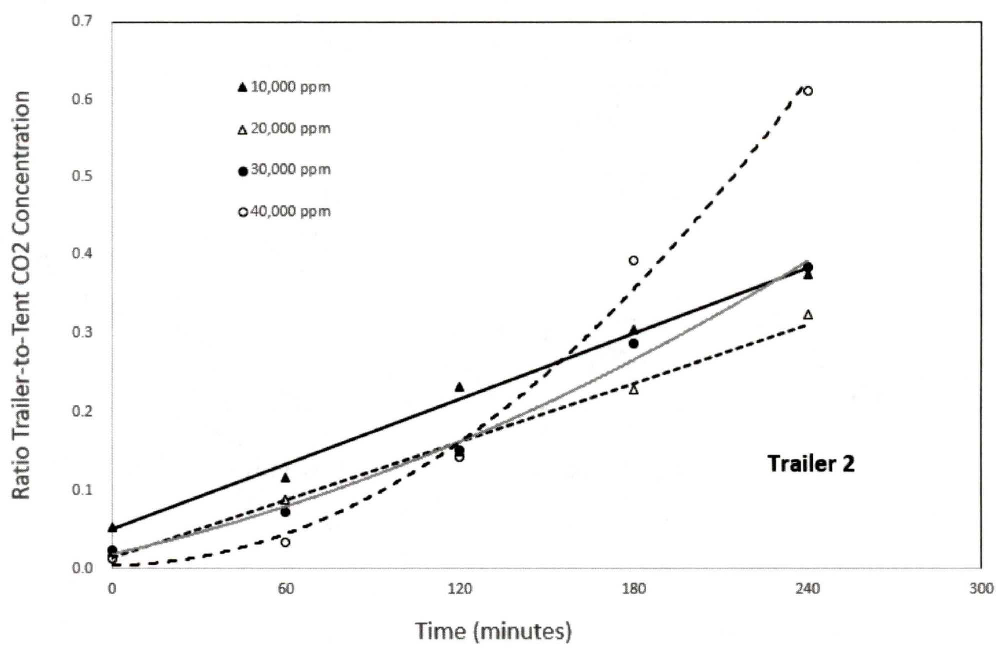


3.3 Trailer CO_2 Loading Relative to Tent Levels Over Time

Figure 3.7 shows the indoor-to-outdoor CO_2 ratios for both trailers across the 10,000 to 40,000 ppm tests. Both trailers exhibited linear increases in ratios across time for the 10,000 and 20,000 ppm tests. Trailer 2 ratios across tests were generally lower than those of Trailer 1, ostensibly due to its less leaky construction. It is uncertain whether the higher rate of ratio increase seen in the 40,000 ppm test data from Trailer 2 is due to an actual shift to different ingress behavior at this CO_2 test level or was an artifact of an unidentified structural change in the Trailer 2 points of entry.

Figure 3.7 Ratios of Trailer to Tent Breathing Zone CO_2 Over Time





3.4 CO_2 Maximum Loading Tests

In order to model worst case scenario, and catastrophic displacement of O_2 with CO_2, a maximum loading test was also conducted, where CO_2 concentration was ≥ 50,000 ppm (Figure 3.8 and Figure 3.9). The maximum loading test was aborted after approximately six minutes due to an identified enclosure leak; measured CO_2 concentrations were 90,000 ppm at the abort time. The trailer with open windows (Trailer 2) rapidly exhibited CO_2 levels that exceeded the indoor instrument's detection limit with a concomitant reduction in indoor 02. Even with this level of CO_2, O_2 decreased to only 18.2% within the tent, and the minimum oxygen inside the trailer with opened windows was 19.5%. O_2 concentration was not affected in the trailer with closed windows.

Figure 3.8 CO_2 and O_2 in the Enclosure Tent During CO_2 Maximum Loading Test

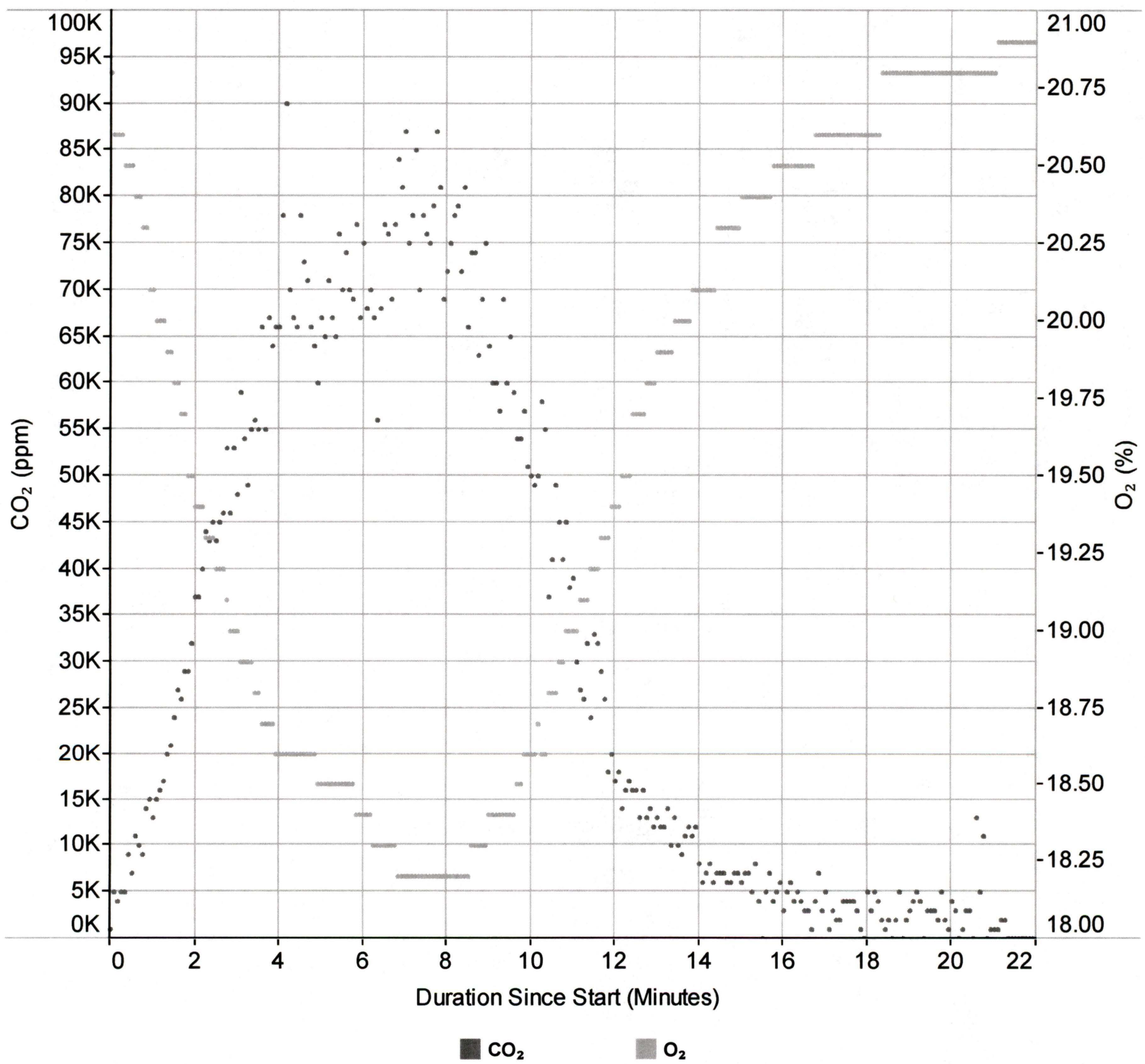
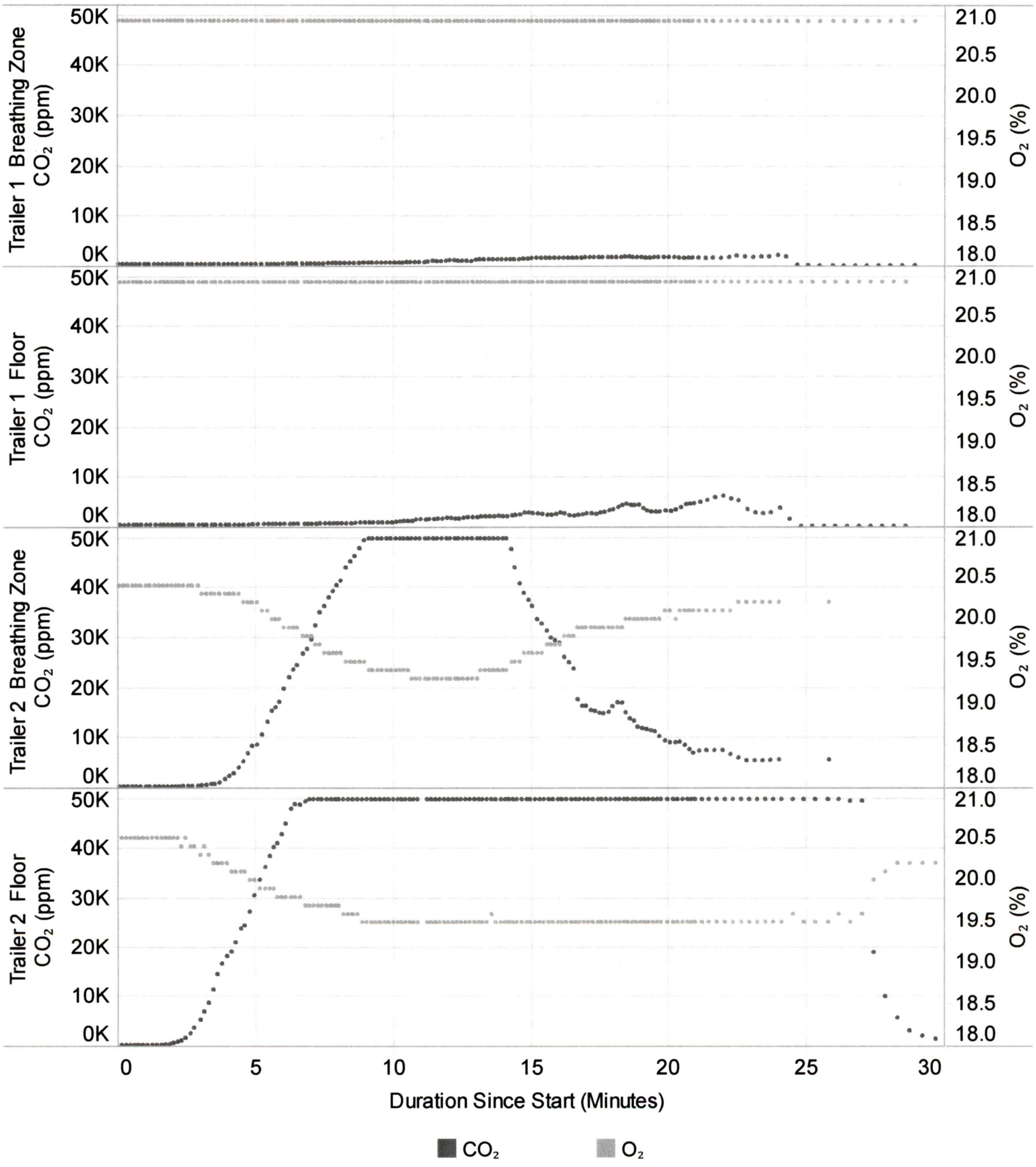


Figure 3.9 CO_2 and O2 Inside the Trailer 1 (windows closed) and Trailer 2 (windows open) During CO_2 Maximum Loading Test



4.0 Discussion

4.1 Potential for O_2 Deprivation in High CO_2 Atmospheres

One of the hazards of high ambient CO_2 levels is the displacement of O_2. However, understanding the conditions for CO_2-induced O_2 displacement is important in emergency response. The tent O_2 levels decreased with increasing levels of CO_2. However, 40,000 ppm CO_2 levels (the NIOSH IDLH level) resulted in relatively small decreases in tent O_2 of just under 20% in the breathing zone during the 40,000 ppm test. Interior trailer O_2 levels were observed to decrease at test concentrations of 30,000 ppm or greater. However, O_2 within the trailers remained greater than 19.5% at all CO_2 concentrations up to and including 40,000 ppm. Even during the maximum CO_2 test, O_2 decreased to 18.2% within the breathing zone of the tent when CO_2 concentrations reached approximately 90,000 ppm.

The observed relationship between test CO_2 and O_2 levels is not unexpected. A formula relating CO_2 levels to O_2 displacement follows:

Equation 4.1 CO_2 levels to O_2 displacement

$$\%\ O_2 = 0.209 \times (1 - fractional\ percent\ CO_2) \times 100$$

Thus, a 40,000 ppm CO_2 atmosphere would be expected to result in an O2 atmosphere of 20%, similar to the levels we observed of 19.5% to 20%. Similarly, a 90,000 ppm CO_2 atmosphere would be expected to result in an O_2 atmosphere of 19%, similar to the levels we observed of 18.2%.

4.1.1 Shelter in Place Implications

All of the exposure simulation tests reported herein whether representing a lingering 4-hour 40,000 ppm exposure or a short (8 minute) "blast" of 90,000 ppm CO_2 did not result in indoor CO_2 levels of more than 30,000 ppm. Further, indoor O_2 levels in closed trailers did not drop below 19.5%.

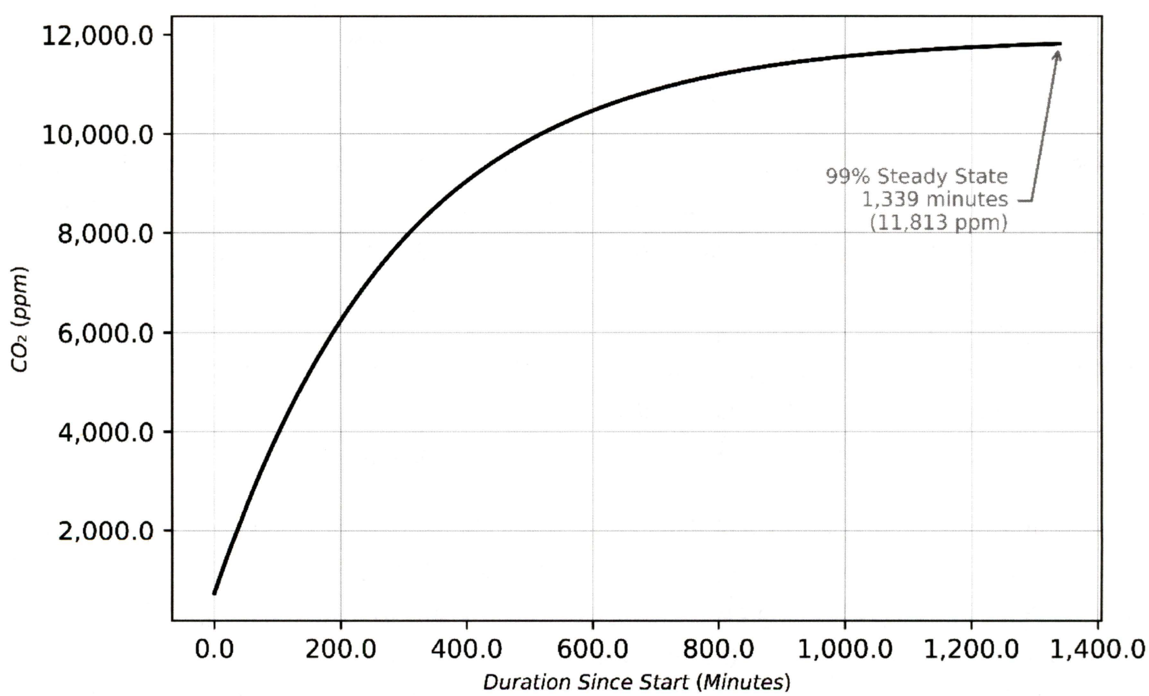
Studies of submariners exposed to 30,000 ppm CO_2 for extended periods of time resulted in only mild changes in pulse and blood pressure, a physiological response of the body to eliminate CO_2 from the circulatory system (Schaefer, 1951 as cited by NIOSH, 1994a). A recent study reported high tolerability of up to 90,000 ppm for 60 minutes in healthy volunteers (van der Schrier et al., 2022). While there is uncertainty in the ability of persons with compromised respiratory systems (i.e., COPD or asthma patients) to tolerate CO_2 levels as healthy volunteers and submariners, SIP during an elevated CO_2 release is likely to provide superior risk reduction than egress from an effected area via vehicle or on foot.

Jetter and Whitfield (2005) and USEPA (2009) asserted that SIP is a viable option in the event of a release of a potentially hazardous agent, with considerations as to the maximums for the number of people sheltering together, and for the period of time. For instance, in their 2009 report, USEPA reported that in a high-density occupied space (i.e., one person per 2 m^2 floorspace), and with an ACH of 0.27, the shelter CO_2 concentrations were estimated to be 13,732 mg/m^3 (7,629 ppm) after three hours. However, the

USEPA (2009) and Jetter and Whitfield (2005) did not adjust for the eventual achievement of steady state CO_2 levels inside the shelter, accounting for the ACH.

According to the U.S. Census Bureau, the average occupancy in US homes is three people. Thus, in the current analysis, four individuals inside a trailer with 177 ft^2 (16.4 m^2) of occupiable floor space is a realistic overestimation of person density and is approximately equal to 4 m^2 per person. Using the same CO_2 accumulation rate calculations from USEPA for the current scenario of SIP in a residential setting with reduced occupancy, wherein four people occupy 4 m^2 each of space, the resulting theoretical CO_2 concentrations were 6,866 mg/m^3 (3,814 ppm) after three hours. To validate this theoretical CO^2 build-up, measured CO_2 loading rates from the occupant loading test in the current study were used. The modeled occupant loading time to reach steady state CO_2 concentration is shown in Figure 4.1 Modeled Occupant Loading Time to Reach Steady Stateand is based on measured data for 90 minutes inside of Trailer 1.

Figure 4.1 Modeled Occupant Loading Time to Reach Steady State



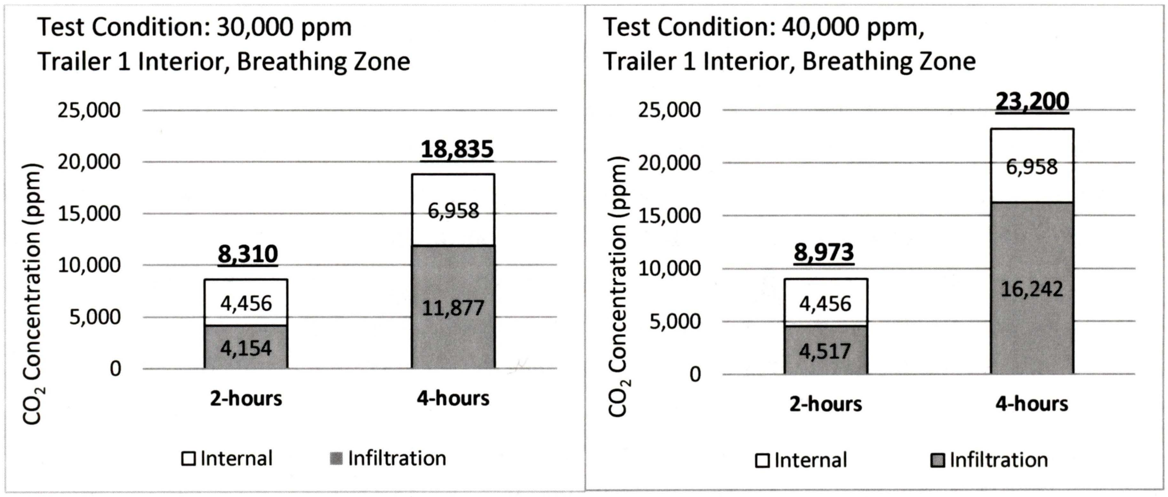
After three hours inside Trailer 1 with four occupants, the CO_2 concentration is estimated to be 8,021 mg/m^3 (4,456 ppm) and is estimated to be 17,514 mg/m^3 (9,730 ppm) after eight hours. The modeled steady state CO_2 concentration does not exceed 21,263 mg/m^3 (11,813 ppm) after 24 hours. For perspective, the CO_2 concentrations for an 8-h time-weighted average CO_2 concentration of 6,393 ppm is slightly above 5,000 ppm limit as set by the Occupational Safety and Health Administration (OSHA), but is well below the American Conference of Governmental Industrial Hygienists (ACGIH) Short-Term Exposure

Limit (STEL) ppm and the National Institute of Occupational Safety and Health (NIOSH) STEL of 30,000 ppm.

In 2006, experts from Argonne National Laboratory published SIP guidance on behalf of the U.S. Army and Department of Homeland Security's Chemical Stockpile Emergency Preparedness Program (CSEPP). The *Shelter in Place Protective Action Guidebook* (CSEPP, 2006) discussed the risks and benefits of evacuation versus SIP before and during arrival of a plume of a gaseous chemical warfare agent. The authors noted that shelters with lower ACH rates (e.g., tighter structures) would result in lower exposure ratios with respect to the outdoor plume concentration. The authors went on to say that SIP strategies should consider the time at which outdoor plume levels become lower than indoor levels, so that sheltering persons leave their shelter and enter an outdoor environment that has a lower plume concentration. In our experiments, the highest recorded indoor breathing zone concentration during the 40,000 ppm test was about 5,000 ppm at two hours and less than 30,000 ppm at four hours of the event. The highest 2-hour value of about 5,000 ppm was similar to the expected occupant load of four adults exhaling CO_2 in a trailer (about 4,000 ppm observed after 90 minutes). The maximum indoor CO_2 level we recorded after an 8-minute plume that rose to about 90,000 ppm was slightly higher than ambient levels. We note that the experimental conditions did not include indoor air movement due to occupants that would be present in a real-world event. Thus, breathing zone-to-floor CO_2 levels over time may be different than seen experimentally. These CO_2 results using low-ACH camper trailers comport with CSEPP guidance for SIP until plume egress, after which structure ventilation should be performed.

The addition of internally generated CO_2 concentrations from residents and the infiltration of CO_2 from outdoors must be considered when evaluating SIP safety. Based on the circa-linear increase in CO_2 concentration in the breathing zone during infiltration (as shown in Figure 3.6) and the similar increase observed during the first four hours of the occupant loading test (Figure 4.1), the infiltrated and internally generated CO_2 concentrations during the 30,000 ppm test can be summed. As shown in Figure 4.2 in the test condition of 30,000 ppm, the maximum CO2 concentration inside the trailer in the breathing zone is estimated to be 18,835 ppm. While not directly applicable, this concentration is well below the ACGIH and NIOSH STELs. The positive rate of increase in CO_2 concentration in the 40,000 ppm test was consistent up to approximately 120 minutes, after which time the rate almost doubled (80% increase in slope after 120 minutes compared with 0 to 120 minutes). However, the CO_2 concentrations in the breathing zone remain well below the STEL of 30,000 ppm and the IDLH of 40,000 ppm, which is based on submariners continuously exposed to 30,000 ppm CO_2 and who exhibited slightly increased respiration (Schaefer, 1951 as cited by NIOSH, 1994a). Of note, the submariner tests were conducted under conditions where O_2 concentrations were maintained, and the authors postulated that an emergency release might result in decreased O_2 concentrations. However, in contrast to the hypothesis by Schaefer (1951), measured O_2 concentrations in the breathing zone of both trailers for the duration of the test period for all 10,000 ppm to 40,000 ppm tests were well above 19.5%, below which is considered an O_2-deficient environment by OSHA. The results of the current study suggest that, even at 40,000 ppm exposures, O_2 concentrations remain at a safe and normal atmospheric concentration while CO_2 concentrations do not exceed highly conservative STEL or IDLH values.

Figure 4.2. Estimated Cumulative Infiltrated and Internally Generated CO_2 Concentrations in Trailer 1.



SIP is a viable, health protective option for at least four hours following a release of at least 40,000 ppm CO_2. The effectiveness of SIP to reduce exposure to plume-level concentrations is less certain for residences that are significantly leakier than the trailers used in this experiment.

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Appendix A: Health and Safety Measures and the Health and Safety Plan (HASP)

CTEH®

Safety Measures

Chemical Hazards

Carbon dioxide (CO_2), CAS# 124-38-9, is a colorless, odorless gas comprised of one carbon atom and two oxygen atoms. Select physical and chemical properties of CO_2 include molecular weight of 44 g/mol, vapor pressure 56.5 atm at 22 °C, vapor density 1.53 (unitless), ionization potential 13.77 eV, and specific gravity of 1.56 at -110.2 °F (NIOSH, 2019). In the event of a release, the public may be exposed to CO_2 via inhalation or skin or eye contact. Symptoms of sufficiently high CO_2 exposure include dizziness, headache, restlessness, tingling 'pins and needles' sensation, difficulty breathing, increased heart rate, cardiac output, and blood pressure, coma, asphyxia, and death.

Hydrogen Sulfide (H_2S) is a colorless gas having a strong odor of rotten eggs and poses a respiratory hazard. The odor threshold, or the concentration of H_2S when the human nose is first able to detect the odor of rotten eggs, is approximately 0.00005-1.4 ppm.(Murnane et al., 2013) H_2S concentrations greater than 100 ppm causes human smell sensory fatigue which means that rotten egg odors cannot be counted on to warn of the continued presence of the gas. The National Institute for Occupational Safety and Health (NIOSH) set and Immediately Dangerous for Life and Health (IDLH) value for H_2S of 100 ppm based on acute inhalation toxicity data in humans and animals; concentrations above 200 ppm for prolonged periods may cause edema or death (NIOSH, 1994b; OSHA, 2022) .

Methane is a colorless odorless gas, also known as marsh gas or methyl hydride. Methane is easily ignited. The vapors are lighter than air. The lower explosive limit of methane is approximately 5% by volume in air. Sufficiently high concentrations may cause asphyxiation through the displacement of oxygen (USCG, 1999), which has a normal ambient range of 19.5-23.5% per Occupational Safety and Health Administration (OSHA) Standard 29 CFR 1910.134.

Total VOCs as a group do not have any established standards or guidelines. However, VOC monitoring was conducted to determine if more specific sampling or investigation is needed.

Chemical Hazard Action Levels

There is no consensus on what concentration of CO_2 is appropriate for a community emergency response guidance value. Health effects reported in older studies include lightheadedness, but details on the extent or transient nature of the effect are scant. NIOSH designated a CO_2 concentration that is 'Immediately Dangerous to Life and Health' (IDLH) of 40,000 parts per million (ppm). For comparison, the current OSHA permissible exposure limit for an eight-hour work period is 5,000 ppm (9,000 mg/m^3) (OSHA, 2018). While permissible short-term (15-minute) exposure limits (STEL) for CO2 are not provided by OSHA, both NIOSH and the American Conference for Governmental Industrial Hygienists (ACGIH) provide a STEL of 30,000 ppm (54,000 mg/m3) (DFG, 2012).

Studies of non-occupational exposures to CO2 inform the tolerance of the human body to a wide range of CO2 exposure concentrations. In a recent review article by Permentier et al. (2017), the physiological effects of CO2 exposure were described in human and animal models, based on decades of research. In general, CO2 concentrations that resulted in human fatalities ranged between 14% and 26%, while CO2 concentrations less than 5% (50,000 ppm) had "little, if any, toxicological effects" (Permentier et al., 2017, p. 2). A recent study by van der Schrier et al., (2022) of CO2 exposure to groups of adult volunteers and rats provides a basis to propose raising the IDLH to as high as 75,000 ppm.

Considering the existing PEL, STEL, IDLH, and the range of responses from human exposures to CO2 summarized by Permentier et al., (2017) and reported recently by van der Schrier et al., we determined that a reasonable and scientifically justifiable acute emergency guidance level for a 60-minute exposure would range somewhere between 20,000 and 75,000 ppm (2% to 7.5%) CO2. The study action levels to protect on-site study participants for CO2, H2S, %LEL, and O2, and their respective actions to be taken if exceeded, are shown in Table 2.1. For the purposes of this study, a detailed Health and Safety Plan (HASP) was developed and is included in Appendix A.

Table A.4.1 Study Action Levels for Study Participant (Worker) Protection

Chemical	Action Level	Action	Basis
Carbon Dioxide	5,000 ppm (15-min)	Notify SSO*	OSHA PEL & ACGIH TLV (8-hr)
	30,000 ppm (5-min)	Egress upwind and notify SSO	ACGIH STEL (15-min)
LEL (as methane)**	0.5%	Notify SSO	$1/10^{th}$ LEL
Hydrogen Sulfide	1 ppm	Notify SSO	ACGIH TLV-TWA (8-hr)
	5 ppm	Egress upwind and notify SSO	ACGIH STEL (15-min)
Oxygen	< 19.5 %	Notify SSO	Oxygen deficient atmosphere

**SSO: Study Safety Officer*

***Based on LEL of methane (100% LEL = 5% methane, or 50,000 ppm)*

Action levels used during the study for CO2 and H2S to protect nearby off-site receptors (community), and their respective actions to be taken if exceeded, are shown in **Error! Reference source not found.**. The United States Environmental Protection Agency's (EPA) Acute Exposure Guideline Level 1 (AEGL-1) is the airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic non-sensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure (NRC, 2010).

Table A.4.2 Study Action Levels for Community Protection

Chemical	Action Level	Basis	Action
Carbon Dioxide	20,000 ppm	Study specific	Report reading to SSO; reevaluate enclosure leakiness or ventilation rate and wind direction
Hydrogen Sulfide	0.51 ppm	AEGL-1 (60 minutes)	

**SSO: Study Safety Officer*

Physical Hazards

A number of physical hazards potentially existed onsite and were controlled administratively during the assessment to include the following: thermal stressors; weather; traffic; equipment; electrical; fire and explosion; slip, trip, and falls; noise; flying debris; and dermal hazard. The full mitigation and hazard list is included in Appendix A.

Administrative Controls

Prior to work commencing each day, a Job Safety Analysis was conducted and documented to outline the tasks for the day as well as the potential hazards and mitigation strategies. Personnel participated in daily safety briefings each day before work started as well as if operations changed during each day. Contingency plans were developed as part of the HASP in the event of an emergency to include evacuation, notification, and containment if a release occurred.

Select workers were also trained in hydrogen sulfide awareness, site hazards, emergency actions, communication, PPE, first aid, CPR, and AED, Denbury HSE Orientation, and Safety Awareness Training.

Indoor Carbon Dioxide Loading Following a Simulated Carbon Dioxide Pipeline Release

CTEH® Site-Specific Health and Safety Plan (HASP)

Version 1.0

Prepared By:

CTEH, LLC

5120 Northshore Drive

North Little Rock, Arkansas 72118

501-801-8500

December 05, 2022

CTEH Project Number PROJ-021914

	Name	Signature	Date Signed
Prepared By:	Micah Kendrick	Micah Kendrick	November 30, 2022
Reviewed By:	Angie Perez, PhD, CIH	Angela L Perez	November 30, 2022

Study Information

Effective Date	December 05, 2022
Study Name	Indoor Carbon Dioxide Loading Following a Simulated Carbon Dioxide Pipeline Release
Location	Brookhaven, MS

5.0 DESCRIPTION OF PROJECT:

Denbury, Inc. (Denbury) and American Petroleum Institute (API) asked CTEH, LLC (CTEH) to design and conduct a carbon dioxide (CO2) exposure simulation study to inform potential revisions to response actions currently described in the Emergency Response Guidebook (ERG) pertaining to protection of public safety in the event of a catastrophic CO2 release from a pipeline or associated infrastructure. Specifically, CTEH was asked to develop data to help first responders better determine whether evacuation or SIP orders represent the safer of two actions for the public in the event of a major CO2 release. This Health and Safety Plan was developed for use during the CO2 release simulation study to be conducted the week of December 5 to December 9, 2022 at the Denbury Pump Station located at 332 Rogers Lane Northeast, Brookhaven, Mississippi.

6.0 PURPOSE:

This plan addresses air monitoring tasks to be performed by CTEH®, LLC (CTEH) during the study. The air monitoring locations include inside towable residential structures (camper trailers), air monitoring outside of camper trailers but inside a large enclosure that houses the camper trailers, and air monitoring outside of the enclosure. Additional air monitoring will be conducted outside of the enclosure to determine the magnitude of fugitive emissions and along the property fence line.

This site-specific information has been developed from the latest available information. Revisions and alterations to this plan may become necessary as further information becomes available (i.e., unexpected sampling results, changes in site conditions, changes in scope of work, etc.). All alterations to this plan will be recorded in the Health & Safety Plan Management of Change section.

All on-site personnel are required to review and comply with this Health and Safety Plan. It is the responsibility of the project manager to ensure this plan is implemented.

7.0 SITE & EMERGENCY CONTACTS

7.1 Emergency Services Contact Information

Fire/Police/Ambulance – 911

Lincoln County Local Dispatch – 601-833-5231

King's Daughters Medical Center: ER - 601-833-6011

7.2 Project Contact Information

Title	Name	Company	Phone
Project Technical Director	Michael Lumpkin, PhD, DABT	CTEH	501-366-8304
Project Safety Officer	Cole Ledbetter, CIH, CSP	CTEH	501-337-2900
Denbury HSE Manager	Ryan Jacob, REM, CES	Denbury Inc.	985-855-4627
Denbury Safety Officer	Kevin Posey	Denbury Inc.	601-757-4143
Denbury Pipeline Manager	Jason Davis	Denbury Inc.	601-540-4808

8.0 SITE CONTROL

See Addendum for a Location map and hospital route.

Site Control	Location
Staging Area:	Brookhaven Pump Station, 332 Rogers Lane NE, Brookhaven, MS 39601
Site Security and Access Points:	The access point for the site will be the gate located off of Rogers Lane. All participants will need to check in and out at the office located on the west side of the facility.
Permit to Work	Denbury will issue a permit for the activities being conducted on location.
Job Safety Analysis	During the safety briefing a JSA will be completed and all safety related issues will be discussed.

9.0 HAZARD ASSESSMENT

9.1 Chemical Hazards

9.1.1 Carbon Dioxide

Carbon dioxide (CO_2), CAS# 124-38-9, is a colorless, odorless gas comprised of one carbon atom and two oxygen atoms. Select physical and chemical properties of CO_2 include molecular weight of 44 g/mol, vapor pressure 56.5 atm at 22 °C, vapor density 1.53 (unitless), ionization potential 13.77 eV, and specific gravity of 1.56 at -110.2 °F (NIOSH 2019). In the event of a release, the public may be exposed to CO_2 via inhalation or skin or eye contact. Symptoms of sufficiently high CO_2 exposure include dizziness, headache, restlessness, tingling 'pins and needles' sensation, difficulty breathing, increased heart rate, cardiac output, and blood pressure, coma, asphyxia, and death.

9.1.2 Hydrogen Sulfide

Hydrogen Sulfide (H_2S) is a colorless gas having a strong odor of rotten eggs and poses a respiratory hazard. According to OSHA, the odor threshold, or the concentration of H2S when the human nose is first able to detect the odor of rotton eggs, is approximately 0.01 ppm (OSHA, 2022). H2S concentrations greater than 100 ppm causes human smell sensory fatigue which means that rotton egg odors cannot be counted on to warn of the continued presence of the gas. NIOSH set the IDLH for H2S at 100 ppm based on acute inhalation toxicity data in humans and animals and concentrations above 200 ppm for prolonged periods may cause edema or death (NIOSH, 1994b; OSHA, 2022). Death or permanent injury may also occur after very short exposure to high concentrations of H2S as it acts directly upon the nervous system resulting in paralysis of respiratory centers (USEPA, 1998).

9.1.3 Methane

Methane is a colorless odorless gas, also known as marsh gas or methyl hydride. Methane is easily ignited and the vapors are lighter than air. The lower explosive limit of methane is approximately 5% by volume in air. It is used in chemical producation and is a constituent of natural gas. High concentrations may cause asphyxiation through the displacement of oxygen (USCG, 1999).

See attached Safety Data Sheet (SDS) in Addendum B for more details on chemical hazards.

9.2 Chemical Hazard Action Levels

There is no consensus on what concentration of CO2 is appropriate for a community emergency response guidance value. As noted above, any spill over 208 liters initiates evacuation orders within 100 m in all directions, irrespective of CO2 concentration in the air in proximity to the release. One approach to determine what is a scientifically justifiable community-based emergency response guideline concentration is to, first, understand the existing occupational exposure guidelines and on what health endpoints these occupational guidelines were derived. Health effects reported in older studies include lightheadedness, but details on the extent or transient nature of the effect are scant. The National Institute for Occupational Safety and Health (NIOSH) designated a CO_2 concentration that is 'Immediately Dangerous to Life and Health' (IDLH) of 40,000 parts per million (ppm), based on acute inhalation toxicity data in humans (Aero Medical Association, 1954; Flury and Zernik, 1931; Schaefer, 1951 as cited by NIOSH, 1994a). However, a recent study by van der Schrier et al., (2022) of CO_2 exposure to adult volunteers and rats provides a basis to propose raising the IDLH to as high as 75,000 ppm. For comparison, the current Occupational Safety and Health Administration (OSHA) permissible exposure limit for an eight-hour work period is 5,000 ppm (9,000 mg/m^3) (OSHA, 2018). While permissible short-term (15-minute) exposure limits (STEL) for CO_2 are not provided by OSHA, both NIOSH and the American Conference for Governmental Industrial Hygienists (ACGIH) provide a STEL of 30,000 ppm (54,000 mg/m^3), shown in **Table 5.1**, below.

Non-occupational exposures to CO2 are especially informative about the tolerance of the human body to a wide range of CO2 exposure concentrations. In a recent review article by Permentier et al., (2017), the physiological effects of CO2 exposure were described in human and animal models, based on decades of research. In general, CO2 concentrations that resulted in human fatalities ranged between 14% and 26%, while CO2 concentrations less than 5% (50,000 ppm) had *"little, if any, toxicological effects"* (Permentier et al., 2017, p. 2). Considering the existing PEL, STEL, IDLH, and range of responses from human exposures to CO2 as summarized by Permentier et al., (2017) and the new data provided by van der Schrier et al., we anticipate that a reasonable and scientifically justifiable acute emergency guidance Level for a 60-minute exposure would range somewhere between 20,000 and 75,000 ppm (2% to 7.5%) CO2.

The community emergency response guideline levels for a CO2 release are shown in **Table 5.2** below. The United States Environmental Protection Agency's Acute Exposure Guideline Level 1 (AEGL-1) is the air-borne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic non-sen-sory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure.

Table 5.1 Study Action Levels for Study Participant (Worker) Protection

Chemical	Action Level	Action	Basis
Carbon Dioxide	5,000 ppm (15-min)	Notify SSO*	OSHA PEL & ACGIH TLV (8-hr)
	30,000 ppm (15-min)	Egress upwind and notify SSO	ACGIH STEL (15-min)
LEL**	0.5%	Notify SSO	1/10th LEL
Hydrogen Sulfide	1 ppm	Notify SSO	ACGIH TLV-TWA (8-hr)
	5 ppm	Egress upwind and notify SSO	ACGIH STEL (15-min)
Oxygen	< 19.5 %	Notify SSO	Oxygen deficient atmos-phere

*SSO: Study Safety Officer, Cole Ledbetter (501) 337-2900
**Based on LEL of methane (100% LEL = 5% methane, or 50,000 ppm)

Table 5.2 Study Action Levels for Community Protection

Chemical	Action Level	Action	Basis
Carbon Dioxide	20,000 ppm	Report reading to SSO; reevaluate enclosure leakiness or ventilation rate and directionality	Internal Proposed AEGL-1 (60 minutes)
Hydrogen Sulfide	0.51 ppm		AEGL-1 (60 minutes)

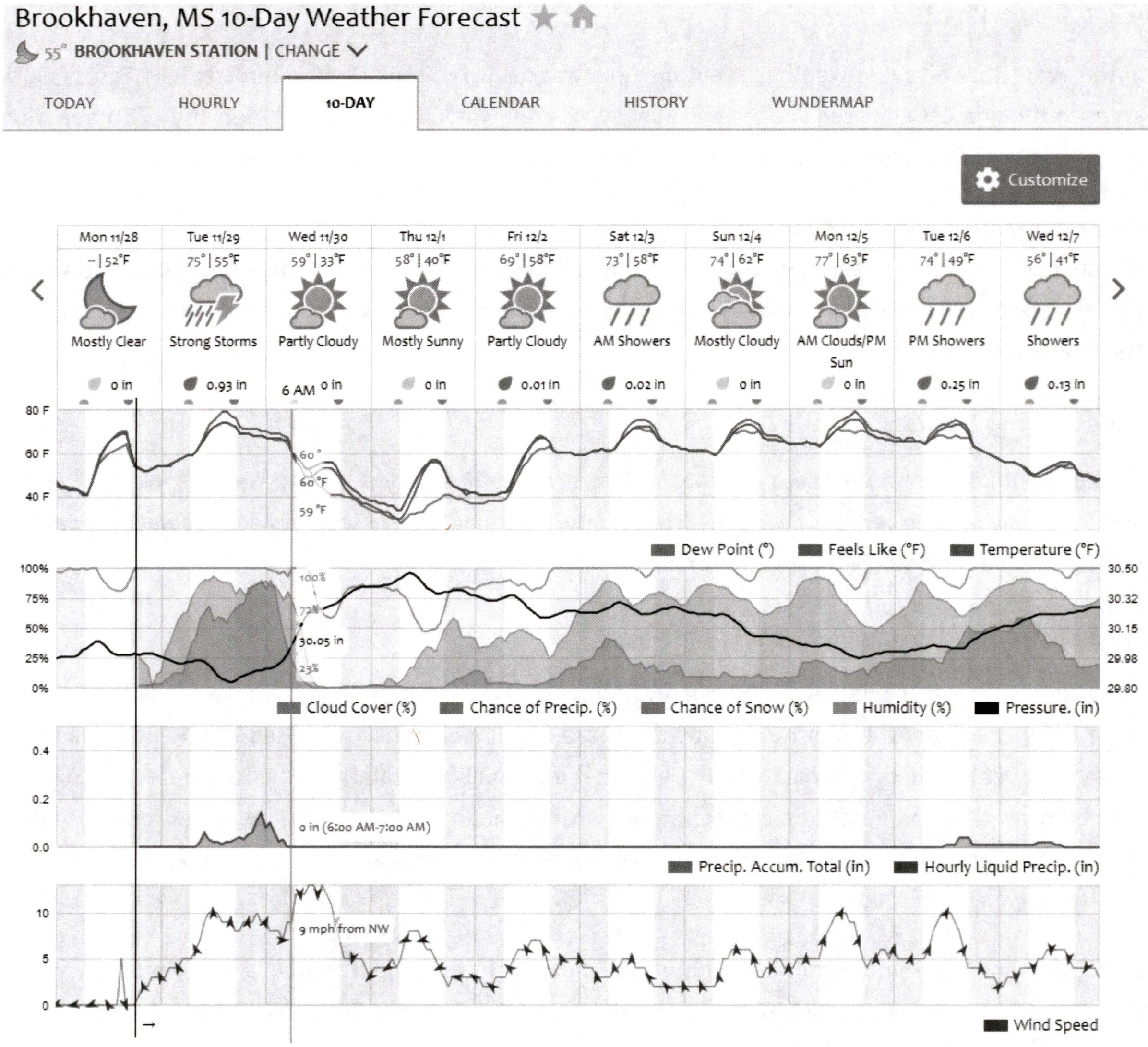
*SSO: Study Safety Officer, Cole Ledbetter (501) 337-2900

9.3 Physical Hazards

9.3.1 Weather Information

Responders should always maintain situational awareness of changing weather conditions through their CTEH® provided handheld device, the National Weather Service, local news networks, and on-site observations. Additionally, a safety briefing will occur prior to the beginning of each shift and weather information will be presented at that time. The current weather for the study site can be accessed via the QR code below:

Link to current weather



9.3.2 Thermal Stress

Thermal stress (heat stress or cold stress) hazards and strategies for mitigating impact on worker safety and health can be addressed based on information obtained in the OSHA-NIOSH Heat App downloadable from Google Play or the Apple Store. An addendum to this document may be added if deemed necessary by the project manager and corporate safety officer.

9.3.3 Severe Weather Hazard

In the event that a severe weather event disrupts work activity, seek shelter immediately. Egress work areas to the nearest enclosed shelter and stay away from windows if possible. Alert the CTEH® division supervisor or project manager as soon as possible and provide a situational update.

If a lightning strike is observed within 6 (six) miles of the work site, a mandatory 30-minute stand down will be in effect. Seek shelter indoors or in a vehicle. The stand down will continue until 30 minutes after the last lightning strike within 6 miles is observed. Stay indoors or in a vehicle until the entire 30-minute stand down period expires.

9.3.4 Moving Vehicles

Be cautious of all motor vehicles on site as well as in the community. As a pedestrian, look 360° before walking to any moving vehicles in your nearby vicinity. Personnel should wear reflective safety gear as the outermost layer of clothing on site, day or night.

9.3.5 Distracted Driving and Driving Safety

CTEH® personnel must abide by CTEH®, client, state, and local regulations and guidelines regarding driving while using cell phones. Under no circumstances are CTEH® personnel permitted to text or email while driving any vehicle on or off road. CTEH® personnel must pull over safely, away from traffic, to conduct cell phone or radio communications except when local regulations allow hands-free operation of communication devices. Use of these devices not in hands-free mode is prohibited at all times while driving any vehicle type on or off road.

CTEH® personnel are not permitted to operate a motor vehicle without seatbelts being properly worn. Once you have secured your seatbelt, please adjust your window and driver mirrors. Do not block windows with contents such that your view is obstructed while driving.

9.3.6 Motor Vehicle Hazards

When operating a motor vehicle, look both ways before entering a roadway or crossing intersections. Look for pedestrians on or near roadways. Driving at dusk and dawn or low light conditions decrease driver visibility and be aware that animals are much more active during these times. Driving on wet, snowy, gravel, or dirt roads warrant operation of the vehicle at a conservative speed. Not all gravel road crossings are controlled crossings; some do not have stop signs. In addition to lack of signage, high grasses may obstruct a driver's view at crossings.

9.3.7 Heavy Equipment

Track hoes, bulldozers, dump trucks, vacuum trucks, commercial pickup trucks, and other heavy machinery may be present at the site. Stay outside of the boom radius of any lever-based heavy machinery. Be aware of high-pressure gas lines when positioning equipment.

9.3.8 Electrical

Underground power lines, generators, light plants, and plug-in power sources may create the potential for electrical shock or electrocution. Assess all CTEH® power equipment and power cords for defects. If any electrical equipment is defective, remove from service, and clearly indicate that the equipment is not safe for use until repaired. For your own safety, maintain awareness of other site personnel and equipment that may cause electrical issues.

9.3.9 Fire & Explosion

Fire and explosion hazard is highly unlikely at this site. The potential existence of trace concentrations of methane, H2S, and an ignition source, may create fire and explosion hazards either indoors or outdoors.

In general, vapors and gases may travel to sources of ignition and flash back. Many vapors and gases are heavier than air, spreading along ground and collecting in low or confined areas (basin, sewers, basements, tanks) resulting in areas of increased concentration. Accumulation in these low-lying areas may create fire or explosion hazard.

Specifically, H_2S is heavier than air and may travel a considerable distance to sources of ignition causing flash back or an explosion.

Methane burns readily at atmospheric pressure and amgient temperature. Methane is a reducing agent and reacts explosively when combined with especially powerful oxidizers such as bromine pentafluoride, chlorine trifluoride, chlorine, iodine, heptafluoride, dioxygenyl tetrafluoroborate, dioxygen difluoride, trioxygen difluoride and liquid oxygen (Handling Chemicals Safely 1980)[5].

9.3.10 Hot Work

Response operations may include hot work (i.e., cutting or grinding). Due to the potential fire and explosion hazards of hydrogen sulfide and methane , **WELDING OR USE OF TORCHES IS NOT PERMITTED UNLESS A HOT WORK PERMIT OR OTHER WRITTEN PERMISSION IS OBTAINED FROM THE SITE HEALTH AND SAFETY OFFICER - NO EXCEPTIONS**. CTEH® employees will not participate or assist in the performance of hot work if this condition is not met. If hot work occurs and CTEH® is tasked with providing air monitoring

[5] Nederlandse Vereniging van Veiligheidstechnici Veiligheidsinstituut (Amsterdam Netherlands) & Vereniging van de Nederlandse Chemische Industrie. (1980). *Handling chemicals safely 1980* (2d ed.). Dutch Association of Safety Experts : Dutch Chemical Industry Association : Dutch Safety Institute.

for the hot work permit, LEL monitoring (confirmed by VOC readings) will be performed to determine whether combustible vapors are detected at or near the relevant Action Levels. CTEH personnel will not sign hot-work permits. See the CTEH® hot work policy or speak with the Corporate Safety Officer for clarification.

9.3.11 Trip Hazards

Uneven or slick terrain provides an environment in which slips, trips, and falls should be considered. Be aware of your travel path prior to walking or changing directions. Search for any obstructions that may present a trip hazard.

9.3.12 Noise

Emergency Response work sites are considered non-traditional and often difficult to characterize noise exposures. Please keep hearing protection readily accessible. For work areas experiencing high noise levels (greater than 90 dB) and/or impact noise (greater than 140 dB), please utilize hearing protection.

9.3.13 Eye Protection

The site may include dusty conditions or particulate hazards from other sources. If dusty conditions are present, helmet-mounted goggles should replace safety glasses to further protect your eyes from particulate-induced eye injury. Safety glasses must be worn whenever there is a potential for flying object or debris from any source (e.g., grinding, cutting, construction activities, etc.). All eye protection including glasses, face shields, and goggles, must meet minimum requirements contained in ANSI standard Z87.1.

9.3.14 Dermal Contact Hazards

Compressed gases may create low temperatures when they expand rapidly. Leaks and uses that allow expansion may cause a frostbite hazard. Wear appropriate protective clothing to prevent the skin from becoming frozen.

Poison Oak and Poison Ivy may be present in areas encountered by field personnel. Use caution to avoid contact with these plants, this includes equipment as well.

10.0 EXPOSURE CONTROL

10.1 Personal Protection Requirements

The following is the default level of PPE required. This level may be modified depending on specific site conditions or job tasks as determined by the Project Manager. Prior to beginning any work task determine the appropriate level of PPE through consultation with the PM or Site Safety Officer.

- Level D - Hardhat, eye protection, foot protection, hearing protection.

- Level D PPE may also include helmet-mounted eye protection goggles.

10.2 Respiratory Protection Guidelines

If CTEH® elects or is requested to engage in operations necessitating respiratory protection, an addendum to this document may be produced. If CTEH® employees are required to work in Immediately Dangerous to Life or Health (IDLH) atmospheres then the CTEH® Respiratory Protection Program will consulted for procedures and controls that shall be in place, including requirements for use of self-contained breathing apparatus (SCBA) equipment.

11.0 JOB SAFETY ANALYSIS

A daily Job Safety Analysis will be discussed prior to the start of work. The names and duties of non-CTEH onsite personnel will be presented at that time. CTEH personnel who will be onsite for the study and associated job tasks are provided in Table 7-1 below.

Table 7-1. CTEH Employees onsite for the Denbury CO2 simulation study and their associated job descriptions for the study duration.

<table>
<tr><th>Name</th><th>Title</th><th>Job Description</th><th>Phone/Email</th></tr>
<tr><td>Cole Ledbetter, CIH, CSP</td><td>Study Safety Officer</td><td>Conducts equipment calibration, pre-study validation testing, air monitoring external to the containment structure during study, clearance air monitoring during study, and air monitoring along the fence line in the event of an emergency release; ensures compliance with the HASP; assumes leadership role for CTEH personnel in the event of an emergency.</td><td>501-337-2900
Cledbetter@cteh.com</td></tr>
<tr><td>Michael Lumpkin, PhD, DABT</td><td>Study Technical Director</td><td rowspan="5">Conducts equipment calibration, pre-study validation testing, air monitoring external to the containment structure during study, clearance air monitoring during study, and air monitoring along the fence line in the event of an emergency release.</td><td>501-366-8304
mlumpkin@cteh.com</td></tr>
<tr><td>Angie Perez, PhD, CIH</td><td>Study Project Manager</td><td>541-901-9000
aperez@cteh.com</td></tr>
<tr><td>Jason Callahan, MS, CIH, CSP</td><td>Study Participant – Ventilation Lead</td><td>501-366-8044
jcallahan@cteh.com</td></tr>
<tr><td>Ernie Shirley</td><td>Study Participant</td><td>601-946-9474
eshirley@cteh.com</td></tr>
<tr><td>Taylor Simoneau</td><td>Study Participant</td><td>501-271-8189
tsimoneau@cteh.com</td></tr>
</table>

12.0 EDUCATION & TRAINING

Training documentation will be verified using the ISN Quick Check process.

- General Safety Awareness Training – Examples include OSHA 10-hour, PEC SafeLand, IADC Rigpass, etc.
- First Aid, CPR, and AED – Minimum of one crew member per work location
- Denbury HSE Orientation

12.1 Site specific training required:

Hydrogen sulfide awareness training will be required by all onsite personnel. Additionally, the following site-specific training topics may be reviewed prior to work on the site:

☒ Site Hazards (chemical hazards, physical hazards, etc.)

☒ Work areas / activities identified

☒ Site Emergency Alerting / Contingency Plan

☒ Evacuation Route / Assembly Areas

☒ Required PPE

☒ Obtaining Medical Treatment / First Aid

☒ Buddy System

☐ Confined Space

Other: Low Oxygen Environments

☐ Other: ______________________________

12.2 Safety Briefing/Hazard Communication

A safety briefing will occur prior to the beginning of each shift and anytime that work conditions change. Site safety briefings will be completed each day and kept on file.

13.0 SAFETY EQUIPMENT, LOCATION, RESPONSIBILITY

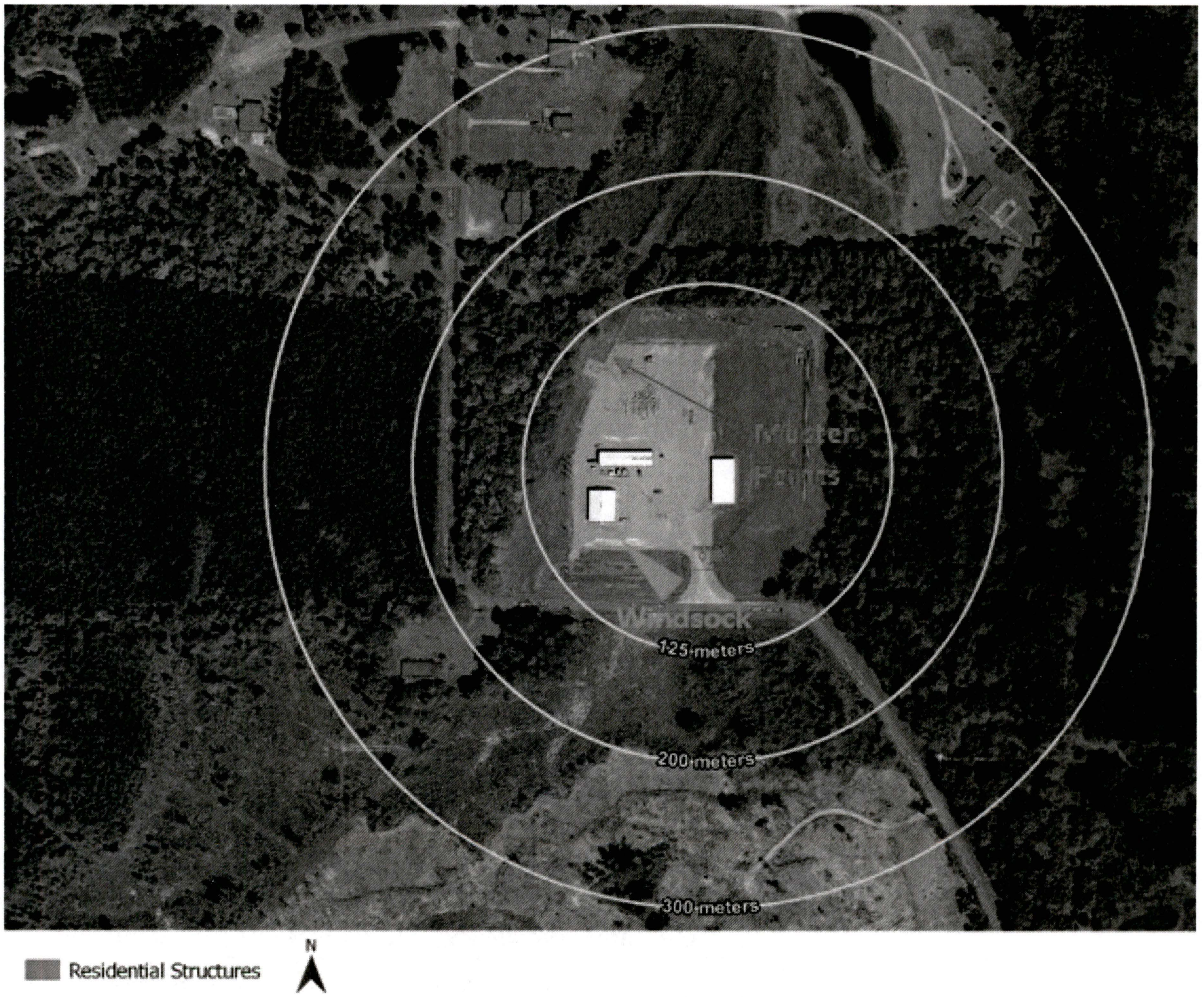
First Aid Kit	All Sites	First Aid/CPR trained personnel may use this kit to administer first aid as necessary.
Fire Extinguisher	Ask Site Safety Officer	Fire Extinguisher trained personnel may use this to extinguish small, manageable fire. Do not attempt to extinguish chemical fires based on compatibility, nor large fires for which the extinguisher is incapable of mitigating. For chemical fires or large fires, contact the fire dept.
Communication	Throughout site	Cell phones shall be used to maintain communication for all personnel.
Sanitation	Throughout site	Portable latrines or designated restroom facilities must be present in compliance with 29 CFR 1910.141 - Sanitation.
Lighting	Throughout site and on personnel	Permanent or temporary lighting must be used to illuminate the work area during dark or night operations. Personnel must be equipped with flashlights or headlamps during dark or night operations where other forms of lighting are not practicable.

14.0 CONTINGENCY PLANS

In the event of an emergency at the worksite, the person first noticing the emergency should notify other workers in the immediate area. Evacuation should commence at once if the emergency poses any threat to the safety of the workers. Upon receiving notification of an emergency, the individual in charge of the work area should take appropriate measures to protect human life, the environment (including wildlife), and property.

14.1 Escape Routes:

Specific to an accidental release of CO_2, on-site personnel will evacuate to the muster location that is uphill and upwind of the release location.



14.2 Emergency Source Control:

In the event of a release that results in CO_2 concentrations exceeding the community air monitoring action level (20,000 ppm), the CO_2 source will immediately be shut off and the enclosure will be evaluated for leaks.

In the event of a catastrophic release, as soon as it is safe to do so, Denbury personnel will don relevant PPE to shut off flow to the leaking source, if applicable.

14.3 Alerting Method:

Be aware of alerting methods, such as air horns, whistles, etc., that may indicate site conditions are no longer safe and workers should egress as directed in the onsite safety briefing or JSA. Communication will be through two-way radios and/or cell phones.

14.4 Community Notification:

In the event of a release that results in CO2 concentrations exceeding the community air monitoring action level (20,000 ppm for one hour or more), the neighboring residents will be notified of the exceedance.

15.0 AMENDMENTS TO SITE SPECIFIC HEALTH & SAFETY PLAN

This Site-Specific Health and Safety Plan is based on information available at the time of preparation. Unexpected conditions may arise which necessitate changes to this plan. Unplanned activities and/or changes in the hazard status should initiate a review of major changes in this plan.

Changes in the hazard status or unplanned activities are to be submitted on "Amendments to Site-Specific Health and Safety Plan" which is included on the following page. Amendments must be approved by the Project Manager prior to implementation.

All notes, documentation, and records must NOT be discarded after their use. Documents are to be submitted to the CTEH Project Manager and departmental policies on document retention shall be followed.

Health & Safety Plan Management of Change

Change 001			
Description of Change (include sections & page numbers):			
	Name/Position	Signature	Date Signed
Prepared By:			
Approved By:			

Change 002			
Description of Change (include sections & page numbers):			
	Name/Position	Signature	Date Signed
Prepared By:			
Approved By:			

Change 003			
Description of Change (include sections & page numbers):			
	Name/Position	Signature	Date Signed
Prepared By:			
Approved By:			

Sign-In

Name	Signature	Date Signed

Addendum A

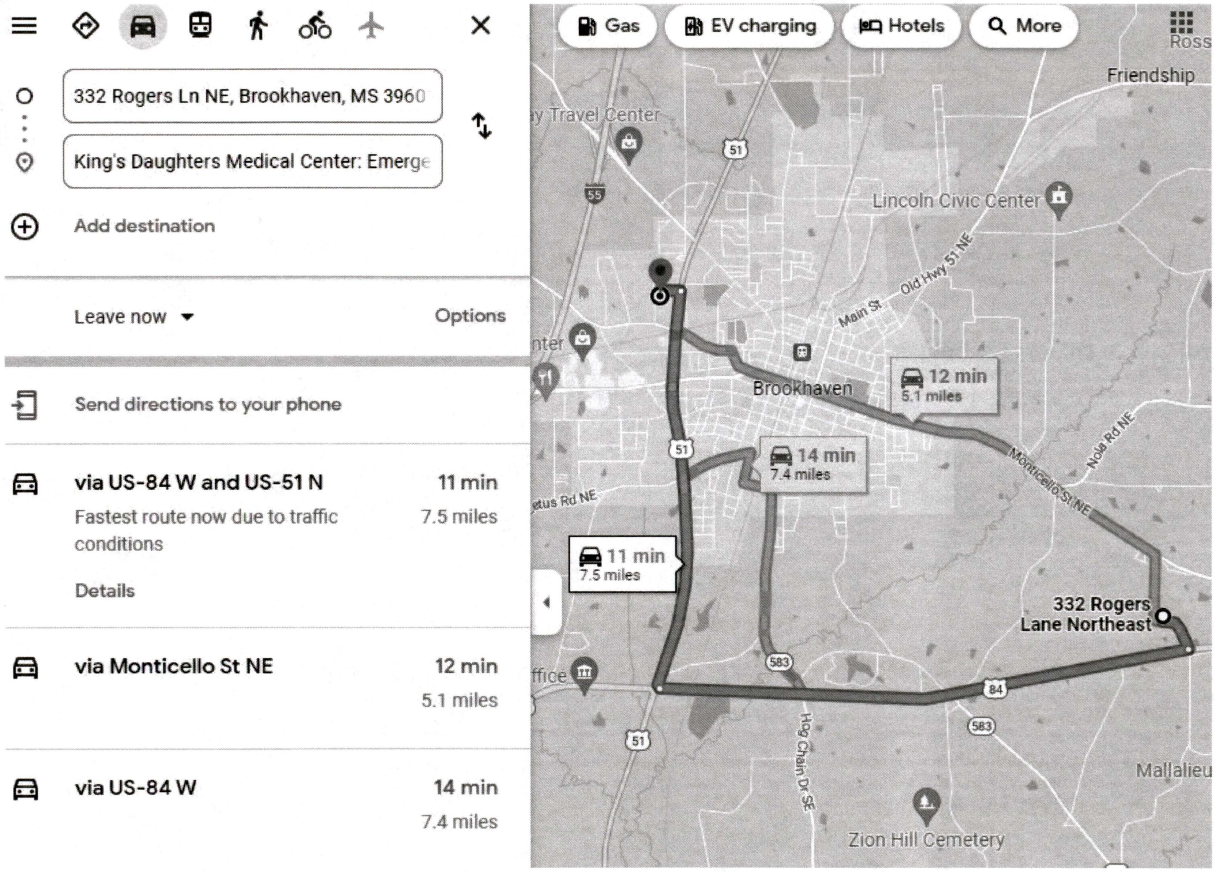
Hospital Map

King's Daughters Medical Center: ER

427 US-51

Brookhaven, MS

601-833-6011



Appendix B: Calibration Logs and Field Forms

Appendix C: Study Gas Certificate of Analysis

CTEH®

Airborne Labs International
22C World's Fair Drive Somerset, NJ 08873 T: 732-302-1950 F: 732-302-3035
E-mail: LabServices@airbornelabs.com Website: www.airbornelabs.com

Carbon Dioxide (CO_2) Analysis
Advanced Feed Gas Characterization Program©

Denbury Onshore LLC	ALI Track No.: 22-1372
332 Rogers Lane	Received On: 12/09/22
Brookhaven, MS 39601	Report Date: 12/16/22
Phone: 601-248-3295, 601-248-1520	Invoice No.: 2022-1619
Attn.: Mr. John Ard and Mr. Jamie Price	
E-Mail: john.ard@denbury.com; jamie.price@denbury.com	Sample Date: 12/05/22
Sample ID.: Vaporized Liquid CO_2 / Gaseous CO_2: "Brookhaven Pump Station"	Process Stage: Feed
Sample ID.: Received in 2L True Blue MLB Polybag 1.2 + MiniCyl 1.0 No-Haz Feed Gas Kit	

Test Description/Units:	Result	LOQ	Spec
CO_2 Identification (Positive / Negative by [DT]):	positive	5	report
Comments: Positive ID = Positive Detector Tube Response.			
CO_2 Purity (% v/v, [GC]):	99.6+	5	report
Comments: Obtained by NCG + target list impurity subtraction method			
Hydrogen (H_2, ppm v/v, [GC]):	nd	10	report
Helium (He, ppm v/v, [GC]):	--*	50	report
Comments: *Not a std feed gas test = special add-on test requiring 2nd minicyl.			
Oxygen + Argon (O_2 + Ar, ppm v/v, [GC]):	nd	10	report
Comments: Result represents Total O_2 + Ar ppm v/v.			
Nitrogen (N_2, ppm v/v, [GC]):	450	10	report
Carbon Monoxide (CO, ppm v/v, [DT]):	nd	2	report
Ammonia (NH_3, ppm v/v, [DT]):	nd	0.5	report
Oxides of Nitrogen (NO_x, ppm v/v,[DT]):	nd	0.5	report
Comments: Speciation performed if NO_x is above 2.5 ppm v/v			
Nitric Oxide (NO, ppm v/v, [DT]):	nd	0.5	report
Nitrogen Dioxide (NO_2, ppm v/v, [DT]):	nd	0.5	report
Phosphine (PH_3, ppm v/v, [DT]):	INT*	0.25	report
Comments: *Interference from sulfides present.			
Total Hydrocarbons (THC, ppm v/v as CH_4, [THA]):	3,400	0.1	report
Comments:			
Total Non-Methane Hydrocarbons (TNMHC, ppm v/v as CH_4, [GC]):	79	0.1	report
Methane (CH_4, ppm v/v, [GC]):	3,300	0.1	report
Acetaldehyde (AA, ppm v/v, [GC]):	0.14	0.05	report
Aromatic Hydrocarbon Content (ppb v/v as Benzene, [GC]):	580	2	report
Benzene (ppb v/v [GC]):	580	2	report
Toluene (ppb v/v, [GC]):	280	2	report
Ethyl Benzene (ppb v/v, [GC]):	nd	2	report
m,p Xylenes (ppb v/v [GC]):	120	2	report
o Xylene (ppb v/v [GC]):	38	2	report
Comments:			
Total Sulfur Content* (TSC* ppm v/v as S, [GC]):	9.6	0.01	report
Comments: *Obtained by summation of all speciated VSC target impurities less SO_2			
Sulfur Dioxide (SO_2, ppm v/v, [GC]):	nd	0.05	report
Hydrogen Cyanide (HCN, ppm v/v, [GC]):	nd	0.2	report
Vinyl Chloride (VCl, ppm v/v, [GC]):	nd	0.1	report
Radon (Rn^{222}, pCi/L, [Lucas Cell]):	--*	0.1	report
Comments: *Not a std feed gas pgm test = specialized add-on test requiring an Rn222 sampling kit.			
Ethylene Glycol (ppm v/v, [GC]):	--*	2	report
Comments: *Not a std feed gas pgm test = specialized add-on test requiring a Sorbent tube sampling kit.			

Sample ID: Denbury Onshore LLC **ALI Track No.:** 22-1372

Speciated Volatile Hydrocarbons (VHC, ppm v/v)	Result	LOQ	Spec.
Ethane:	21	0.1	report
Ethylene:	nd	0.1	report
Propane:	4.2	0.1	report
Propylene:	nd	0.1	report
Isobutane:	0.8	0.1	report
n-Butane:	1.1	0.1	report
Butene:	nd	0.1	report
Isopentane:	0.6	0.1	report
n-Pentane:	0.5	0.1	report
Hexanes+:	4.3	0.1	report

Comments: C_6+ results include VOX compounds and C_6+ alkanes/alkene hcs. Pk ID based upon t_r match vs target analyte std. CH_4 result on pg 1.

Speciated Volatile Sulfur Compounds (VSC, ppm v/v)			
Hydrogen Sulfide (H_2S):	9.5	0.01	report
Carbonyl Sulfide (COS):	0.016	0.01	report
Methyl Mercaptan:	nd	0.01	report
Ethyl Mercaptan:	nd	0.01	report
Dimethyl Sulfide:	nd	0.01	report
Carbon Disulfide:	nd	0.01	report
t-Butyl Mercaptan:	nd	0.01	report
Isopropyl Mercaptan:	nd	0.01	report
n-Propyl Mercaptan:	nd	0.01	report
Methyl Ethyl Sulfide:	nd	0.01	report
2-Butyl Mercaptan:	nd	0.01	report
i-Butyl Mercaptan:	nd	0.01	report
Diethyl Sulfide:	nd	0.01	report
n-Butyl Mercaptan:	nd	0.01	report
Dimethyl Disulfide:	nd	0.01	report
Unknown VSC:	nd	0.01	report

Comments: Peak ID based upon t_r match against target analyte standards. Note: SO_2 + TSC* results reported on pg. 1.

Speciated Volatile Oxygenates (VOX, ppm v/v)			
Dimethyl Ether:	nd	0.1	report
Ethylene Oxide:	nd	0.1	report
Diethyl Ether:	nd	0.1	report
Propionaldehyde:	nd	0.1	report
Acetone:	0.3	0.1	report
Methanol:	0.2	0.1	report
t-Butanol:	nd	0.1	report
Ethanol:	0.8	0.1	report
Isopropanol:	nd	0.1	report
Ethyl Acetate:	0.9	0.1	report
Methyl Ethyl Ketone:	nd	0.1	report
2-Butanol:	nd	0.1	report
n-Propanol:	nd	0.1	report
Isobutanol:	nd	0.1	report
n-Butanol:	trace	0.1	report
Isoamyl Alcohol:	nd	0.1	report
Isoamyl Acetate:	trace	0.1	report
Unknown VOX:	3.6	0.1	report

Comments: Peak ID based upon t_r match against target analyte standards. AA & Ethylene Glycol results reported on pg. 1.

LOQ = Limit of Quantitation (lowest amount of analyte quantitatively determined with suitable precision and accuracy) **MDL** = method detection limit (lowest amount of analyte detected). **trace** = unquantified amount observed between MDL and LOQ. **nd** = indicates the impurity was not detected (below MDL). **--** = test not performed. **na** = not available. **LT** = less than the amount specified. **GT** = greater than the amount specified. **%** = percent. **ppm** = parts per million. **ppb** = parts per billion. **v/v** = volume analyte/volume sample. **w/w** = weight analyte/weight sample. **[result]** indicates the result was obtained by the method listed within brackets. **TSC*** = ISBT Total Sulfur Content excluding SO_2. **Unit Conversions:** 1ppm v/v = 1μL/L = 1000 ppb = 0.0001% v/v. **Date format:** MM/DD/YY.

Report Summary:

Customer requested an advanced CO_2 feed gas test program.

Reviewed by / Date:

Jeff Wahome 12/16/22

Jeff Wahome - Analytical Operations Manager

Attachments: none

Addendum: Signatures, Instrument & Notebook data on-file

ilac-MRA PJLA Testing

Accreditation # 68099

ISO Statement

Statements of conformity (pass or fail) resulting from the test/analysis performed on the above sample will not take into account the reported measurement uncertainty unless otherwise specified. This is a shared risk decision rule in which the customer also has responsibility for determining acceptance of the results. The methods Airborne Labs International uses are developed by Airborne Labs International and are based on the current revisions of international, national, or industry standards unless otherwise specified. Methods can be reviewed by the customer upon request. The acceptance criteria of the above item are based on ISBT specifications, NFPA, CGA, USP, or other industry specifications unless otherwise specified on the contract.

F-21.3.2v3 (04/21)

Appendix D: Monitoring Equipment Information Sheets

CTEH®

Honeywell
RAE SYSTEMS

AreaRAE Pro

Easy to use transportable area monitor for multiple threat detection.

AreaRAE Pro

Remote visibility on more threats than ever for a new level of real-time situational awareness

AreaRAE Pro is a wireless, transportable area monitor that can simultaneously detect toxic and combustible gases, volatile organic compounds, radiation and meteorological factors. Whether you're carrying it into a hazmat response, setting up perimeter at a fire or protecting a public venue, the AreaRAE Pro works with Honeywell's remote monitoring software to give you a real-time view of threat readings so you can make real time decisions to ensure the safety of your teams and the general public.

AreaRAE Pro delivers maximum flexibility and versatility in one device:

- **Up to six 4R+ sensors for toxic and combustible gas.**
AreaRAE Pro offers more than 20 interchangeable sensors that can be swapped at a moments notice to meet the changing needs of first responders.

- **7R+ photoionization detector.**
Monitor VOCs in parts per billion, with built-in compensation for temperature and humidity.

- **Meteorological station for tracking toxic plumes.**
Honeywell's compact RAEMet sensor sits at the top of the AreaRAE Pro and measures wind speed, wind direction, temperature and humidity. This information is then modeled in Honeywell's real time monitoring software which integrates the ALOHA hazard monitoring program.

- **Optional gamma sensor for radiation detection.**
Detect and measure gamma radiation with increased sensitivity and faster response without using an additional sensor slot.

Applications
- First responders
- Hazmat
- Civil Defense & Military
- Public Venue Protection

Ease and Fexibility
- Available in Rapid Deployment Kit for quick threat assessment
- User-friendly interface; turn it on and go
- Supports long-distance remote monitoring
- Built-in mesh modem for short-range monitoring — no external router required
- Flexible power options for short- and long-term deployments
- Easy to hear and see, with 108-decibel alarm
- Easy USB connection to configuration software
- Device Management with Honeywell Sotera™

Remote Visibility on Threats
- Delivers real-time readings to Honeywell's remote monitoring software, so you can instantly determine the location and severity of a threat
- Map-based display is accessible from any computer with an internet connection — or from our laptop as a turnkey host
- Enables coordination and data sharing in joint operations

Specifications

DIMENSIONS	314 x 306 x 166 mm (with rubber boot) 12.36" x 12.04" x 6.53" (with rubber boot)
WEIGHT	6.3 kg (13.88 lb) full option configuration 6.5 kg (14.33 lb) full option configuration (+RAEMet)
GAS SENSORS SLOTS	up to 7; see Sensor list
ADDITIONAL SENSORS	Gamma; RAEMet (Wind Speed, Wind Direction, Temperature & Humidity)
GPS	Standard equipment in every unit
BATTERY	Rechargeable 7.2 V / 10 Ah Li-ion battery pack with built-in charger Alkaline Battery Adapter
OPERATING HOURS	~20 hours with wireless connectivity on Li-ion battery pack ~12 hours with wireless connectivity on Alkaline battery adapter
	Specification at room temperature (20°C)
DISPLAY	Large 240 x 320 pixel LCD backlit display
	64 x 85 mm / 2.5" x 3.33"
KEYPADS	3 operation and programming keys
ALARMS	Multi-tone 108 dB buzzer @ 3.3 ft / 1 m, Bright LED 360 degree view and on-screen indication of alarm conditions
	Additional diagnostic alarm and display message for low battery
	Wireless connectivity alarm
DATA LOGGING	Continuous data logging (90 days for 7 gas sensors, 1 Gamma sensor, 1 RAEMet (wind speed & direction, temp and RH), and GPS at 1 min intervals, 24/7)
DATA STORAGE	24M bytes (memory full action: stop when full or Wrap around)
DATA INTERVAL	User-configurable from 1 to 3,600 sec
WIRELESS[1]	Bluetooth Low Energy module (BT4.0) and GPS
	Primary radio module: - Long range ISM License Free 900 MHz or 2.4 GHz radio - IEEE 802.11 b/g Wi-Fi
	Secondary radio module: Short Range IEEE 802.15.4 900 MHz or 868 MHz Mesh Radio
	Wireless range[3]: Up to 2 miles (3 km) for ISM 900 MHz; Up to 1.2 miles (2 km) for ISM 2.4 GHz; Up to 330 ft (100m) for Wi-Fi; Up to 660 ft (200m) for Mesh secondary radio; Up to 15 ft (5m) for BLE.
	Wireless Approval: FCC Part 15, CE R&TTE, Others[4]
COMMUNICATION	Communicates to ProRAE Studio II via USB cable to PC;
	Wireless data and alarm status transmission via Wi-Fi or ISM modem;
	Act as gateway to connect up to 8 remote instruments (using secondary radio module)
SAFETY CERTIFICATION	US / Canada: Class 1, Division 2 Groups A, B, C, D
SAMPLING PUMP	Built-in pump, typical flow rate 450 cc/min
TEMPERATURE	-20 °C to +50 °C / (- 4 °F to +122 °F)
HUMIDITY	0% to 95% relative humidity (non-condensing)
INGRESS PROTECTION (IP)	IP 65
PERFORMANCE TESTS	MIL-STD-810G and 461F
	LEL CSA C22.2No. 152, ISA-12.13.01
WARRANTY[2]	Four years for O_2 Liquid Oxygen sensors Three years for CO, and H_2S sensors Two years for non-consumable components, catalytic LEL sensor and 10.6eV 7R+ PID lamp One year on all other sensors, battery, and other consumable parts Six months for 9.8eV lamp PID sensor

RAEMet SPECIFICATIONS	
WIND SPEED	Range: 0 to 20 m/s (0 to 44 mph) Start Speed: 0.1 m/s (0.22 mph)
WIND DIRECTION	Range: 360° (No dead band)
TEMPERATURE	- 20 °C to 60 °C (-4 °F to 140 °F) Resolution 0.1 °C (1.8 °F)
HUMIDITY	10 to 95% RH Resolution 1% RH
COMPASS	Resolution 1°
POWER	Power supplied by the AreaRAE Pro

[1]Additional equipment and/or software licenses may be required to enable remote wireless monitoring and alarm transmission
[2]Against factory defects
[3]Receiving > 80%
[4]Contact RAE Systems for country specific wireless approvals and certificates
Specifications are subject to change

Supported Sensors

SENSOR	RANGE	RESOLUTION
PID SENSORS		
4R+; 10.6eV ppb	0 to 2,000 ppm	10 ppb
7R+; 10.6 eV ppb	0 to 2,000 ppm	10 ppb
4R+; 9.8 eV*	0 to 2,000 ppm	0.1 ppm
COMBUSTIBLE SENSOR		
CATALYTIC BEAD SENSOR	0 to 100% LEL	1% LEL
NDIR SENSOR		
CARBONE DIOXIDE (CO_2)	0 to 50,000 ppm	100 ppm
ELECTROCHEMICAL SENSORS		
AMMONIA (NH_3)	0 to 100 ppm	1 ppm
CARBON MONOXIDE (CO)	0 to 500 ppm	1 ppm
CARBON MONOXIDE EXT. (CO HR)	0 to 2,000 ppm	10 ppm
CARBON MONOXIDE H_2 Comp (CO H_2 Comp)	0 to 2,000 ppm	10 ppm
CHLORINE (Cl_2)	0 to 50 ppm	0.1 ppm
CHLORINE DIOXIDE (ClO_2)	0 to 1 ppm	0.03 ppm
ETHYLENE OXIDE (ETO-A)	0 to 100 ppm	0.5 ppm
ETHYLENE OXIDE (ETO-B)	0 to 10 ppm	0.1 ppm
ETHYLENE OXIDE (ETO-C)	0 to 500 ppm	10 ppm
HYDROGEN (H_2)	0 to 2,000 ppm	10 ppm
HYDROGEN CHLORIDE (HCl)	0 to 15 ppm	1 ppm
HYDROGEN CYANIDE (HCN)	0 to 50 ppm	0.5 ppm
HYDROGEN FLUORIDE (HF)	0.5 to 10 ppm	0.1 ppm
HYDROGEN SULFIDE (H_2S)	0 to 100 ppm	0.1 ppm
HYDROGEN SULFIDE EXT. (H_2S HR)	0 to 1,000 ppm	1 ppm
OXYGEN (O_2)	0 to 30 %	0.10 %
SULFUR DIOXIDE (SO_2)	0 to 20 ppm	0.1 ppm
NITRIC OXIDE (NO)	0 to 250 ppm	0.5 ppm
NITROGEN DIOXIDE (NO_2)	0 to 20 ppm	0.1 ppm
PHOSPHINE (PH_3)	0 to 20 ppm	0.1 ppm
GAMMA RADIATION SENSOR		
GAMMA I-SENSOR	0.01 µSv/h to 0.2 mSv/h (1 µrem/h to 0.02 rem/h)	50 keV to 3 MeV

Honeywell Gas Detection

Honeywell is able to provide gas detection solutions to meet the requirements of all applications and industries.
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While every effort has been made to ensure accuracy in this publication, no responsibility can be accepted for errors or omissions. Data may change, as well as legislation, and you are strongly advised to obtain copies of the most recently issued regulations, standards, and guidelines. This publication is not intended to form the basis of a contract.

AreaRAE Pro_DS01162_V3_EN
01-17

Device Management with
Honeywell Sotera™

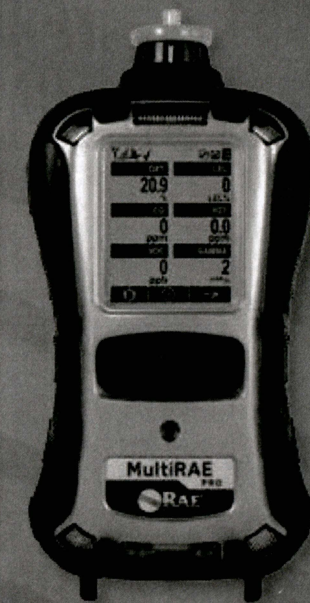
honeywellanalytics.com/products/
Honeywell-Sotera

Honeywell

RAE SYSTEMS by Honeywell

MultiRAE Pro

Wireless Portable Multi-Threat Radiation and Chemical Detector



The MultiRAE Pro is the industry's only portable wireless multi-threat monitor. The MultiRAE Pro's ability to simultaneously detect gamma radiation and toxic industrial chemicals (TICs/TIMs) enables responders to reduce the equipment footprint and achieve greater agility when operating downrange.

The MultiRAE Pro's optional wireless capability improves safety by providing commanders and safety officers real-time access to instrument readings and alarm status from any location[1] for better situational awareness and faster incident response.

- **Detector of choice for government agencies and top HazMat teams worldwide**
- **Highly versatile and customizable**
- **Man Down Alarm with real-time remote wireless notification**
- **Compliant with MIL-STD-810G and 461F performance standards**
- **Fully automatic bump testing and calibration with AutoRAE 2**

KEY FEATURES

Wireless. Versatile. Proven.

- All-in-one monitoring capabilities for radiation, VOCs, oxygen, toxic and combustible gases, up to 6 threat types at a time[2]
- Over 25 interchangeable sensor options, including parts-per-billion PID and gamma radiation
- Wireless access to real-time instrument readings and alarm status from any location
- Unmistakable five-way local and remote wireless notification of alarm conditions
- Intelligent sensors store calibration data, so they can be swapped in the field[3]
- Large graphical display with easy-to-use, icon-driven user interface

APPLICATIONS

- Civil defense (search and rescue)
- Homeland security
- HazMat response
- Military
- Semiconductor manufacturing
- Environmental

CBRN detection with the MultiRAE Pro

MIL-STD-461F | MIL-STD-810G | Wireless | AutoRAE 2 Compatible | ISO 9001 CERTIFIED | CSA US | ATEX | IECEx | CE | Ex | FCC

MultiRAE Pro

Wireless Portable Multi-Threat Radiation and Chemical Detector

RAE SYSTEMS by Honeywell

SPECIFICATIONS

Instrument Specifications[4]

Size	7.6" H x 3.8" W x 2.6" D (193 x 96.5 x 66 mm)
Weight	31 oz (880 g)
Sensors	Over 25 intelligent interchangeable field-replaceable sensors including gamma radiation, ppb and ppm PID sensors for VOCs, electrochemical sensors for toxic gases and oxygen, combustible LEL and NDIR sensors, and CO_2 NDIR sensor
Battery Options, Runtime[5] and Recharge Time	- Rechargeable Li-ion (~12-hr. runtime, < 6-hr. recharge time) - Extended duration Li-ion (~18-hr. runtime, < 9-hr. recharge time) - Alkaline adapter with 4 x AA batteries (~6-hr. runtime)
Display	Monochrome graphical LCD display (128 x 160) with backlighting Automatic screen "flip" feature
Display Readout	- Real-time reading of gas concentrations; PID measurement gas and correction factor; Man Down Alarm on/off; visual compliance indicator; battery status; datalogging on/off; wireless on/off and reception quality. - STEL, TWA, peak, and minimum values
Keypad Buttons	3 operation and programming keys (Mode, Y/+, and N/-)
Sampling	Built-in pump. Average flow rate: 250 cc/min. Auto shutoff in low-flow conditions
Calibration	Automatic with AutoRAE 2 Test and Calibration System or manual
Alarms	Wireless remote alarm notification; multi-tone audible (95 dB @ 30 cm), vibration, visible (flashing bright red LEDs), and on-screen indication of alarm conditions - Man Down Alarm with pre-alarm and real-time remote wireless notification
Datalogging	Continuous datalogging (6 months for 5 sensors at 1-minute intervals, 24/7) - User-configurable datalogging intervals (from 1 to 3,600 seconds)
Communication and Data Download	- Data download and instrument set-up and upgrades on PC via desktop charging and PC comm. cradle, travel charger, or AutoRAE 2 Automatic Test and Calibration System - Wireless data and alarm status transmission via built-in RF modem (optional)
Wireless Network	ProRAE Guardian Real-Time Wireless Safety System or EchoView Host-based Closed-Loop System
Wireless Range (Typical)	MultiRAE Pro to RAELink3 [Z1] Mesh modem ~330 feet (100 meters) MultiRAE Pro to EchoView Host, RAEMesh Reader or RAEPoint ~660 feet (200 meters)
Operating Temperature	-4° to 122°F (-20° to 50°C)
Humidity	0% to 95% relative humidity (non-condensing)
Dust and Water Resistance	IP-65 ingress protection rating
Safety Certifications	CSA: Class I, Division 1, Groups A, B, C and D, T4 Class II, Division 1, Groups E, F, G T85°C ATEX: 0575 II 1G Ex ia IIC T4 Ga 2G Ex ia d IIC T4 Gb with IR Sensor installed I M1 Ex ia I Ma IECEx: Ex ia IIC T4 Ga Ex ia d IIC T4 Gb with IR Sensor installed I M1 Ex ia I Ma IECEx/ANZEx: Ex ia IIC T4 Ga Ex ia d IIC T4 Gb with IR Sensor installed Ex ia I Ma
EMI/RFI[5]	EMC directive: 2004/108/EC
Performance Tests	MIL-STD-810G and 461F compliant. LEL CSA C22.2 No. 152; ISA-12.13.01
Languages	Arabic, Chinese, Czech, Danish, Dutch, English, French, German, Indonesian, Italian, Japanese, Korean, Norwegian, Polish, Portuguese, Russian, Spanish, Swedish, and Turkish
Warranty	- Two years on non-consumable components and catalytic LEL, CO, H_2S, and O_2 sensors - One year on all other sensors, pump, battery, and other consumable parts
Wireless Frequency	ISM license free band. IEEE 802.15.4 Sub 1GHz
Wireless Approvals	FCC Part 15, CE R&TTE, Others[4]
Radio Module	Supports RM900A

Sensor Specifications[4]

Radiation Sensor	Range	Sensor Type
Gamma	0 to 20,000 μRem/h (dose rate)	1cc CsI (Tl) scintillator with photodiode
PID Sensors	**Range**	**Resolution**
VOC 10.6 eV (Ext. Range) VOC 10.6 eV (ppb)	0 to 5,000 ppm 0 to 2,000 ppm	0.1 ppm 10 ppb
Combustible Sensors	**Range**	**Resolution**
Catalytic LEL NDIR (0-100% LEL Methane) NDIR (0-100% Vol. Methane)	0 to 100% LEL 0 to 100% LEL 0 to 100% Vol.	1% LEL 1% LEL 0.1% Vol.
Carbon Dioxide Sensor	**Range**	**Resolution**
Carbon Dioxide (CO_2) NDIR	0 to 50,000 ppm	100 ppm
Electrochemical Sensors	**Range**	**Resolution**
Ammonia (NH_3)	0 to 100 ppm	1 ppm
Carbon Monoxide (CO) Carbon Monoxide (CO), Ext. Range Carbon Monoxide (CO), H_2-comp. Carbon Monoxide (CO) + Hydrogen Sulfide (H_2S) Combo	0 to 500 ppm 0 to 2,000 ppm 0 to 2,000 ppm 0 to 500 ppm 0 to 200 ppm	1 ppm 10 ppm 10 ppm 1 ppm 0.1 ppm
Chlorine (Cl_2)	0 to 50 ppm	0.1 ppm
Chlorine Dioxide (ClO_2)	0 to 1 ppm	0.03 ppm
Ethylene Oxide (EtO-A) Ethylene Oxide (EtO-B)	0 to 100 ppm 0 to 10 ppm	0.5 ppm 0.1 ppm
Formaldehyde (HCHO)	0 to 10 ppm	0.05 ppm
Hydrogen Cyanide (HCN)	0 to 50 ppm	0.5 ppm
Hydrogen Sulfide (H_2S)	0 to 100 ppm	0.1 ppm
Methyl Mercaptan (CH_3-SH)	0 to 10 ppm	0.1 ppm
Nitric Oxide (NO)	0 to 250 ppm	0.5 ppm
Nitrogen Dioxide (NO_2)	0 to 20 ppm	0.1 ppm
Oxygen (O_2)	0 to 30% Vol.	0.1% Vol.
Phosphine (PH_3)	0 to 20 ppm	0.1 ppm
Sulfur Dioxide (SO_2)	0 to 20 ppm	0.1 ppm

1 Additional equipment and/or software licenses may be required to enable remote wireless monitoring and alarm transmission.
2 A two-gas combination sensor is required for a 6-gas configuration.
3 RAE Systems recommends calibrating sensors on installation.
4 Specifications are subject to change.
5 Specification for non-wireless monitors.
6 Please contact RAE Systems for specific wireless approvals

ORDERING INFORMATION (MODEL: PGM-6248)

- Wireless[1] and non-wireless configurations are available
- Refer to the Portables Pricing Guide for part numbers for monitors, accessories, sampling and calibration kits, gas, sensors, and replacement parts

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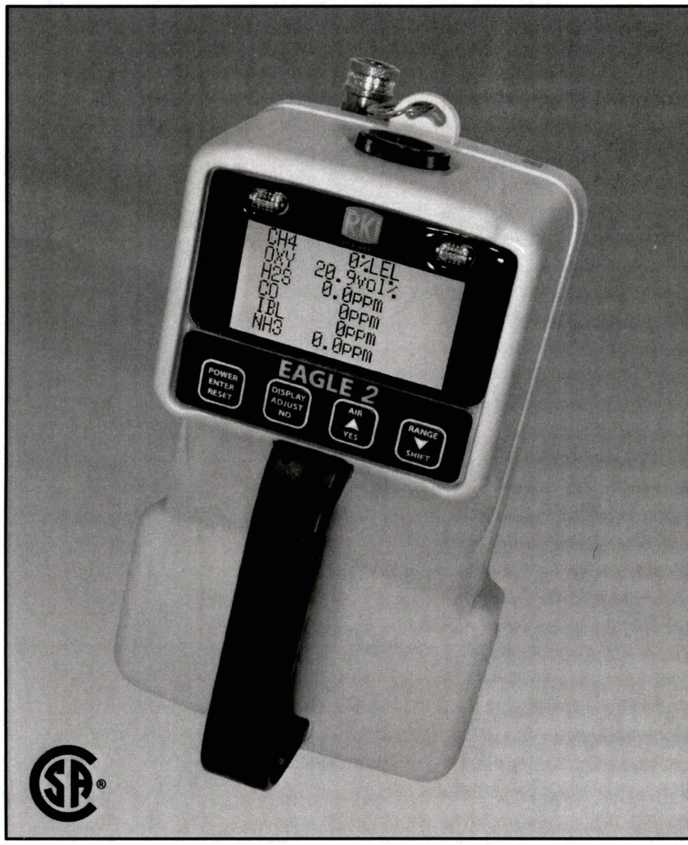
DS-1068-08

P028-2304

INSTRUMENTS

ONE TO SIX GAS PORTABLE MONITOR

Gas Detection For Life **EAGLE 2 Model**



Features

- **Monitor up to 6 different gases**
- **PPM, % LEL, or % Vol. auto-ranging combustible detection**
- **Specialty Sensors**
  - **PID (Photoionization Detector)**
    - Low or high range for VOC detection
    - Fence Electrode Technology for humidity and contamination resistance
  - **Infrared (IR)**
    CO2, % LEL CH4, % Vol. CH4, % LEL HC, % Vol. HC
  - **Thermal Conductivity (TC)**
    % Vol. H2, % Vol. CH4
  - **Smart toxic, plug and play sensors**
    NH3, AsH3, Cl2, HCN, PH3, & SO2
  - **Hydrogen specific LEL / ppm sensor**
- **Powerful long-life pump up to 125' range**
- **Low flow pump shut off and alarm**
- **Methane elimination for environmental use**
- **Alkaline 18 hours or NiMH 20 hours capability**
- **EPA Method 21 VOC Monitoring**
- **Internal hydrophobic dust filter**
- **External probe with hydrophobic filter**
- **Multilingual (5 languages)**
- **Ergonomic RFI / EMI / chemical / weather resistant enclosure**
- **Intrinsically safe design, CSA approval**
- **Datalogging standard**

The EAGLE 2 is the solution for just about any portable gas monitoring situation. Equipped with features that are not available on competitive units, the EAGLE 2 is a powerful instrument that does more than just offer the standard confined space protection for LEL, O2, H2S and CO. The EAGLE 2 offers easy access to controls such as autocalibration, alarm silence, demand zero, peak hold, and methane elimination. Each channel has two alarm levels plus TWA and STEL alarms for toxic channels. The two alarm levels are user adjustable and can be latching or self resetting.

The EAGLE 2 available features include a PID sensor for detecting high or low ppm levels (0-50 & 0-2,000) of VOC gases; % volume capability for CH4 and H2 using a TC (thermal conductivity) sensor; PPM or LEL hydrocarbon detection at the push of a button; infrared sensors for CO2 (ppm or % volume), methane or hydrocarbons in LEL and % volume ranges; methane elimination feature for environmental applications; and a variety of super toxic gases. The EAGLE 2 has a strong internal pump with a low flow auto pump shut off and alarm, which can draw samples from up to 125 feet. This allows for quick response and recovery from distant sampling locations. The EAGLE 2 will continuously operate for over 18 hours on alkaline batteries or 20 hours on NiMH. A variety of accessories are also available to help satisfy almost any application such as long sample hoses, special float probes for tank testing, and dilution fittings, just to name a few. Datalogging is a standard feature for all sensors on all versions.

The Eagle 2 is ideal for performing EPA Method 21 fugitive emission monitoring of VOC leaks from process equipment.. EPA Method 21- Determination of Volatile Organic Compound Leaks, is a test method used for the determination of leaks of VOCs from process equipment. The Eagle 2 meets the equirements for portable instruments used for this purpose as outlined in Sections 6 and 8 of Method 21.

RKI Instruments, Inc. · 33248 Central Ave. Union City, CA 94587 · Phone (800) 754-5165 · (510) 441-5656 · Fax (510) 441-5650

EAGLE 2 Model

Enclosure	Weatherproof, chemical resistant, RFI / EMI coated high impact polycarbonate-PBT blend. Can operate in 2.0" of water without leakage. Ergonomically balanced with rugged top mounted handle. Water & dust resistant equivalent to IP64.
Dimensions	9.5" L x 5.25" W x 5.875" H
Weight	3.8 Lbs (standard 4 gas with batteries).
Detection Principle	Catalytic combustion, electrochemical cell, galvanic cell, infrared, Photoionization detector, and thermal conductivity.
Sampling Method	Powerful, long-life internal pump (over 6,000 hours) can draw samples over 125 feet. Flow rate approximately 2.0 SCFH.
Display	3 display modes: display all gases, large font-autoscroll, or large font-manual scroll. Polyurethane protected overlay. Backlight, illuminates for alarms and by demand, with adjustable time.
Language	Readout can display in 5 languages (English, French, German, Italian, or Spanish).
Alarms	2 Alarms per channel plus TWA and STEL alarms for toxics. The two alarms are fully adjustable for levels, latching or self reset, and silenceable.
Alarm Method	Buzzer 95 dB at 30 cm, four high intensity LED's.
Controls	4 External glove friendly push buttons for operation, demand zero, and autocalibration. Buttons also access LEL/ppm, alarm silence, peak hold, TWA/STEL values, battery status, conversion factors, and many other features.
Continuous Operation	At 70°F, 18 hours using alkaline batteries, or 20 hours using NiMH.
Power Source	4 alkaline or NiMH, size C batteries (Charger has alkaline recognition to prevent battery damage if charging is attempted with alkalines).
Operating Temp. & Humidity	-20°C to 50°C (-4°F to 122°F), 0 to 95% RH, non-condensing.
Environmental	IP-64
Response Time	30 Seconds to 90% (for most gases) using standard 5 ft hose.
Safety Rating	Intrinsically Safe, Class I, Groups A, B, C, D. Approval: CSA
Standard Accessories	Shoulder strap, alkaline batteries, hydrophobic probe, and 5 foot hose, internal hydrophobic filter.
Optional Accessories	• Dilution fitting (50/50) • NiMH batteries • Battery charger, 115 VAC, 220 VAC, or 12 VDC (charge time 4 hours) • Continuous operation adapter, 115 VAC or 12 VDC • Extension hoses • IRDA cable for datalogging download
Warranty	Two year material and workmanship, one year for PID sensor.

Gas	Measuring Range	Accuracy * Which ever is greater
Gases & Detectable Ranges		
Standard Confined Space Gases		
Hydrocarbons (CH_4, std)	0 - 100% LEL	± 5% of reading or ± 2% LEL (*)
	0 - 5% Vol. (CH_4)	
	0 - 50,000 ppm	± 50 ppm or ± 5% of reading (*)
Oxygen (O_2)	0 - 40% Vol.	± 0.5% O2
Carbon Monoxide (CO)	0 - 500 ppm	± 5% of reading or ± 5 ppm CO (*)
Hydrogen Sulfide (H_2S)	0 - 100 ppm	± 5% of reading or ± 2 ppm H2S (*)
Toxics		
Ammonia (NH_3)	0 - 75 ppm	± 10% of reading or ± 5% of full scale (*)
Arsine (AsH_3)	0 - 1.5 ppm	
Chlorine (Cl_2)	0 - 3 ppm	
Hydrogen Cyanide (HCN)	0 - 15 ppm	
Phosphine (PH_3)	0 - 1 ppm	
Sulfur Dioxide (SO_2)	0 - 6 ppm	
IR Sensors		
Carbon Dioxide (CO_2)	0 - 10,000 ppm 0 - 5% Vol. 0 - 60% Vol.	± 5% of reading or ± 2% of full scale (*)
Methane (CH_4)	0 - 100% LEL/ 0 - 100% Vol.	
Hydrocarbons	0 - 100% LEL/ 0 - 30% Vol.	
PID Sensors		
VOC	0 - 2,000 ppm 0 - 50 ppm	–
TC Sensors		
Methane (CH_4)	0 - 100% Vol.	± 5% of reading or ± 2% of full scale (*)
Hydrogen (H_2)	0 - 10% Vol. 0 - 100% Vol.	
Hydrogen Specific		
Hydrogen (H_2)	0-100% LEL 0-40,000 ppm	± 5% of reading or ± 2% of full scale (*)

The EAGLE 2 can be configured with up to 6 gas sensors from the above list.

Specifications subject to change without notice.

Made in the USA

RKI INSTRUMENTS

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