Safety and Health at Work 9 (2018) 352–355

Contents lists available at ScienceDirect

Safety and Health at Work

journal homepage: www.e-shaw.org

Case Report

The "Warm Zone" Cases: Environmental Monitoring Immediately Outside the Fire Incident Response Arena by Firefighters

Alberto J. Caban-Martinez [1,2,*], Bob Kropa [5], Neal Niemczyk [5], Kevin J. Moore [1], Jeramy Baum [4], Natasha Schaefer Solle [2,3], David A. Sterling [6], Erin N. Kobetz [2,3]

[1] Division of Environment and Public Health, Department of Public Health Sciences, University of Miami, Miller School of Medicine, Miami, FL, USA
[2] Sylvester Comprehensive Cancer Center, University of Miami, Coral Gables, FL, USA
[3] Department of Medicine, University of Miami, Coral Gables, FL, USA
[4] Department of Chemistry, College of Arts and Sciences, University of Miami, Coral Gables, FL, USA
[5] Palm Beach County Fire Rescue, West Palm Beach, FL, USA
[6] School of Public Health, University of North Texas Health Science Center, Fort Worth, TX, USA

ARTICLE INFO

Article history:
Received 7 August 2017
Received in revised form
6 December 2017
Accepted 13 December 2017
Available online 20 December 2017

Keywords:
Firefighters
Multigas detectors
Respiratory protection
Warm zone

ABSTRACT

Hazardous work zones (i.e., *hot*, *warm*, and *cold*) are typically established by emergency response teams during hazardous materials (HAZMAT) calls but less consistently for fire responses to segment personnel and response activities in the immediate geographic area around the fire. Despite national guidelines, studies have documented the inconsistent use of respiratory protective equipment by firefighters at the fire scene. In this case-series report, we describe *warm* zone gas levels using multigas detectors across five independent fire incident responses all occurring in a large South Florida fire department. Multigas detector data collected at each fire response indicate the presence of sustained levels of volatile organic compounds in the "warm zone" of each fire event. These cases suggest that firefighters should not only implement strategies for multigas detector use within the *warm* zone but also include respiratory protection to provide adequate safety from toxic exposures in the *warm* zone.

1. Introduction

During a fire incident, firefighters and emergency response personnel are frequently exposed to various hazardous atmospheric conditions in and around the fire scene [1–3]. The National Fire Protection Association provides technical guidance, model requirements, and standards, in which first responders should use self-contained breathing apparatus (SCBA) and other respiratory equipment to limit exposure to harmful gases and particulates emitted from the fire [4]. Numerous studies have investigated and documented laboratory-based and real-life fire conditions within burning structures [2, 5, 6]. Exposure studies during fire incident response, suppression, and overhaul have also demonstrated carcinogenic exposures [5,7] among first responders. Despite available National Fire Protection Association guidelines, some studies have documented inconsistent use of SCBA equipment by firefighters at the fire scene [8–10].

Hazardous work zones are typically established during HAZMAT calls and inconsistently during fire incident response to segment the immediate geographic area around the incident. These hazardous work zones are known as the *cold*, *warm*, and *hot* zones [11]. The *hot*, or exclusion, zone includes the area where direct and immediate threat of exposure to immediately dangerous to life and health (IDLH) conditions exists. Firefighters must use special chemical or HAZMAT protective equipment to function in this area. Typical personal protective equipment (PPE) worn during fire incidents would include bunker gear and SCBAs. The *cold*, or support, zone provides safe space for command operations and a check point for incoming response crews. Lastly the *warm* or decontamination zone is in-between the hot and cold zone, usually upwind from the fire. The concept and use of a *warm* zone on a fire incident is relatively new, but *warm* zones have been used for decades pertaining to hazardous material and other special operations–type incidents, such as confined space and biohazard incidents.

* Corresponding author. Department of Public Health Sciences, Leonard M. Miller School of Medicine, University of Miami, Miller School of Medicine 1120 N.W. 14th Street, Room #1025, Miami, FL 33136, USA.
E-mail address: acaban@med.miami.edu (A.J. Caban-Martinez).

2093-7911/$ – see front matter
https://doi.org/10.1016/j.shaw.2017.12.003

Typical activities performed in the *warm* zone during HAZMAT incidents include on-scene decontamination, such as removal of safety gear, clothing, showering, and atmospheric monitoring by an incident safety officer [11]. In the *warm* zone of a fire incident, activities include rapid intervention team staging for deployment, ventilation crews creating openings in the structure to allow for heat and smoke to escape, and fire pump operations conducted by engine operators. All of these firefighters functioning within the *warm* zone without SCBAs may be at risk of respiratory hazards such as carbon monoxide (CO), polycyclic aromatic hydrocarbons, and other volatile organic compounds (VOCs) found in smoke, including formaldehyde, hydrogen cyanide (HCN), aldehydes, isocyanates, and nanoparticulates [12]. Single-compound detectors, such as mobile CO monitors, used by firefighters in the *warm* zone may not provide sufficient exposure information or may provide misleading hazard and safety information to responders in the hot and *warm* zone. Traditionally, atmospheric monitoring of fire incidents has been restricted to acute hazards such as oxygen, CO, HCN, hydrogen sulfide, and explosive gases and neglected to identify VOCs which could lead to detrimental long-term effects due to chronic exposures [13–17].

Epidemiologic studies have shown that firefighters have increased the incidence of select cancers compared with the general population [18]. The occurrence of site-specific cancers documented in this unique workforce [19], as compared with the general population, raises concern that certain work-related exposures may be contributing to the disproportionate burden of cancer. Taken together, this growing evidence of site-specific cancer within the workforce combined with laboratory and real-life fire exposure studies suggest that operating within the *warm* zone outside of the fire without proper PPE and a lack of a postfire decontamination process may contribute to a firefighter's overall exposure to harmful gasses and particulate.

During a structure fire, firefighters expose themselves to high amounts of known carcinogens while inside the structure or in the IDLH environment [20]. This observation has been extensively studied, and firefighter behavior and PPE guidelines have adapted over the years to minimize the exposure risk [4]. However, what about the firefighters outside the IDLH environment, meaning those responders situated in the *warm* zone? Throughout the United States, rapid intervention teams, safety officers, ventilation crews, forcible entry crews, driver engineers, and incident commanders routinely operate within the "warm zone", somewhere in the vicinity of 25 feet from the IDLH environment, typically wearing no respiratory protection.

In the present case-series report, we document *warm* zone gas exposures in five independent fire incident response cases using multigas detectors in a large fire department in South Florida. We hypothesized that firefighters may be exposed to VOCs near the vicinity of fires or the "warm zone."

2. Methods

[20]During five routine fire incident response cases in South Florida that took place between August 2016 and February 2017, we describe multigas detector levels situated within the *warm* zone of the fire response to document gas exposures from gas and particulate emissions for those firefighters who did not enter the hot zone, but operated in the *warm* zone only. We define the *warm* zone based on the Environmental Protection Agency (EPA) definition which characterizes the fire in potential for hazard [21]. Wind condition and volume, velocity, and temperature play a great deal into size of *warm* zone for smoke conditions.

The HAZMAT response team of a large South Florida fire department equipped several fire investigators and fire Captains with a Dräger Pac 7000 portable, multigas detector (Drägerwerk AG & Co. KGaA, Lübeck, Germany). The Dräger 7000 unit is a battery-powered device that weighs 3.8 ounces and measures 3.3 × 2.5 × 1.0 inches. It has a typical battery life span of 5,500 hours and measures carbon dioxide, sulfur dioxide, chlorine, HCN, ammonia, nitrogen dioxide, nitric oxide, phosphine, and volatile organic vapors. The instrument is calibrated using various gases specific to the group in questions, for VOC gases used in this case report, ethylene is used for calibration. Ambient gas concentrations in ppm are continuously measured and indicated on a light-emitting diode display. Alarm thresholds are set at different values by the type of gas (i.e., VOC 2.5 ppm) based on North American Standards. If the threshold value is exceeded, a visual (i.e., blinking light), an auditory loud alarm, and a vibration sensor are activated. The Dräger alarm can be acknowledged and silenced by the firefighter by pressing a button on the device. If a higher specified threshold is exceeded for a specific gas (i.e., VOC 4.5 ppm), the same alarm notifications are activated by the device, however at a double-repeating pattern. In this type of alarm, it is not possible to silence the alarm, and the alarm will not stop until the hazardous area is vacated. The range of gas detection varies on the type of gas measured either by ppm (i.e., 1,999 ppm for CO, 100 ppm for H_2S) or by 25% of the gas volume (i.e., low O_2 concentration). The levels of detection for VOCs that are confirmed carcinogens, for example, formaldehyde, benzene, 1,3-butadiene, and benzo[a]pyrene are 1 ppm, 2.5 ppm, 1 ppm, and 0.02 ppm, respectively, being well within the range of the Dräger unit. Data, up to 60 alarms, are stored internally in the device, including time, duration, and degree of exposure, and can be downloaded to a personal computer in Excel.

Several fire investigators and fire Captains were trained in the use of the multigas monitor. These on-duty fire officers were instructed to respond to structure fires and, on arriving, obtain readings as part of standard operation procedure from specific areas of the fire scene including the *warm* zone. Fire investigators and fire Captains obtained real-time readings from the device at specific distances and documented their findings on a standard fire incident response operations form. The fire investigators responding to structure fires would sometimes respond from a long distance, resulting in a delay to arriving at the fire incident and therefore, data collection was during the postfire phase. Fire Captains typically respond to far fewer fire incidents as they typically respond only to incidents within their primary or secondary zone, as opposed to an investigator whose response is typically county-wide. However, fire Captains are typically among the first people on scene when responding to a structure fire within their primary zone which resulted in unique data that were collected during the active phase of the fire incident. Fire inspectors and fire Captains were instructed to hold the device in their hand at approximately face level and obtain readings at specific distances from the IDLH area. This secondary data analysis study was reviewed and approved by the university's institutional review board (#2017-0421).

3. Results

Summary results of multigas detector data collected at each fire response are shown in Table 1, indicating that sustained levels of VOCs were detected in the "warm zone" of each of the fire cases.

3.1. Case 1

A fire Captain responded to a residential structure fire in a nearby zone and arrived during the active phase of the fire. Readings were obtained during active firefighting operations with

Table 1
Volatile organic compounds (VOCs) measured at the *warm* zone using multigas devices during HAZMAT team real-life and training fire scenarios from August 2016 to February 2017

Case ID	Call type	Description	Reading (VOC) at *warm* zone	Readings of other gasses detected within *warm* zone	Distance from fire
1	Structure fire	25% involved, couch on porch caught fire extending to the eaves/attic area	2 ppm 1 ppm	CO = 0 ppm O_2 = 20.9% H_2S = 0 ppm LEL = 0%	15′ from the door of home 20′ away from the area of rapid intervention team
2	Training burn	Vehicle set on fire with accelerants and allowed to burn out for Cause and Origin Class	10 ppm 3 ppm 1.5 ppm	CO = 4 ppm O_2 = 20.9% H_2S = 0 ppm LEL = 0% CO = 0 ppm O_2 = 20.9% H_2S = 0 ppm LEL = 0%	25′ from vehicle 50′ from vehicle 100′ from vehicle
3	Vehicle fire	Recreational vehicle fire with flames through roof	1.5 ppm	CO = 0 ppm O_2 = 20.9% H_2S = 0 ppm LEL = 0%	10′ from vehicle
4	Structure fire	Small electrical fire contained to living room of an apartment	3.5 ppm 5 ppm	CO = 10 ppm O_2 = 20.9% H_2S = 0 ppm LEL = 0% CO = 2 ppm O_2 = 20.9% H_2S = 1 ppm LEL = 0%	10′ from the door During overhaul in the living room
5	Structure fire	Garage of single-family home and 3 vehicles fully involved through attic. Fire was contained to the garage and stopped at the laundry room just inside the home from the garage.	10 ppm 5 ppm	CO = 3 ppm O_2 = 20.9% H_2S = 0 ppm LEL = 0% CO = 0 ppm O_2 = 20.9% H_2S = 0 ppm LEL = 0%	15′ from front of home driver operator pump panel was 50′ & incident command post was 60′ away from garage

CO, carbon monoxide; H_2S, hydrogen sulphide; LEL, lower explosive limit

several crews operating within the *warm* zone. The documented readings were immediately obtained when entering the *warm* zone, and these levels persisted until well after the fire was in the decay phase. Gas detector identified 2 ppm organic vapor 15 feet from door of the home and 1 ppm of organic vapor 20 feet from the rapid intervention team.

3.2. *Case 2*

In Case #2, a vehicle was intentionally doused with accelerants and set on fire during an arson investigation class. This vehicle was allowed to burn freely until it reached the decay phase. High readings were immediately obtained within the *warm* zone and persisted throughout the fire and even well into the decay phase. At approximately 100′ away, a reading of 1.5 ppm was obtained; in many incidents, this would be the cold zone. At approximately 50′ away, where the driver operator of the fire engine would be working, typically with no respiratory protection, a reading of 3 ppm was obtained.

3.3. *Case 3*

In Case #3, a fire investigator responded to a fully involved vehicle fire. On arrival, the fire was out; however, the investigator obtained peak readings of 1.5 ppm 10′ from the vehicle. This reading, once again, persisted well into the investigation activities.

3.4. *Case 4*

In Case #4, a fire Captain was the first on scene of a small electrical fire within an apartment structure. An initial reading of 3.5 ppm was recorded 10′ from the front door during the active phase of the fire. The fire was contained to the living room, and a peak reading of 5 ppm was obtained there during the decay phase of the fire. Overhaul operations typically occur during the decay phase of a fire. During overhaul operations, crews will search for extension and douse smoldering and hot material to prevent the fire from rekindling. Traditionally, firefighters would doff their PPE including SCBAs during overhaul operations [13, 22]. However, through education and culture change, many firefighters will wear full PPE including SCBA during the overhaul operations [23]. Peak readings of 5 ppm were obtained within the living room during the decay phase and persisted throughout the overhaul operations.

3.5. *Case 5*

In Case #5, a fire Captain was among the first on scene of a structure fire where the garage, three vehicles, and the attic above the garage were involved. An initial reading of 10 ppm was obtained in the *warm* zone before firefighting activities. In addition, initial readings of 5 ppm were obtained at the fire engine pump panel and at the incident command post where firefighters typically wear no respiratory protection. Although the concentrations of VOCs decreased as the fire decayed, levels as high as 1–2 ppm persisted well after the fire was out at the same locations.

4. Discussion

The safety and protection of firefighters and other emergency responders from harmful atmospheric exposures is a complex problem. The real-world five cases presented in this case series document varying levels of VOC exposure among first responders in the *warm* zone of both live fire and training/controlled fires. Adequate protection from noxious gasses and cancer-causing particulate is critical in this workforce as ambient hazardous gas levels such as CO monitored during structure fires in other studies frequently exceed 500 ppm and have been measured as high as 27,000 ppm [2, 13]. The short-term exposure limit for CO is 200 ppm, for naphthalene, a VOC and possible human carcinogen, the Occupational Safety and Health Administration (OSHA) limit is 10 ppm and the IDLH environment level is 1,200 ppm [24]. Although many studies have discussed the protective value of wearing an SCBA during fire suppression activities, few suggest the need for monitoring atmospheric levels and use of respiratory protection in the *warm* zone during all phases of a regular fire incident response. Researchers are encouraged to carefully collect through epidemiologic studies the type and concentration of organic vapors experienced by firefighters situated in the *warm* zone. In brush fire scenarios, the *warm* zone includes all the brush; therefore, monitoring gas levels around the entire brush is important. Based on the measures collected in each of these cases, it is apparent that firefighters should not only implement the use of multigas detectors in the *warm* zone but also include respiratory protection when in this proximity.

Strategies to monitor multigas detection and to implement the use of PPE by firefighters are necessary. For example, VOC-filtering half face masks may be a potential solution to the frequently raised concern that full SCBAs limit the dexterity and visual field of the first responders positioned/stationed in the *warm* zone. These masks have the added benefit of N100 particulate protection and VOC protection. Training to use these types of masks will have to be a priority as firefighters must understand that they are not to be worn inside of IDLH conditions as it does not protect against low oxygen environments and respiratory damage due to high heat.

The five cases presented in this series document two important points for occupational health and safety research and practice within the fire service. We detected and documented standard and above-standard sustained levels of VOCs within the "warm zone" of non-HAZMAT, regular fire incident cases, and one live fire training session. *First*, future studies coupling ambient gas detection in the *warm* zone with individual firefighter biomarkers (i.e., urine, saliva, blood) are needed to further understand *warm* zone levels of exposures on biological responses and internal dose. *Second*, fire incident response strategies that encourage and support the use of respiratory protection for responders operating within the *warm* zone are needed. The combination of respiratory protection such as half face masks with multigas detectors at the fire scene may improve decision support by the responders and limit exposure to cancer-causing particulate present in the *warm* zone.

Conflict of interest

The authors declare no conflict of interest in the conduct of this study.

Acknowledgment

The authors would like to acknowledge funding support from State of Florida appropriation #2382A (Principal Investigator Dr. Kobetz) to the University of Miami (UM) Sylvester Comprehensive Cancer Center, Grant IRG 98-277-13 from the American Cancer Society (Principal Investigator Dr Caban-Martinez), and funds from the Sylvester Comprehensive Cancer Center.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.shaw.2017.12.003.

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