A Study on Chemicals found in the Overhaul Phase of Structure Fires using Advanced Portable Air Monitoring available for Chemical Speciation

Deric C. Weiss and Jeff T. Miller

Tualatin Valley Fire & Rescue
25 February 2011

ABSTRACT

During the overhaul phase of a structure fire, firefighters commonly doff their self contained breathing apparatus SCBA protection for easier working conditions and traditionally rely upon carbon monoxide (CO) detection as the determinate for this action. A CO level of below 35 ppm has traditionally been the acceptable limit for firefighters to wear this lesser level of respiratory protection. Removal of respiratory protection during fire overhaul activities or in the general area can expose firefighters and fire investigators to an unknown variety of toxic chemicals and particulates. Typical structure fires involve high temperature destruction of many types of plastics, foams, various species of wood, fabrics and other materials.

Gases and particulates liberated from these burning materials often contain toxic, reactive and otherwise unhealthy chemicals that are both inhalation hazards and skin absorptive hazards. This study focused on the direct reading of gases present during overhaul, measurement of these gases over an extended period of time in comparison to CO, and on the compilation of data to support and continue the understanding of post-fire event airborne hazards to firefighters and fire investigators.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

The authors would like to acknowledge the crews of Tualatin Valley Fire & Rescue Station 34 for their tireless dedication to the study. This report would not have been possible without their commitment to the procedures and standards established for data collection. The authors would also like to acknowledge Kermit McCarthy C.I.H., Michael Holcomb, Ph.D, and Mohamud Daya, M.D., M.S. for their contributions to the data collection process and analysis of the results.

The support and commitment of Tualatin Valley Fire & Rescue, the Governors Fire Service Policy Council, and the Oregon Office of State Fire Marshal was greatly appreciated.

INTRODUCTION

Fire departments across the country use carbon monoxide detection equipment to determine when it is safe to enter and work in a structure without the use of a SCBA. A growing number of studies [1,2,4,5] have concluded that there are many other chemicals and known carcinogens produced in a structure fire that should be monitored after the fire is knocked down, yet the fire service continues to utilize carbon monoxide detectors for establishing SCBA guidelines. The purpose was to demonstrate that the fire service could improve on respiratory protection guidelines and establish procedures to reduce dermal exposure. Emerging technology provides a means to sample several gases in a mixture after a fire is knocked down and presents some of the data necessary to establish best practices for firefighters and fire investigators.

Previous studies[1,2,4] concluded that SCBA should be worn continually during the overhaul phase unless the fire department had the ability to purchase detection equipment to speciate the airborne hazards. This study demonstrates that firefighter protection and best practices should not be limited to carbon monoxide detection and SCBA use. There are several other practices that will limit the exposure to firefighters and fire investigators after the fire has been knocked down and after the crews have returned to their stations.

This report outlines an eight month study and presents the data collected in the overhaul phase of thirty-eight structure fires of varying types. Real time portable gas analyzers were tested and validated against known standards. Particulate measurements were taken throughout the study and carbon monoxide levels were compared to the other toxicants found. Conclusions were drawn and recommendations made based on the data collected as well as toxicologist, industrial hygienist, and medical toxicologist/EMS medical director review.

Although this study followed guidelines for calibration, sampling, and data collection, it was performed in the field with unpredictable conditions and circumstances. This was compounded by the fact that structure fires present a mixture of chemicals with synergistic effects. Concentrations and even chemicals present may depend on what is burning.

"This report will be presented to the Oregon Fire Chiefs Association, Safety Committee. The Safety Committee will use this report to write recommendations for the Fire Service."

METHODS

Thirty two hazmat technicians were trained on the chemical detection equipment, including calibration, time synchronization, troubleshooting, post clean-up and re-calibration, and sampling strategy. Training was conducted with and under the direction of the Hazmat Team Monitoring Specialist. Training recommendations and observations were made by a technical review committee. Members of this committee were made up of the Oregon Occupational Safety and Health Administration (OR-OSHA) and Oregon Department of Environmental Quality (DEQ) lab managers and the State of Oregon Health Authority's (OHA) toxicologist. The training was conducted over six days, providing each crewmember experience in handling and performing all of the equipment checks and functions. A final controlled training burn was completed and evaluated to ensure that all personnel utilized consistent response, set-up, and monitoring techniques throughout the study. Four technicians responded to every structure fire in Tualatin Valley Fire & Rescue's 210 square miles; however, a majority of the fires occurred within an area approximately 1/3 that size.

The participating technicians were located at a central fire station in Tualatin, Oregon which housed Tualatin Valley Fire & Rescue's hazmat team (Oregon State Fire Marshal Team HM09). This team used a fire response apparatus, either a hazmat truck or suppression engine, to travel to each fire in a code three (lights and sirens) response status. The response started immediately when a 911 situation was confirmed to be a working structure fire. The participating technicians were primarily tasked with fire-gas monitoring duties unless the fire was in the immediate area surrounding their station (first-due area). For first due area fires the technicians, who were also responding firefighters, would first perform suppression duties and then quickly transition to fire-gas monitoring. Three of the documented fires were in this first due area. Response times to fires were calculated as the time after knock-down until monitoring for chemicals had commenced. Knock down is generally defined as the point where the majority of fire has been extinguished; however, overhaul operations can reveal areas that continue to smolder. The times were taken from dispatch records and monitoring data log times (Figure 1).

Upon reaching a scene, the hazmat technicians were allowed to monitor any areas where fire personnel were working including nearby rooms, outside the structure, at the fire apparatus, and at rehabilitation areas where firefighters traditionally rest, rehydrate and cool down. The monitoring period established generally lasted a minimum of 5 minutes at each point and increased if specific positive detections were being collected. Additionally, if levels obtained exceeded safe OR-OSHA established levels for crews in the overhaul areas, monitoring continued until safe levels could be reported to the Command Officer present. The sampling team dictated when SCBA use was no longer necessary.

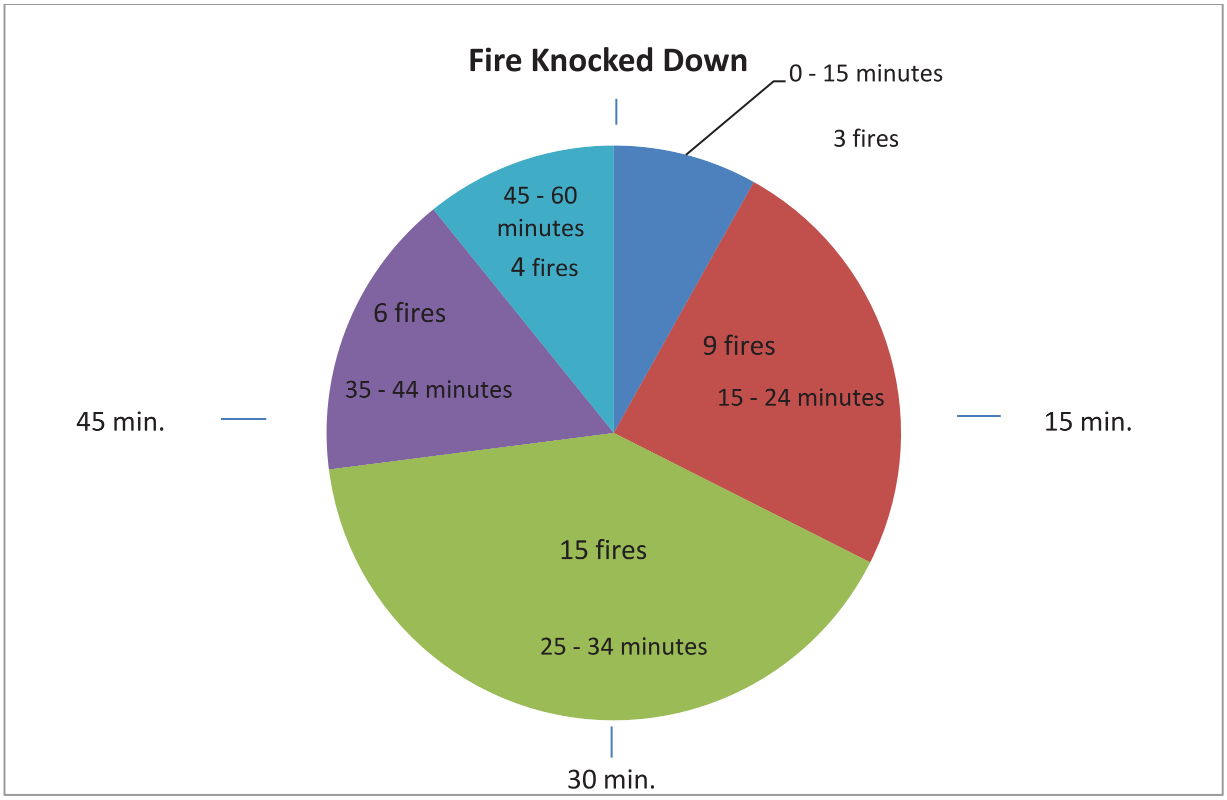


Figure 1 - Elapsed time after knock-down to commencement of monitoring

The sampling procedure relied on a trained four person crew responding to each fire. The crew would turn on all equipment at sufficient distance from the fire scene to obtain a clean background sample prior to entering. One firefighter was charged with taking digital pictures and documenting temperature, humidity and other pertinent information for all locations. A second firefighter utilized the primary instrument and ensured that it was placed at the prescribed locations and in "breathing zones" (4 to 5 feet off the ground). A third firefighter carried a "monitor board" which held a photo-ionization detector (PID) and two electrochemical sensor detectors (e-c detectors). The board also held two colorimetric devices, a pull tube device, and a colorimetric chip system for benzene, formaldehyde, hydrogen chloride, nitrogen dioxide and sulfur dioxide. A fourth firefighter carried a particulate meter set at 10 µmor less. This fourth firefighter also placed badge style mercury (Hg) packets adjacent to the UV spectrometer device for Hg confirmation and carried a portable quadrupole GC-MS device on the last 3 fires.

Minimum sampling time at each event was thirty minutes. Data was extracted from the instruments and sent to the Oregon OSHA lab manager, Hazmat Team Monitoring Specialist, and OHA Toxicologist for review and compilation. When data collected indicated a potential health concern for responders, TVFR's medical director was contacted for opinion and recommendations.

MONITORING APPARATUS

The primary monitoring device used during the study was the UVHoundFR™ portable UV spectrometer by CEREX Monitoring Solutions LLC. This detector was used in conjunction with the following detection equipment to provide a variety of sampling methods:

- Hapsite ER™ portable GC-MS; INFICON
- HAZ-Dust EPAM 5000™ particulate meter; Environmental Devices Corporation
- BW gas alert Micro5™ electrochemical detectors; Honeywell
- iTX™ electrochemical detector; Industrial Scientific Corporation
- PAC III™ electrochemical detector and CMS Chip Measuring System; Drager Safety
- Chromair™ Mercury detection badges; MORPHIX Technologies
- Arsine and Acrolein colorimetric tubes; GASTEC CORPORATION
- MiniRAE™ PID – UV broad range detector; RAE Systems
- TIMS flame spectrophotometer; PROENGIN

To ensure the integrity and proper functioning of all equipment, technicians were trained on instrument calibration and synchronization. The technicians performed daily calibration of all portable monitoring equipment, including ensuring all instrument times were exactly synchronized so a direct comparison based on time could be gathered after extracting data post-fire. All equipment had clean filters and proper dates were documented for tubes and sensors. Select media was refrigerated per manufacturer specification. A daily log with signatures from study personnel was kept for calibration and equipment checks.

Temperature and humidity were measured each morning and calibrated to the local thermo hygrometer and local meteorological recordings. The temperature and humidity measurements were taken at each fire from multiple locations. Temperatures recorded during this study never exceeded operating parameters for the variety of instruments used. Temperature corrections for the GASTEC acrolein and arsenic tubes were necessary on occasion and were used per manufacturers' listed equations[8] at each event applicable.

During the study it was noted that the hydrogen chloride (HCl) direct read electrochemical detector was reporting high levels of this chemical at the same time and with high correlation to nitric oxide (NO) and CO. The levels reported were always at an approximate 1:3 relationship with NO. This suspicious data prompted an accuracy test using a separate electrochemical device and a colorimetric device alongside. It was determined (and verified by the company's sensor data) that the HCl sensor used was cross sensitive to NO. Subsequent fires were then monitored using the PACIII^{TM} and CMS chip system^{TM} by Drager which are not cross-sensitive.

In general, the device testing highlighted problems with the common practices of relying on electrochemical sensors to determine toxicant levels other than CO, such as HCN or HCl. It was found that not all electrochemical sensors are alike, and their readings should be approached with caution and with an awareness of potential false results. Electrochemical sensors, a standard atmospheric detection method used by fire departments, commonly give false readings in the presence of interferents such as NO, carbon oxides and even humidity. This proves especially problematic at fire scenes where hundreds of chemicals likely exist.

Using a large photo ionization detector (PID) lamp (miniRAE 2000^{TM} 10.6 IP) may have potential value as an indicator for the presence of many hydrocarbons and common airborne hazards at fires. The use of a standard size PID lamp, available from many manufacturers in multi-gas detectors, proved ineffective as compared to the larger lamp dedicated to PID use. Only 1 of 37 fires had obtained a PID measurement with the smaller PID unit from BW by Honeywell, where the larger PID from RAE systems provided consistent measurements at each fire. The team added a correction factor of 1.8 to the instrument based on 10 expected chemicals found and the manufacturer's published correction factor sheet (TN-106, correction factors for mixtures).

A description of the monitoring equipment and their minimum limits of detection (LOD) for each chemical are presented in Appendix A. Monitors were also compared to each other for validation of findings and this information can be found in Appendix B.

RESULTS

Chemicals Studied

In the overhaul phase of a fire, there is the potential for a large number of chemicals to be liberated. Based on previous studies[1,2,4] and toxicologist recommendations, the chemicals monitored in this study were reduced to a set of known probable carcinogens, common toxicants, and particulate at less than 10 μm in size.

Thirty-eight fires were evaluated from June 6, 2009 to February 2, 2010. Of these fires, 22 involved single family residences, 5 were apartment residences, 2 barn fires, 3 commercial/industrial structures, 4 involved recreational vehicles, and 1 was an adult foster care home. One additional fire, a single family residence was added from the beginning of the program in 2008. The monitoring was well documented, including proper calibration practices and valid on-scene monitoring performed. Appendix C, Fire Structure Descriptions and Conditions, describes all fires studied in detail.

During the study period the following chemicals exceeded National Institute for Occupational Safety and Health (NIOSH) Immediately Dangerous to Life and Health (IDLH) levels: ***Nitrogen dioxide*** *(NO_2),* ***acrolein, carbon monoxide*** *(CO),* ***arsenic,*** *and* ***mercury***.

The following chemicals were present at or above the Oregon OSHA Short Term Exposure Limit (STEL) or NIOSH Recommended Exposure Level - Short Term (REL – ST) levels as applicable but below IDLH levels: ***Nitrogen dioxide*** *(NO_2),* ***hydrogen chloride*** *(HCl), and* ***carbon monoxide*** *(CO).*

The following chemicals were found present at or above the Oregon OSHA Permissible Exposure Limit Time Weighted Average (PEL-TWA): ***Arsenic, acrolein, benzene, carbon monoxide*** *(CO),* ***formaldehyde, glutaraldehyde, hydrogen cyanide*** *(HCN),* ***hydrogen chloride*** *(HCl),* ***mercury*** *(Hg),* ***ozone*** *(O_3),* ***nitrogen dioxide*** *(NO_2), and* ***particulate matter*** **(otherwise undifferentiated)** *(<10 μm diameter).*

Exposures	**OSHA TWA PEL (ppm)**	**NIOSH REL ST (ppm)**	**IDLH (ppm)**	**# fires analyzed**	**# fires found**	**#>PEL**	**#>STEL**	**#>IDLH**
Acrolein	0.1	0.3	2	11	4	4	4	2
Aldehydes (total aliphatic)	n.d.	n.d.	n.d.	29	19	n.a.	n.a.	n.a.
Ammonia	50	35	300	29	8	0	0	0
Arsenic	0.05	n.d.	3	8	2	2	n.a.	1
Benzene	1	5	500	29	10	3	0	0
Benzyl chloride	1	1	10	12	3	0	0	0
Carbon disulfide	20	10	500	3	3	0	0	0
Carbon monoxide	50	200	1200	38	30	3	1	1
Formaldehyde	0.75	2	20	29	4	0	0	0
Furfural	5	n.d.	100	3	3	*n.a.	*n.a.	*n.a.
Glutaraldehyde	n.d.	0.2	n.d.	12	12	n.a.	***5**	n.a.
Hydrogen chloride	5	5	50	37	8	5	**1 very near IDLH**	0
Mercury vapor	0.012	n.d.	0.24	29	5	3	n.a.	1
Naphthalene	10	15	250	37	7	0	0	0
Nitrogen dioxide	5	1	20	37	28	13	22	1
Nitrogen monoxide	25	n.d.	100	29	28	0	0	0
Ozone	0.1	n.d.	5	29	21	17	n.a.	0
Phenol	5	5	250	29	9	0	0	0
PID	n.d.	n.d.	n.d.	19	19	n.a.	n.a.	n.a.
Sulfur dioxide	5	5	100	29	2	0	0	0
Styrene	100	100	700	29	25	0	0	0
Toluene	200	150	500	29	27	0	0	0
Particulates (<10 µm)	5	n.d.	n.d.	21	21	14	0	0

Table 1 - Summary of measured chemical levels

Toxicants where findings exceeded NIOSH (REL- ST) or OSHA (IDLH) levels are shown in bold. A detailed description of all known and probable carcinogenic chemicals that were positively identified during the study is located in Appendix D.
* presence not confirmed (near detection limit or qualitative indication only)
n.a.: not analyzed
n.d.: not determined

NOTE: Not all chemicals were sampled at every fire due to equipment failures or insufficient personnel.

Chemicals Studied Discussion

The toxicants found at the most incidents exceeding established threshold values and thereby posing the greatest acute danger to responders were NO_2, O_3, HCl, glutaraldehyde, and acrolein. The results indicate that many other chemicals do not generate significant acute hazards on their own during overhaul periods; specifically phenol, styrene, sulfur dioxide, ammonia, naphthalene, and toluene. "Total Aldehydes" has the potential of describing a severe overexposure depending on the aldehydes present, so the actual aldehydes present deserves further study. The glutaraldehyde numbers indicated severe overexposure to responders as well, and quantification should be confirmed in the future. CO did not seem to be a good indicator of the other chemicals present and will be discussed in the Carbon Monoxide Correlation section.

Mercury's presence was unexpected, but is most likely explained by the presence of fluorescent bulbs and electric switches, among other possible sources. Arsenic detection, in the form of elemental arsenic or arsine, was determined to be due to CCA (copper chromium arsenate) or similar treated wood, which when burned at a high temperature allows the arsenic to sublime and escape its bond in the wood[12]. Hirata et al[13,14] performed an isothermal pyrolysis of CCA-treated wood and reported that most chromium and copper content from the wood was retained to some degree in the fly ash, however the majority of the remaining arsenic content had evolved into a gas or aerosol state.

Ozone levels; although below IDLH, were significant and persistent throughout many fires. The average maximum ozone level reached over 27 events was 0.740 ppm with several maximum peaks individually above 2.0 ppm. Ozone exposures have been documented in some studies[4], but due to the absence of specific monitoring equipment in previous studies it has not been studied substantially.

The information gained from this study generally supports findings from earlier studies[1,2,4,5] and supplements the standard list of toxicants present during the overhaul phase of fires with mercury, ozone, and arsenic.

Carbon Monoxide Correlation

Fire departments currently rely upon carbon monoxide levels as the standard for determining acceptable atmospheric conditions. The data shows that there is no statistically significant correlation between CO levels and levels of other chemicals. For example, a comparison of CO to nitrogen dioxide (NO_2) present during overhaul gave a correlation r value of 0.2652, CO compared to ozone (O_3) gave an r value of -0.0278, CO compared to particulate values gave an r value of 0.079, and CO to toluene gave 0.23. In comparison to the remainder of chemicals analyzed, CO levels were not found to be indicators of any others present. Fifty seven measurements of CO versus NO_2 were compared at various locations in and near the fire building on each incident. The CO detectors (2 in many cases) were compared to other instruments (within 3 feet) and measured at the "breathing zone." As evidenced by the following chart, CO levels did not show a sufficient correlating relationship to the NO_2 levels.

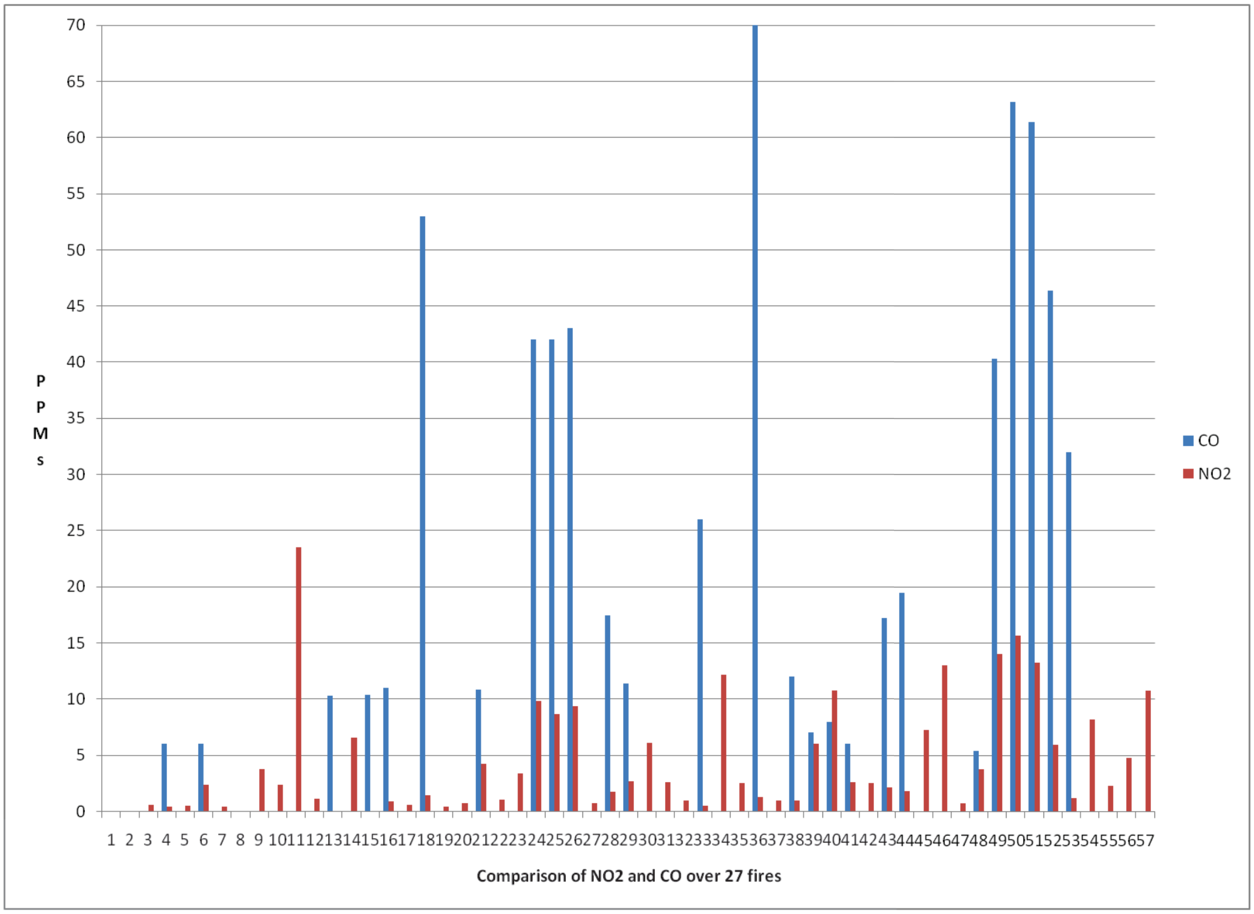


Figure 1 NO_2 and CO compared over 27 fires

Carbon monoxide was also compared to ozone and aliphatic aldehyde readings at 37 fires. CO levels were found below the 35-ppm threshold while ozone was measured at levels well above the PEL. In several instances, CO was not measurable and ozone remained above PEL. The relationship to aldehydes was found to be similar. Low molecular weight aldehydes found present additional hazards since some are known carcinogens and most are harmful by dermal contact. The following graphs demonstrate that CO cannot be relied upon to indicate when harmful levels of ozone or aldehydes are present.

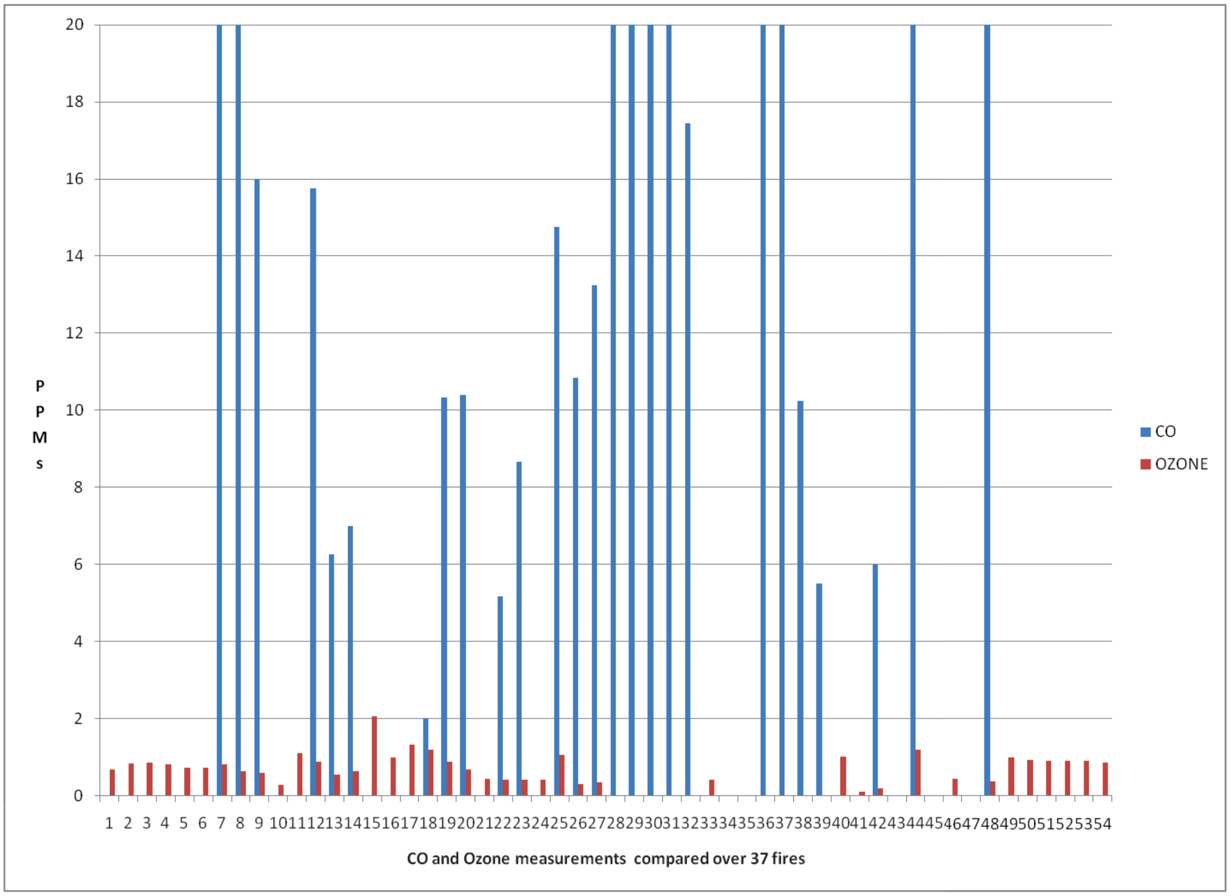


Figure 2. O_3 and CO compared over 37 firescomparison

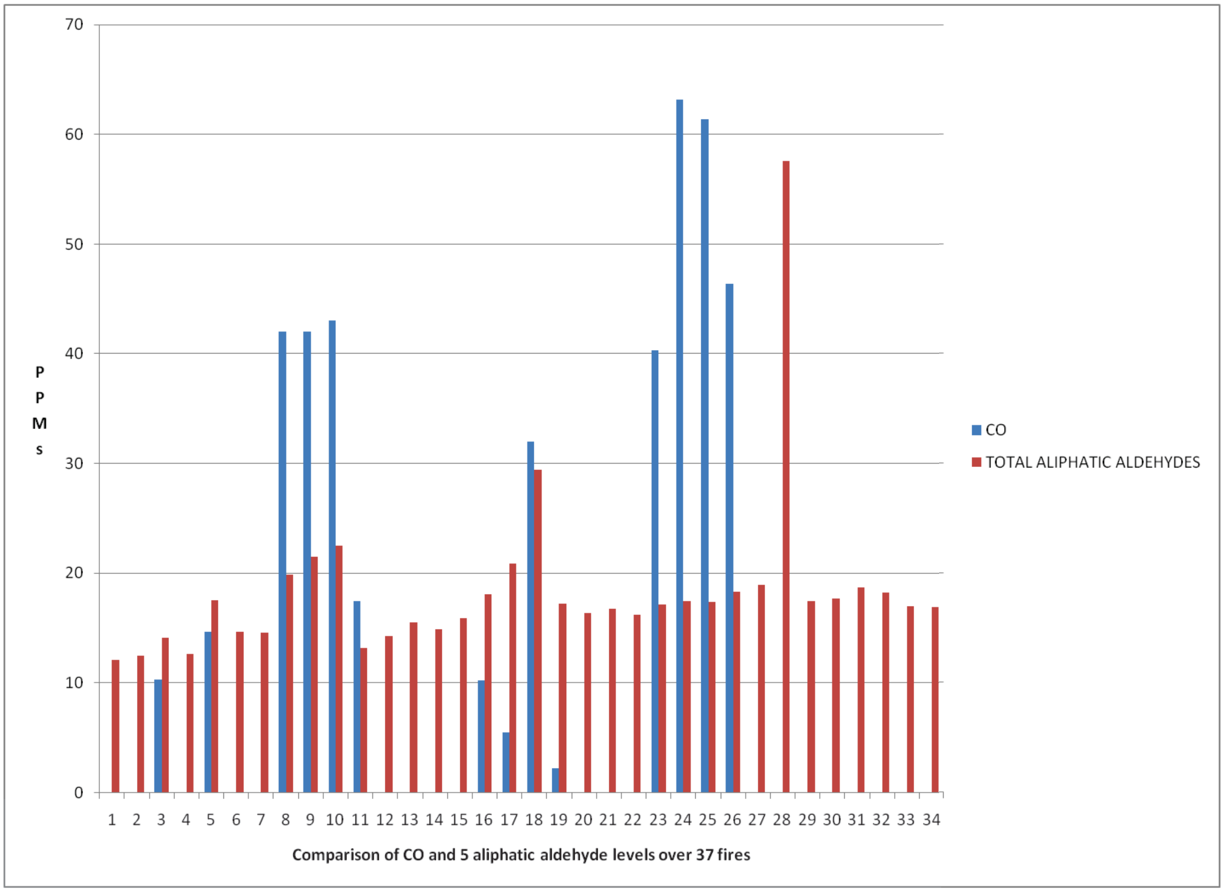


Figure 3. Aliphatic aldehydes and CO levels compared over 37 fires

Chemical Correlation

In addition to carbon monoxide correlation, the authors sought to determine if there was a single chemical found in the products of combustion that would reliably indicate if other chemicals were present at unsafe levels. Data was collected from multiple monitors to determine if any other correlation existed.

Analysis of the UV spectrometer's measurements with respect to simultaneous chemical measurements showed some correlations. Specifically, the first four months of the study (June 6, 2009 to October 11, 2009) gave the following correlations of chemicals by this machine:

r values 0.75 or higher:
Ozone – NO2: 0.966
Toluene* – Phenol*: 0.943
r values between 0.5 and 0.749:
Toluene* – Benzene: 0.564
Styrene* – Benzene: 0.515

NOTE: Over this period the following chemicals were added to the UV spectrometer: benzene, formaldehyde, sulfur dioxide, styrene, nitrogen dioxide, nitrogen monoxide, toluene, mercury, phenol, napthalene, ammonia, ozone, and total aldehydes. This period had 17 unique data sets over 643 separate events.
*See Appendix A, footnote[3], and Appendix B, pg 30 for further styrene and toluene discussion.

The next analysis was completed after UV spectrometer adjustments were made by the manufacturer based on the previous 4 months of data. Ozone spectra during that initial period were re-evaluated and a different absorption peak used to indicate its presence in future measurements. In doing so, NO_2 was eliminated as an interferent to ozone detection. During this next period of study, glutaraldehyde and benzyl chloride were also added to the spectrometer. Over this next period (October 12, 2009 to February 2, 2010) 12 unique data sets with over 476 separate events were evaluated. A strong correlation was made between aldehydes and phenol as well as toluene and glutaraldehyde respectively.

r values 0.75 or higher:
total aldehydes – phenol: 0.945
toluene – glutaraldehyde: 0.889
r values between 0.5 and 0.749:
styrene – benzene: 0.559
total aldehydes – benzene: 0.516

Correlation discussion

The information supports earlier studies (Phoenix study 9-2000), that showed CO levels did not predict other chemicals' presence or concentrations at fire scenes. While the presence of some chemicals seems to predict that of others, there is no specific chemical that will reliably predict them all. Based on these results, active monitoring for nitrogen dioxide, ozone, acrolein, and mercury at structure fires could improve decision making about the need for personal protective equipment.

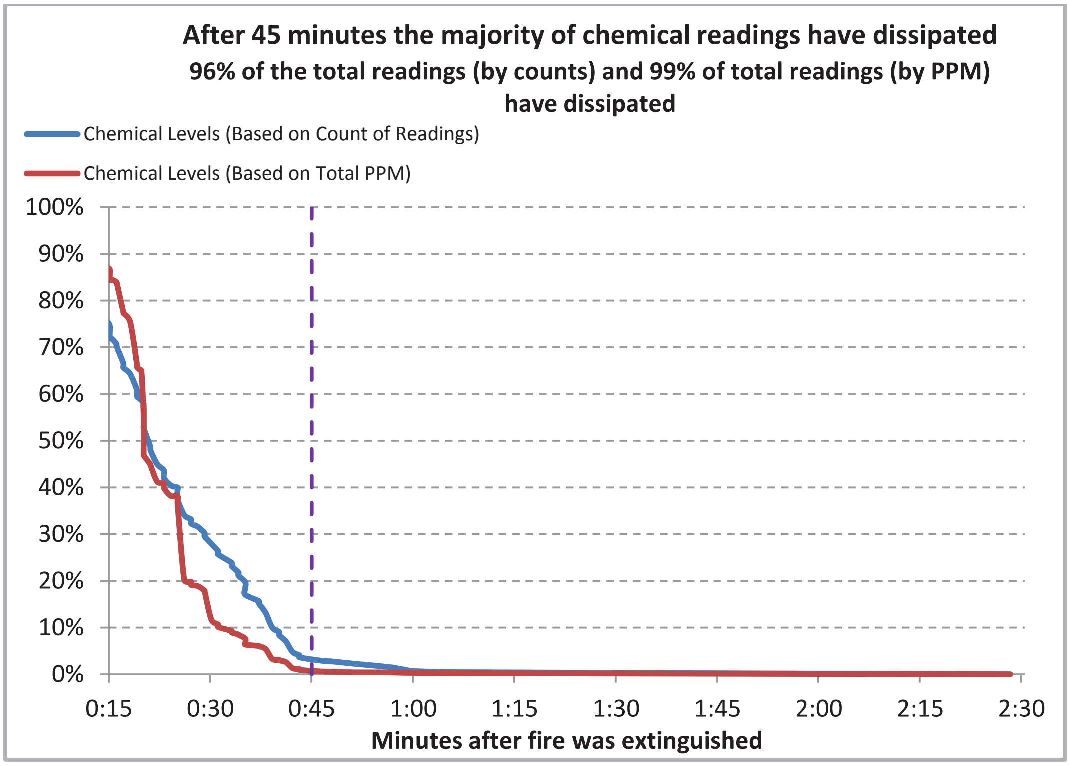
Correlation calculations were processed using the correlation tool of Microsoft Excel's^{TM} Analysis Tool Kit; this uses Pearson's correlation coefficient, which is one measure of association between two variables. This association has been expressed as a number (the correlation coefficient) that ranges from –1 to +1. The population correlation is expressed as the Greek letter rho (ρ) and the sample statistic (correlation coefficient) is r.

Chemical Dissipation

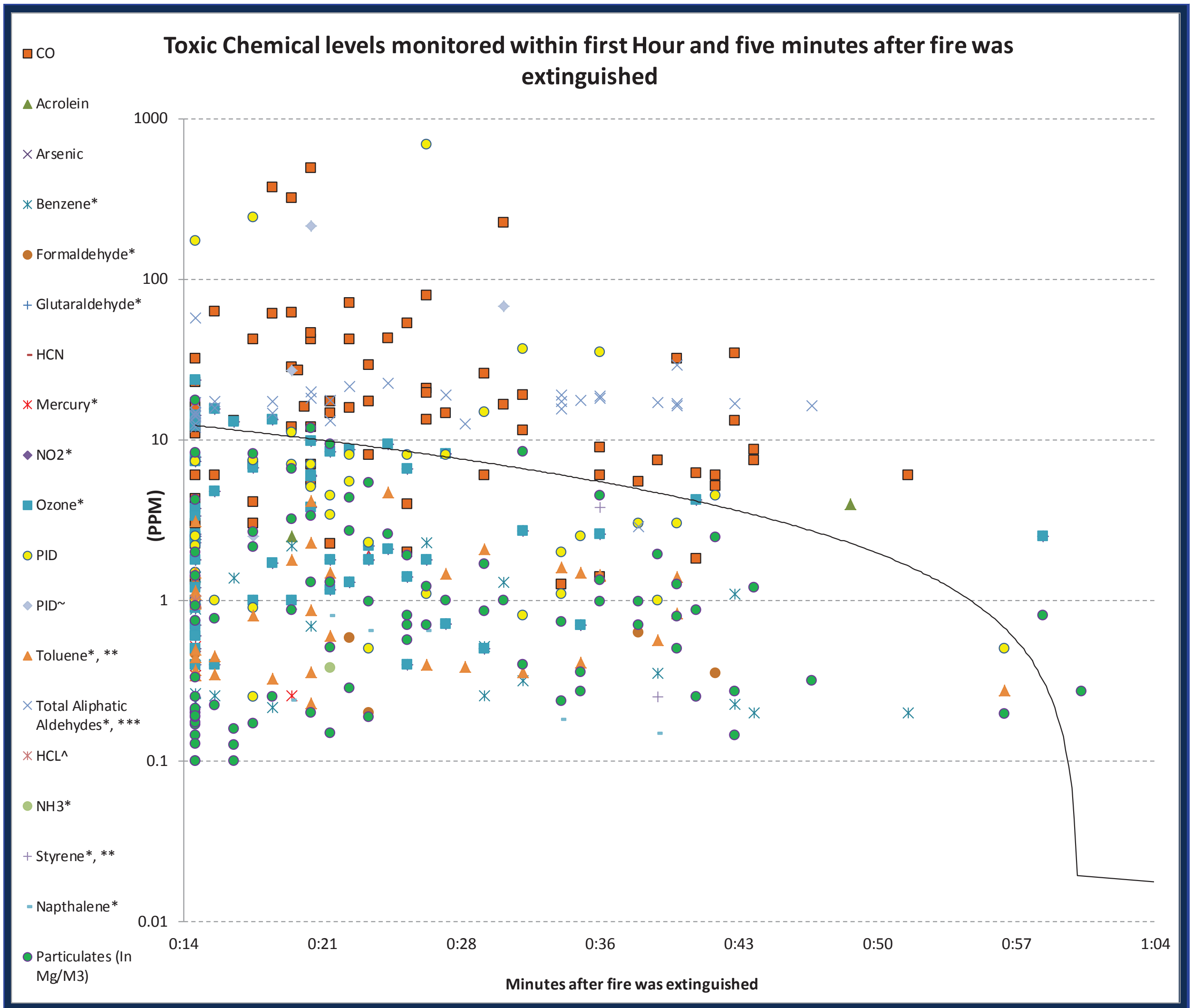
As part of the data analysis, 147 events were compared where CO was detected along with other chemicals. Chemical levels were recorded up to 65 minutes after the fire was knocked down (Graph 5). During this period of time, contents of the structures were cooling and either natural or mechanical ventilation had commenced. The study showed that there was a natural dissipation of chemical levels detected over the first 45 minutes post knock down. After 1 hour, most products had completely dissipated (Graph 4). Monitoring was typically discontinued after this period.

Due to the fact that hazardous airborne toxicants were documented many hours and sometimes days after extinguishment, this study could not conclude that time alone was a reliable determinate of safe atmospheric levels. The data did show that allowing more time after knock-down was beneficial and should be an important consideration when determining the best practices for firefighters during overhaul.

Natural and mechanical ventilation were not primary considerations of the study; however, a ventilation profile was developed for the same dataset to determine how ventilation affected the reduction of toxicants. Ventilation seemed to improve conditions (Appendix E); however, time after extinguishment seemed to have been a more significant factor in improving atmospheric air quality.



Graph 4. Chemical levels measured as a function of time



* All UV spectrometer measurements are reported as averages over the 1 minute preceding the time measured. CO, Particulates, and PID readings were all averaged to directly compare results.

** Toluene and Styrene were found likely to be present but in values of an order of magnitude less in most cases due to an unknown aldehyde present which overlaps the marker lambda/spectra in the UV spectrometer for those chemicals.

*** Total aliphatic aldehydes is the total measurement of valeraldehyde, butyraldehyde, propionaldehyde, and acetaldehyde.

^ Initial HCL detection found to be highly cross sensitive to NO. Further testing with separate meter showed this and levels were zero thereafter on all fires in the overhaul stages .

~ 1.8 correction factor added to the miniRAE PID readings based on RAE systems Applications and Technical notes TN-106 for mixtures.

Figure 5. Graphical display of chemical levels as a function of time

DISCUSSION

Our understanding of the toxicology associated with occupational exposure to harmful chemicals present after a fire is extinguished began in 1775 in an article titled *the Chirurgical Observations Relative to Cataract, the Polypus of the Nose, Cancer of the Scrotum*. The gist was that chimney sweeps were getting scrotum cancer from exposure to soot. A lot has happened to protect the public and workers from harmful chemicals that are present during and after fire extinguishment. Good hygiene played a key role in reducing dermal exposures to soot and scrotum cancer caused by contact with soot. However, hundreds of years later we are gaining a new understanding and appreciation of the potential harm that chronic low level multiple chemical exposures during overhaul phase of fire fighting can potentially pose to the health of first responders. The current study on firefighter chemical exposures during the overhaul phase using real time portable monitoring instruments demonstrated that many harmful chemicals are present in fires of different structural types at levels that exceed NIOSH's IDLH values. The chemicals of concern identified in the study included both organic and inorganic chemicals.

Some known human cancer causing agents were detected at trace levels. The perplexing toxicology question is whether the presence of these chemicals at low levels presents an increased health hazard to first responders. In toxicology we are acutely aware that even trace amounts of harmful chemicals can present a potential hazard, especially with synergistic or potentiating effects from repeated or continual respiratory or dermal exposure to multiple chemicals. Clearly, we need more toxicological research to determine the health impacts to firefighters from exposure to chemicals involved in overhaul.

In the absence of more definitive scientific data, we recommend precautionary measures to protect firefighters from potential harm. "The respiratory tract is the only organ system with vital functional elements in constant, direct contact with the environment. The lung also has the largest exposed surface area of any organ on a surface area of 70 to 100 square meters versus 2 square meters for the skin and 10 square meters for the digestive system".[12] We are finding that a great number of these chemicals that are involved in fires are being reclassified as human carcinogens in light of new scientific data. Our understanding of multiple chemical exposures is still in the distant future, but we can learn from the past by using good hygiene and avoiding unnecessary exposure, when possible, to potentially harmful chemicals in the overhaul phase.

The results of this study, along with those from previous studies[1,2,4,5] suggest that firefighters may benefit from changing on-scene practices after aggressive fire fighting activities are completed to further protect themselves from unnecessary chemical exposures. In this study, advanced monitoring technologies were utilized to gather the data; however, the authors and study partners are not asserting that this technology is the only component of a comprehensive approach to ensuring safe atmospheric levels for responders and investigators. Time, cooling, and decontamination should also be considered when approaching activities post-fire attack during the overhaul and later stages of fire fighting.

Firefighter Recommendations

This study demonstrates that time influences the levels of airborne chemicals post knock down. If crews are able to exit the structure as soon as reasonably possible and allow for the chemicals to dissipate naturally, their exposure will be reduced. Charts presented in this report illustrate the natural dissipation of toxicants over time. Timely replacement of crews working in the fire structure and allowing them to rehabilitate can also reduce the exposure times of individual crews. An additional benefit of timely crew removal is that it will allow fire investigators to gather information before a scene is further disturbed by overhaul.

The study shows that heat increases the liberation of harmful chemicals into the air. As fire crews cooled the materials and smoldering debris, there was a drop in the levels of airborne chemicals detected potentially reducing chemical exposure. Overhaul commonly must be performed within the structure, but applying water remotely if possible provides the most protection to firefighters. Ventilation was evaluated as it relates to the levels of toxicants and did assist in the reduction of airborne levels; however, toxicant levels rapidly increased when ventilation was discontinued. Further, when specifically used, gas powered fans were found to increase carbon monoxide levels. See Appendix E for data on ventilation.

The results of this study suggest that firefighters need to improve decontamination and personal hygiene practices post structure fire. Findings reveal that initial fire attack crews face the most significant exposure to a multitude of chemicals. Toxicologists have demonstrated that these chemicals pose an immediate threat to the respiratory tract and latent threat through cutaneous exposure.

Firefighters are aware of the respiratory hazards associated with the products of combustion and have policies and practices in place to protect themselves. Fire departments should also provide policy with regard to dermal exposure and the potential for contact with carcinogens. Known carcinogens and hazardous chemicals can attach themselves to structural personal protective equipment (PPE) and exposed skin. Firefighters may reduce their exposure to these chemicals by performing simple water decontamination on scene. Identifying chemicals, such as aldehydes and mercury, with advanced portable detection could provide information required for specific decontamination or future treatment.

At a minimum, policy should provide for simple decontamination on scene and expand to include machine washing of PPE after each fire and a thorough cleaning twice per year to reduce secondary exposure. Cutaneous exposure should also be addressed with better personal decontamination. Structural firefighting PPE generates body heat retention and increased perspiration in the wearer, resulting in dilated skin pores; this may result in enhanced dermal absorption. With proper use of PPE at structure fires, most toxicants will likely remain outside the epidermis; therefore, a wash down on scene and a shower at quarters could reduce further exposure.

The ability to monitor the air for particulate and harmful toxicants provides the best information to fire ground personnel. Discerning and quantifying the toxicants present not only indicates when it is safe to doff SCBA, it provides the information that dictates proper decontamination and post fire medical monitoring. This study demonstrates that a simple CO detector, or any other detection device by itself, cannot be relied upon to make this determination. Based on information obtained in this study, active monitoring for mercury, ozone, nitrogen dioxide, and acrolein are highly encouraged. UV spectrometry was found to be a suitable technology in quantifying these chemicals in real time and at the low human health hazard levels needed during overhaul. Regardless of whether advanced monitoring equipment is available, firefighters may benefit from receiving physicals that would provide a baseline for comparison in the event that an exposure was suspected. Firefighters should also consider documenting construction type, materials, actions, and conditions for the fires that they respond to. This may be the only information available to isolate an exposure that causes injury or illness in the future.

Fire Investigator Recommendations

This study did not specifically address the risks to fire investigators from airborne chemicals and particulate. The monitoring team typically completed their detection prior to fire investigator activities; however, conclusions can be drawn as to the potential risks based on data collected. Fire investigators enter structures that continue to cool over time, but there remains the potential for smoldering materials to liberate hazardous chemicals. Investigators commonly dig through the debris to determine cause and origin agitating particulate that had previously settled over time. As a result, investigators potentially face dermal and inhalation exposures that should be reduced through better practices. Further study to describe airborne hazards to investigation personnel is addressed in another section of this document.

Policies for investigators should outline respiratory protection and although SCBA is practical for firefighting operations, lengthy operational periods using SCBA pose an increased physical demand on investigators. SCBA use seems appropriate to reduce exposure initially, but use of lighter equipment in non-IDLH atmospheres should be considered. Supplied air respirators provide an alternative to the SCBA and similar amount of protection. They are considered positive pressure as long as they are qualitatively or quantitatively fit tested. Investigators in some departments use powered air purifying respirators or air purifying respirators. This study demonstrated that there is a vast list of chemicals and particulates liberated in a fire that cannot reliably be predicted or quantified without advanced detection. Air purifying respirators are limited by the selected filter and thus provide protection for a narrow range of the potential exposures.

Investigators can reduce hazardous dermal exposures by wearing inexpensive lightweight Level B chemical protective suits, gloves, and over boots. This PPE will provide dermal protection and can be disposed of prior to leaving the incident. Decontamination of equipment and clothing on scene and a shower after returning to quarters will also limit the exposure and should be a component of the policy.

Advanced detection equipment should be considered for use by investigators to provide information as to the airborne hazards. Current practices should be enhanced with the addition of UV spectrometers, IR spectrometers, particulate meters, PID's, or electrochemical detectors.

Study Limitations

While we attempted to evaluate and characterize toxicant levels at fire scenes the study conditions were not comparable to the same rigorous and controlled conditions a laboratory setting could provide. This study specifically used actual fire scenes, with on-scene portable, real-time monitoring in order to evaluate the practicality and effectiveness of that equipment at these scenes. We thus did not use the NIOSH Manual of Analytical Methods standards and therefore expected some degradation of data quality.

Data from this study were gathered using multiple detection methods to provide for direct device comparisons. We compared our data to that in previous studies.[1,4,5,6]. The comparisons to other studies data, with respect to levels of toxicants found, were expected to be within an order of magnitude when comparisons were possible. These comparisons were subject to the differing detection conditions of each study (i.e. time of detection after fire knock-down, time elapsed after sorbent tube or summa canister was evaluated versus real-time measurement, and detection technology differences).

Every effort was made to ensure equipment were calibrated daily, all filters and equipment were clean before each shift and adjustments for pressure, temperature and humidity were observed during data acquisition. However, due to the nature of fire scenes, the widely varying atmospheric conditions, and even potential air current differences between detection devices to name a few, there existed multiple opportunities for instrument differences and error.

Interpreting the results for the main instrument, a long path UV spectrometer to other devices proved problematic. The UV spectrometer had a sample air flow of approximately 15 ft^3/min. This flow converted to SI units was 4.25×10^5 ml/min. and the device averaged its detection over a one minute period. The other devices used had much smaller sampling flow (5 ml/min to 300 ml/min depending on device) and some were point sampling devices. The electrochemical sensor devices used recorded data that was then downloaded and averaged as necessary to compare to the UV spectrometer, however other devices used were incapable of constant monitoring. The GC-MS device used had a method which allowed constant monitoring as an option; however, that method was for ppm level detections only and was determined to be unsuitable for the lower levels needed during this study.

The location of the devices to one another also presented a potential data gathering discrepancy. The devices were kept apart by a minimum of 8 inches (electrochemical sensors, and CMS chip system device), and typically 2-3 feet apart for the larger devices (UV spectrometer, GC-MS, particulate meter, and flame spectrophotometer). The goal was to keep the devices close enough to assume similar air volumes were being sampled, however not so close that a larger device such as the UV spectrometer would be "stealing" the air from adjacent lower-flow devices.

Additionally, throughout a fire-scene, measurements were taken for sometimes an extended period of time. Firefighters were not able to change filters during an incident, as it would have required them to leave the scene, remove contaminated clothing, re-glove etc… in order to properly ensure a clean filter were replaced. The accumulating dirty filters at these scenes provided a means where toxicants being measured could potentially be accumulating in these filters and greater than actual results could have been measured toward the later stages of each incident.

Further, the detection equipment operators at these scenes often had to manipulate tubes and chips using gloved hands, where soot and particulate had likely accumulated. The sample inlets of all devices at each scene had potential exposure to soot and particulates through the devices being bumped or rubbed against contaminated surfaces. Every attempt was made however to neatly, carefully, and purposely carry each device to each sampling area. Pictures and occasional video confirmation at each fire proved useful to documenting this practice. This study did not document specific fire personnel exposure to toxicants, rather the study focused on areas where fire personnel were working or likely to work during the overhaul stage. The areas were then measured and assumptions made on potential exposure to fire personnel. The data did not include exact locations of crews with relation to monitoring sites or specific concentrations, and no attempt was made to specifically link a specific exposure to any responder.

RECOMMENDATIONS AND CONSIDERATIONS FOR FUTURE STUDY

Careful consideration of gas monitoring practices with respect to other interfering factors such as fire apparatus and gas powered fans should be considered. In fourteen events where CO was measured adjacent to gas fans outside of the structure, five events exceeded the NIOSH Recommended Exposure Limit (REL). These results were not intentionally staged for measuring CO production, rather recognized from photographs and instrument data logs. Similar data were unintentionally documented from rehabilitation areas and fire apparatus staged near the incident.

Newly observed toxicants at fire scenes were identified in this study such as mercury arsenic and ozone. Because little to no literature exists on these toxicant's presence at fire scenes, they should be considered in future work. As previous studies[1,4] have suggested further data is also required on firefighter exposure to low molecular weight aldehydes (glutaraldehyde, acetaldehyde, acrolein, et al) and should be a priority. Toxicologists remind us that exposure to trace levels of harmful chemicals and the synergistic effects of multiple chemicals may increase our risk for cancer. The synergistic and potentiating effect of these chemicals also requires further study.

The intent of this study was not specific to fire investigators; however, a reasonable conclusion can be drawn as to the hazards they encountered based on the results. Providing fire investigators with advanced technology monitoring equipment should be a priority. Data collected from chemical and particulate detection could provide a better understanding of the protection required to reduce exposure.

REFERENCES

1. D. Bolstad-Johnson, J. Burgess, C. Crutchfield, S. Storment, R. Gerkin, J.R. Wilson: *Characterization of Firefighter Exposures During Fire Overhaul*. Am. Ind. Hyg. Assoc. J. 61:636-641 (2000)
2. T. R. Anthony, P. Joggerst, L. James, J. L. Burgess, S. S. Leonard, E. S. Shogren: *Method Development Study for APR Cartridge Evaluation in Fire Overhaul Exposures.* Am. Ind. Hyg. Assoc. J. Vol. 51 No. 8 pp 1-14 (2007).
3. ACGIH. (2006) *TLV's and BEIs Based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices.* Cincinnati, OH: American Conference of Governmental Industrial Hygienists, 2006.
4. H. Harrison, D. Elkabir. *Products of Combustion.* Health Protection Agency, Chemical Hazards and Poisons Division, London UK. (2002).
5. L. Weger. *Surviving Fire Entrapments, comparing conditions inside vehicles and fire shelters Appendix B*. Characterizing Gases Generated in Vehicles and Fire Shelters. (2008).
6. C. C. Austin, B. Roberge, N. Goyer. *Cross sensitivities of electrochemical detectors used to monitor worker exposures to airborne contaminants: False positive responses in the absence of target analytes.* Journal of Environmental Monitoring, 2006, 8, 161-166.
7. CRC Handbook of Fundamental Spectroscopic Correlation Charts ch 1. Pp 1-17.
8. Gastec Corp No. 93 instruction manual for Acrolein detector tube use
9. Drager Safety AG & Co. KGaA Hydrochloric acid instruction sheet for Drager CMS systems chip application.
10. Chromair^{TM} Mercury strip instruction manual
11. RAE systems Application & Technical Notes, 3rd ed. 2005
12. Report on Carcinogens, Eleventh Edition; U.S. Department of Health and Human Services, Public Health Service, National Toxicology Program
13. Hirata, T; Inoue, M; Fukui, Y. *Wood Sci Technology, 1993, 24, 35-47*
14. Biswas, P; Wu C.Y.J. *Air and Waste Management Association, 1998, 48, 113-127*

DISCLAIMER

Specific policies regarding the best practices for personal protective equipment and respiratory protection must be established by individual departments. The best practices outlined in this report and principles of time, cooling, decontamination, and monitoring are recommendations based on the study results.

The State of Oregon Governor's Fire Service Policy Council, Tualatin Valley Fire & Rescue and its Board of Directors make no warranties, express or implied, nor assume and disclaim any legal liability or responsibility to any person for any loss or damage arising out of or in conjunction with the interpretation, application, or use of or inability to use, any information, data, apparatus, product, or processes disclosed in the report.

This report may not be modified or reproduced, in part, without prior written permission of the State of Oregon Governor's Fire Service Policy Council, Tualatin Valley Fire & Rescue, and the Oregon Office of State Fire Marshal.

APPENDIX A

Analytical Limits of Detection (LOD) and Devices Used

Analyte	**Number of Fires Device Used/ Times Chemical Found above LOD**	**Device(s) used**	**LOD (Limit of Detection)**	**Published Device Precision[4]**
Acrolein	12, above LOD 4 times	GASTEC colorimetric tubes	2 ppm	Standard Deviation (SD) 10%
Aliphatic Aldehydes, Total value of valeraldehyde, acetaldehyde, butyraldehyde, propionaldehyde	29, above LOD 19 times	UV HoundFR™ (CEREXMS LLC)	Various LODs. Less than 1 ppm for each	UV = (+/-) 1% of reading
Ammonia	29, above LOD 9 times	UV HoundFR™ (CEREXMS LLC)	UV: 0.015 ppm	UV = (+/-) 1% of reading
Arsenic compounds	8, above LOD 3 times	TIMs Flame spectrophotometer, GASTEC colorimetric tube	TIMs: 1.6 ppm, tube 1.5 ppm, E-C sensor 0.1 ppm	TIMs = (+/-) .5 ppm , e/c sensor= 0.1 ppm
Benzyl Chloride	12, above LOD 3 times	UV HoundFR™ (CEREXMS LLC), Hapsite(ER)™ portable GC-MS	UV: 0.01 ppm, GC-MS low ppt	UV = (+/-) 1% of reading
Carbon Monoxide	38, above LOD 30 times	iSC™ ITX and BW Micro5™ electrochemical sensors	E-C sensor: 1 ppm	Repeatability: 1% of signal. Linear output.
Carbon Disulfide	3, above LOD 1 time	UV HoundFR™ (CEREXMS LLC), Hapsite (ER)™ portable GC-MS	UV: 0.094 ppm, GC-MS low ppt	UV = (+/-) 1% of reading
Formaldehyde	29, above LOD 4 times	UV HoundFR™ (CEREXMS LLC), Drager CMS measurement system™	UV: 0.5 ppm, CMS: 0.2 ppm	UV = (+/-) 1% of reading
Glutaraldehdye	12, above LOD 12 times	UV HoundFR™ (CEREXMS LC), Hapsite (ER)™ portable GC-MS	UV: estimated 0.01 ppm, GC-MS unpublished	UV = (+/-) 1% of reading
Hydrogen Chloride	37, above LOD 8 times[2]	iSC™ ITX and Drager PAC III™ electrochemical, Drager CMS measurement system™	E-C: 0.2 ppm (max 30 ppm), CMS 1 ppm	CMS = (+/-) 10% of reading
Hydrogen Cyanide	25, above LOD 6 times	iSC™ ITX and BW Micro5™ electrochemical, Drager CMS measurement system	E-C: 0.3 ppm (max 30 ppm)	Linearity <5%
Mercury Vapor	29, above LOD 5 times	UV HoundFR™ (CEREXMS LLC), Chromair™ Colorimetry	UV: 0.01 ppm, colorimetry: 0.12 mg/M3(hr) (max 3.2 mg/M3(hr)	UV = (+/-)1% of reading
Naphthalene	29, above LOD 7 times	UV HoundFR™ (CEREXMS LLC), Hapsite (ER)™ Portable GC-MS	UV: 0.01 ppm	UV = (+/-) 1% of reading
Nitric Oxide	29, above LOD 28 times	UV HoundFR™ (CEREXMS LLC)	UV: 0.02 ppm	UV = (+/-) 1% of reading
Nitrogen Dioxide	37, above LOD 28 times	UV HoundFR™ (CEREXMS LLC), BW Micro5™ electrochemical	UV: 0.12 ppm, e-c : 0.2 ppm	UV = (+/-) 1% of reading
Ozone	29, above LOD 21 times	UV HoundFR™ (CEREXMS LLC), BW Micro5™ Electrochemical	UV: 0.012 ppm, e-c: 0.02 ppm	UV = (+/-) 1% of reading
Phenol	29, above LOD 9 times	UV HoundFR™ (CEREXMS LLC), Hapsite (ER)™ portable GC-MS	UV: 0.01 ppm	UV = (+/-) 1% of reading
Phosphine	9, above LOD 1 time[1]	BW Micro5™ electrochemical	E-C: 0.1 ppm	Repeatability: 2% of signal. Linear output
Styrene[3]	29, above LOD 25 times	UV HoundFR™ (CEREXMS LLC), Hapsite (ER)™ portable GC-MS, Drager CMS measurement system™	UV: 0.04 ppm, GC-MS low ppt,	UV = (+/-) 1% of reading
Sulfur Dioxide	29, above LOD 3 times	UV HoundFR™ (CEREXMS LLC), Hapsite (ER)™ portable GC-MS, Drager CMS measurement system™	UV: 0.02ppm, GC-MS low ppt, CMS: 0.4 ppm	UV = (+/-) 1% of reading
Toluene[3]	29 , above LOD 27 times	UV HoundFR™ (CEREXMS LLC), Hapsite (ER)™ portable GC-MS	UV: 0.04 ppm, GC-MS low ppt	UV = (+/-) of reading
Particulates (<10 µm)	26, above LOD 26 times	EPAM 5000™ light scattering nephelometer (particulate meter)	EPAM: 0.001 mg/M3	EPAM= (+/-) 7.66% coefficient of variation

[1] Suspect arsenic was present not phosphine as sensor is directly cross sensitive.

[2] Suspect cross sensitivity of iTX™ sensor to NO and CO, HCl probably not present. Drager PAC III™ HCl sensor not cross sensitive to NO or CO.

[3] Styrene and toluene were found present with UV spectrometry and confirmed presence by GC-MS corroborates the UVHoundFR results, however quantification likely over-reported due to presence of unknown aldehyde (see Appendix B for explanation).

[4] Published device precision is listed to describe a manufacturer's stated device detection "accuracy" under controlled conditions and at standard temperature and pressures. Many variables existed during this study which had the potential to change or degrade a specific device's precision at a fire scene including but not limited to: Differing temperatures, pressures, humidity, unknown chemical interferents and filter accumulations. The expected error created by the sum of these factors was no more than +/- 10% of any device's readings, device dependent.

APPENDIX B

Monitoring Apparatus Technology Description

UV HoundFR^{TM}

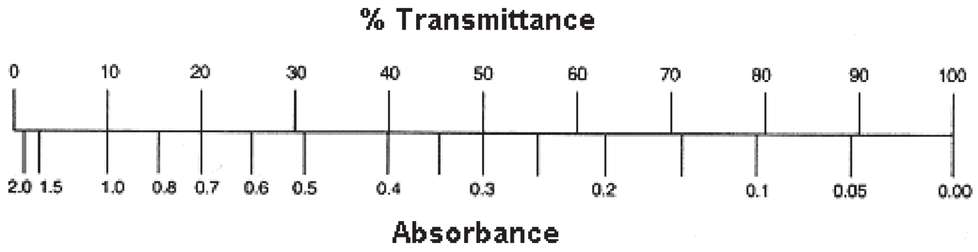
The main monitoring instrument employed during this study was a portable UV spectrometer. This device measured 15-20 chemicals with a resolution of 0.2 nanometer (NM) wavelength between the UV spectrum of 185 NM and 400 NM. The device used a deuterium lamp source and a 15 cubic ft^3/min. pump, a miniature spectrometer and advanced computational software. The device measured the chemicals in a path length of 17 meters allowing reliable chemical detection down to low ppb for most chemicals. The formula for quantification for this device was dependent on the path length.

Beer's law describes the method employed for computation of quantities measured by UV absorption:

$$\mathbf{A = \varepsilon b c}$$

Where **A** is absorbance (no units, since $A = \log_{10} P_0 / P$). Absorbance is measured by the device and is used by the software in the quantification. Absorbance can be related to transmittance as seen in the picture below.
Ɛ = the molar absorbtivity of each specific chemical with units of L mol^{-1} cm^{-1}. Each chemical to be measured has a specific calculated molar absorbtivity.
b = the path length of the sample. This is the path length in which the UV light is shined to absorb the chemical. In the UV HoundFR the UV light beam path length totaled 17 meters due to specialized mirrors located within the device.
c = the concentration of the compound, expressed in mol L^{-1}

Solving for C expresses an absorbed gas quantity. Solving for units can then show standard measurement in parts per billion.



*Manufacturer's Note on Toluene Data:

> The influence of an unknown compound was determined to have caused the CLS regression analysis in the UV spectrometer to "false positive" toluene detections in many data sets reviewed. Toluene and this unknown compound share a fairly similar lambda max, which potentially confused the regression. This is further corroborated by the lower than expected R2 value occasionally observed given the concentrations of toluene being reported.

*Manufacturer's Note on Styrene data:

> In sample data sets reviewed it appears that the presence of low levels of styrene is being influenced by another compound, most likely an aldehyde of some form. The additive nature of DOAS can cause an increase in concentration readings for compounds that are present in the spectra. Another possible source of concentration error could be in the value set in the Cerex reference library. Further study will be needed to identify if this is an influencing factor.

*Manufacturer's Note on R2 value:

> Low R2 values were most commonly found for benzene during the study. When R2 values were found acceptable, high concentrations of benzene were present; therefore, rendering correlation analysis between benzene and other chemicals suspect. Baseline shift and shared spectra absorption regions complicated the true value of the lower concentration chemical.

INFICON HapsiteER^{TM}

This device was a portable quadrupole gas chromatograph, mass spectrometer from INFICON. This device used a mass spectrometer which detected chemicals from 41 to 300 AMU at a scan rate of 1000 AMU/second at 10 pts per AMU.

The device used an electron multiplier for detection, with 70 eV electron impact and non-evaporative getter (NEG) pump in its design.
The dynamic range is listed as 7 decades.

Gas chromatograph column – 15 meters, RTX-1ms, 0.25 mm inside diameter, 1.0 µm d.f. at a temperature range of 45° C to 200° C.

Monitoring Apparatus Validation

Following were three incident fires where the UV HoundFR^{TM} spectrometer was used alongside the INFICON HapsiteER^{TM} GC-MS.

DATE	Chemical	UV Hound	INFICON GC-MS	Chromair Hg strip
1/18/2010 #1	Benzene	2.0 ppm	N.A.	
1/18/2010 #2		1.419 ppm	1.22 ppm	
1/31/2010 #1		1.16 ppm	1.72 ppm	
1/31/2010 #2		1.03 ppm	2.04 ppm	
2/2/2010 #1		1.96 ppm	0.69 ppm	
2/2/2010 #2		0.355 ppm	0.350 ppm	
1/18/2010 #1	Naphthalene	N.D.	Present.	
1/31/2010 #1		0.621 ppm	Present	
1/31/2010 #2		0.666 ppm	N.A.	
2/2/2010 #1		N.D.	Present	
2/2/2010 #2		0.143 ppm	Present	
1/18/2010 #1	Toluene	R2 not acceptable	0.12 ppm	
1/18/2010 #2		0.12 ppm	0.15 ppm	
1/31/2010 #1		R2 not acceptable	2.0 ppm	
1/31/2010 #2		R2 not acceptable	0.13 ppm	
2/2/2010 #1		2.29 ppm (R2 value low)	0.12 ppm	
1/18/2010 #1	Styrene	R2 not acceptable	1.36 ppm	
1/18/2010 #2		0.368 ppm (low R2)	1.56 ppm	
1/31/2010 #1		0.347 ppm (low R2)	2.94 ppm	
1/31/2010 #2		0.368 ppm	0.35 ppm	
2/2/2010 #1		0.236 ppm	0.89 ppm	
2/2/2010 #2		0.202 ppm	0.026 ppm	
1/31/2010 #1	SO2	0.184 ppm	Present	
1/31/2010 #2		0.188 ppm	Present	
1/12/2010 #1	Mercury	0.026 ppm	N.A.	0.02 ppm
1/12/2010 #2		0.023 ppm	N.A.	0.014 ppm

Notes regarding data represented:

- **UV HoundFR^{TM} was typically in the fire-gas atmosphere and measuring much earlier than the GC-MS device as the GC-MS device took longer to be ready to sample.**
- **UV spectrometer and GC-MS were time synched to ensure a direct comparison of readings.**
- **The device's inlets were placed about 2 feet apart, at the same room height (~3-4 feet high).**
- **UVHoundFR^{TM} sampled at 15 ft^3/min. in 1 minute increments and then gave an average over that period. The GC-MS device sampled 5 ml of air (ppm method) or 100ml of air (ppb method) over a 1 minute period and then an additional 10-15 minutes separating the chemicals in the gas chromatography column was required after the sample times.**

The following were additional tests conducted over four dates where the UV HoundFR^{TM} spectrometer was used alongside the INIFCON HapsiteER^{TM} GC-MS.

DATE	Chemical	UV Hound	INFICON GC-MS
12/2/2009	Benzene	4.003 ppm	4.78 ppm
1/19/2010		0.628 ppm	2.64 ppm
1/30/2010 test 1		0.739 ppm	1.111 ppm
1/30/2010 test 2		R2 not acceptable	0.047 ppm
1/30/2010 test 3		R2 not acceptable	0.190 ppm
1/24/2010 test 1		R2 not acceptable	0.035 ppm
1/24/2010 test 2		0.100 ppm	0.0877 ppm
12/2/2009	Naphthalene	0.499 ppm	Present
1/19/2010		0.968 ppm	Present
1/24/2010 test 1		0.249 ppm	Present
1/24/2010 test 2		0.436 ppm	Present
1/30/2010 test 1		N.D.	Present
1/30/2010 test 2		0.016 ppm	Present
1/30/2010 test 3		N.A.	N.A.
12/2/2009	Toluene	0.863 ppm (low R2)	0.260 ppm
1/19/2010		0.826 ppm (low R2)	0.170 ppm
1/30/2010		N.D.	0.053 ppm
1/24/2010 test 1		0.0057 ppm	Present
1/24/2010 test 2		0.0079 ppm	Present
12/2/2009	Styrene	0.175 ppm (low R2)	0.710 ppm
1/19/2010		0.116 ppm (low R2)	2.83 ppm
1/24/2010 test 1		0.179 ppm	N.D.
1/24/2010 test 2		0.139 ppm (low R2)	0.005 ppm
1/30/2010 test 1		N.D.	N.D.
1/30/2010 test 2		N.D.	N.D.
1/30/2010 test 3		N.D.	N.D.

Notes regarding data represented:

- **UV HoundFR^{TM} was typically in the fire-gas atmosphere and measuring much earlier than the GC-MS device as the GC-MS device took longer to be ready to sample.**
- **UV spectrometer and GC-MS were time synched to ensure a direct comparison of readings.**
- **The device's inlets were placed about 2 feet apart, at the same room height (~3-4 feet high).**
- **UVHoundFR^{TM} sampled at 15 ft^3/min. in 1 minute increments and then gave an <u>average</u> over that period. The GC-MS device sampled 5 ml of air (ppm method) or 100ml of air (ppb method) over a 1 minute period and then an additional 10-15 minutes separating the chemicals in the gas chromatography column was required after the sample times.**
- **Present: No quantification available from that machine on this chemical. Verified presence of chemical only.**

Test 12/2/2009

In a 15'X15' fire room at Tualatin Valley Fire & Rescue's Regional Training Center, Sherwood, OR with wood pallets, straw and plastic materials set on fire:
Test fire was conducted where the portable UV HoundFR^{TM} spectrometer was placed adjacent the HapsiteER^{TM} portable GC-MS device. Sampling was completed in the smoke column and compared as shown in table above.

Test issues: The UV spectrometer was placed in the fire room window in heavy smoke several minutes before the GC-MS device was ready to sample. This timing allowed large hits of chemicals to be retained by the UV spectrometer before the GC-MS was ready to be placed in the smoke. The UV spectrometer was not designed for full smoke conditions. The GC-MS device inlet filter was also not replaced/cleaned before or after use.

Test 1/24/2010

Another test fire was conducted where the portable UVHoundFR^{TM} spectrometer was placed adjacent the HapsiteER^{TM} portable GC-MS device. Sampling was completed in the chamber of a wood pellet grill (inside grill at low temperature on start up) and in full smoke. Pellets were comprised of a hardwood composite.

Test issues: The UV spectrometer was placed in the wood pellet smoker several minutes before the GC-MS device was ready to sample. This timing allowed large hits of chemicals to be retained by the UV spectrometer before the GC-MS was placed in the smoke. The UV spectrometer was not designed for full smoke conditions. The GC-MS device inlet filter was also not replaced/cleaned before or after use.

Test 1/30/2010

In a 10'X12' utility shed an additional test fire was conducted where the portable UV HoundFR^{TM} spectrometer was placed adjacent the HapsiteER^{TM} portable GC-MS device. Sampling was completed in the smoke column created from burning a cloth and hardwood grill pellets in a coffee tin. Test #3 a road flare was added to the ignited materials (noted high SO_2 reading among data). See above table for comparisons.

UV Spectrometer and Portable GC-MS Device Discussion

Measurable benzene values were consistently similar for both machines (including real incident fires), regardless of test condition or which machine was placed in smoke first. Toluene and styrene measurements by the UV spectrometer appear to have been averaged at a higher level (typically 1 order of magnitude) throughout the tests. The UVHoundFR^{TM} manufacturers analyzed the data and concluded that the tests themselves were conducted in conditions that the spectrometer was not designed for. High levels of smoke and high (respectively) levels of benzene likely attributed to the consistently inflated readings of those chemicals. It is also possible that an unknown aldehyde was influencing the software analysis of the toluene and styrene reported levels. The typically lower R2 levels reported for those chemicals added to that suspicion. The manufacturer's recommended solutions to the toluene and styrene errant data involved: Only allowing higher R2 spectra matches to be included in the data (R2 >0.7), using the UVHoundFR^{TM} in conditions that are not in heavy smoke conditions, and properly representing the averaging software, and high pump flow sampling method the device employs as compared to other devices.

A note on the instruments sampling differences: The UVHoundFR^{TM} averages its readings over a one minute time frame. The 15 ft^3/min. sample average is documented as the minute before the time stamp on each file (ie time 2:30 pm on a file is actually the average of the minute preceding 2:30 pm). The HapsiteER^{TM} GC-MS takes a relatively small volume of air, either 5 ml or 100 ml depending on method chosen at the time given on each file. The volume of air is measured as a grab sample and not an averaged reading.

Toxic chemicals found in test fires and not reported in above tables:

12/2/2010 test fire: **Mercury at 320.0 ppb** (above NIOSH STEL) UVHoundFR^{TM} detection
Other chemicals found by GC-MS all at low ppb levels: Vinyl chloride, bromomethane, acetone, carbon disulfide, methyl ethyl ketone, 1,2 dichloroethane, chlorobenzene, ethyl benzene. Other chemicals reported were in part per trillion levels.

1/30/2010 test fire: **Mercury at 251.0 ppb** (above NIOSH STEL) UVHoundFR^{TM} detection
HCl at 30.0 ppm (above NIOSH STEL) PacIII^{TM} electrochemical sensor detection.

APPENDIX C

Fire Structure Descriptions and Conditions

Fire date	Time of monitoring after fire extinguished	Fire type Category	Main products combusted (furniture, wood, roofing, mixed)	Atmospheric conditions	Ventilation profile	Highest concentrations	CO levels
4/4/2008	0 min	Residential	Wood, pressure treated wood	43° F, 81% humidity, wind 10 mph	Open, outside, vented	Arsenic: 3.8 ppm	300 ppm max
6/6/2009	29 mins	Residential	Attic (wood, comp shingles)	61° F, 64% humidity, wind 7mph	Vertical, PPV	O_3: 0.689 ppm max stel. Benzene: 0.26 ppm	CO: 0 ppm over event
6/7/2009	30 mins	Residential	Wood, siding, deck, room contents	55° F, 84% humidity, wind 5.8 mph	Vertical, PPV	O_3: 1.5 ppm max. STEL	CO: 25-31 ppm over 40 sec
6/7/2009 Labrousse	0 mins	Barn	Wood, siding, barn contents	54° F, 86% humidity, wind 3.5 mph	Open, outside, vented	Particulate (outside) 10-12 mg/m3	CO: 33-189 ppm over 2 mins 13 - 170 over 2 min. 5 - 152 over 2 min. Ave. for event: 18 ppm
6/23/2009	15 mins	Commercial	Forklift + battery	76° F, 42% humidity, wind 4.6 mph	PPV fan, sprinkler	Arsenic: 1 ppm E/C sensor. Particulate up to 19 mg/m3	5-48 ppms over 48 min. STEL ave. 6 ppms over event
6/27/2009	4 mins	Residential	Shake Roof	82°F, 29% humidity, wind 0 mph	Vented through roof	O_3: 1.1 ppm max 41 mins STEL. Particulate up to 16.9 mg/m3	CO: 3-41 ppm over 1 minute
6/28/2009	10 mins	Residential	Wood, siding	55° F, 69% humidity, wind 9.2 mph	Open, natural vent	O_3: 0.62 ppm max STEL. Particulate up to 8.2 mg/m3	CO: 2-41 ppms over 34 min. STEL average 18.67
6/30/2009	21 mins	Residential	Vegetation, wood shake, minor attic involvement	57° F, 55% humidity, wind 0 mph	Roof open to outside	Particulate: 0.6 mg/m3 STEL	CO: 3-11 ppms over 6 min. STEL 2.27 average
7/10/2009	20 mins	Barn	Barn and contents (several autos)	73.9° F, humidity 56%, wind 0 mph	Open, roof gone	O_3: 2 ppm max/STEL (above 0.5 for 15 min). Particulate	CO: 0 ppms over event
7/13/2009	27 mins	Residential	Attic member (wood), venting	65° F, 90% humidity. Clear day	Open-vented	Particulate: 0.6 mg/m3	Not analyzed
7/22/2009	24 mins	Residential	Wood, some kitchen contents	55° F, humidity 86%, wind 0 mph	Horizontal-PPV, back rooms not well vented	O_3: over 1 ppm for 15 min. Particulate 2-2.3 mg/m3	CO: 2-3 ppms over event
7/23/2009	29 mins	Residential	Wood, siding, contents	64° F, humidity 63%, wind 0 mph	Vented, non-enclosed	NO_2: 6.6 ppm. O_3: > 0.5 ppm for 18 min. Particulate 19.6 mg/m3	CO: 10-125 ppm over 13 min 8-18 ppm over 10 min. STEL average 20 ppms
7/30/2009	27 mins	Residential	Wood, contents of kitchen, insulation	88° F, 62% humidity	Vertical venting of structure	PID 4.5 max	CO 5-24 ppms
7/31/2009	47 mins	Residential	2 vehicles, wood siding and garage contents	80° F, 75% humidity. Sunny day	Horizontal fan vented, garage opened to atmosphere	UVHound not available. HCN 30 ppms 5 min	CO above 100 for 2 min. Max 466 near engine

Fire date	Time of monitoring after fire extinguished	Fire type Category	Main products combusted (furniture, wood, roofing, mixed)	Atmospheric conditions	Ventilation profile	Highest concentrations	CO levels
8/3/2009	13 mins	Commercial	Boxes, plastic, paper	84° F, humidity 40%, wind 6.9 mph	Horizontal ventilation, light smoke showing	Particulate: 7.4 mg/m3	CO: 54 ppm TWA
8/4/2009	27 mins	Commercial	Cash register, paper and plastic	66° F, humidity 64%, wind 7 mph	Horizontal/open windows. Natural vent.	UVHound not available. Particulate: 0.67 mg/m3, PID 12 .0 ppm peak	CO: 0 ppm
8/10/2009	33 mins	Residential	Wood, insulation, plywood	70° F, 80% humidity, clear evening	Vertical natural ventilation	O_3: 0.263 ppm over 7 min	CO 5-29 ppm over 20 min
8/11/2009	29 mins	Residential	Wood, contents of home/mixed	68° F, 78% humidity	Roof vented, home open	NO_2: 19 ppms. O_3 0.4 ppm, HCN: 7.1 ppm, 10 max. Particulate: 4.2 mg/m3	CO 6-36 ppm, 46 ppm peak
8/19/2009	27 mins	Residential	Structure and contents. Wood and siding/mixed	100° F, 28% humidity	Horizontal & natural vent.	O_3: 0.4 -1.7 ppm 20mins. Particulate >1.6/15 min	CO 9-35 ppm/43 min
8/27/2009	14 mins	Motor Home - trailer	Structure and contents of motor home	76° F, 56% humidity. 89° F, and 55% humidity next to fire structure	Open/outside.	Formaldehyde: 0.35 ppm (same as CMS chip at 12:41) Particulate high peaks @ 17 mg/m3	CO 5-10 ppm
9/23/2009	20 mins	Residential	Paint, contents, some wood structure	72° F, 44% humidity, clear	Some PPV ventilation and horizontal openings	NO_2: 2.5-10 ppm/10 mins Total Aldehydes 13-22.5 ppm. PID 18 ppm	CO 30-43 ppms over 26 min.
9/24/2009	13mins	Residential	Exterior siding and structure plus tree	58° F, clear evening	PPV and natural openings (window)	PID 25 ppm. Particulate 0.7 mg/m3. NO_2 1.6-2.7 ppm	CO above 10ppm/12 min max 20 ppm
9/26/2009	14 mins	Motor Home - trailer	Wood, vinyl and trailer contents	70° F, Nice/clear day	Open/natural outside ventilation	NO_2: 0.5-6.1 ppm. Particulate 8-17 mg/m3	CO: 0 ppm
10/4/2009	25 mins	Residential	Wood, contents, T111 siding	58° F, clear evening	PPV ventilation with open windows	PID: 82 max, above 20/15 min NO_2: 0.4-2.6 ppm	CO 6-36 ppm/16 min
10/11/2009	22 mins	Residential	Attic fire, no smoke inside	53° F, humidity 24%, wind 13 mph	PPV with roof vented by fire	NO_2: 4-12 ppm. PID: 1-3.5	CO 5 ppm
10/12/2009	20 mins	Residential	Basement fire/kitchen in basement. Wood/cabinets/kitchen items melted	63° F, 70% humidity, clear evening	2 PPV fans at garage. Difficult ventilation in home	Acrolein: 2.5 ppm. Glut: 0.2-1.6 ppm /30 min PID: 10 ppm	CO 70 ppm/15 min, 200 ppm peak

Fire date	Time of monitoring after fire extinguished	Fire type Category	Main products combusted (furniture, wood, roofing, mixed)	Atmospheric conditions	Ventilation profile	Highest concentrations	CO levels
10/21/2009	26 mins	Residential	Structure and contents	58° F, clear	Ventilation not documented	O_3: 0.4-1 ppm/4 min. Glut: 0.2-1.3 ppm, NO_2: 11.2 ppm. PID: 75.0 ppm, max 981.0	Not analyzed
11/4/2009	08 mins	Residential	Hallway, some apartment structure, wood siding and contents of one structure	64° F, Clear day	PPV ventilation, with natural window and door venting	Glut: 0.25-5.9 ppm, NO_2: 2-10.8 ppm, O_3: 0.27-1.3 ppm	CO 38 ppm high. 10 ppm STEL high over 25 min.
11/10/2009	13 mins	Residential	Wood/cabinets some contents	75° F, Clear day	PPV ventilation with windows	NO_2: 0.9 ppm, HCN: 0.2 ppm, PID 10.9 ppm	32 ppm high. 16 ppm STEL high over 30 min.
11/12/2009	13 mins	Residential	Laundry room fire to structure	45° F, 48% humidity	PPV with natural ventilation	Glut: 1.352 ppm, Benzene: 0.7-0.9 ppm, NO_2: 12.4 ppm, O_3: 0.6 ppm	CO 43 ppm high 4 ppm, STEL ave. over 5 min.
11/14/2009	17 mins	Residential	Kitchen fire with structure, mostly contents consumed	50° F, 62% humidity	ppv at front and rear of structure	Glut: 1.05 ppm, O_3 0.432 ppm, NO_2: 7.6 ppm, Mercury 0.255 ppm	CO 2 ppm over 1 minute
11/20/2009	10 mins	Residential	Deck, kitchen, family room contents	54° F - 59° F, 93% humidity	Natural ventilation. Large 10X10 opening at back	Total Aldehydes 18 ppm, NO_2: 7.6 ppm	Not analyzed
12/12/2009	40 mins	Residential	Structure and room contents	23° F, 40% humidity	Open, natural ventilation	O_3: 0.8 ppm, NO_2: 3.8 ppm, aldehydes 20.0 ppm, Particulates 17 mg/m3	CO 6 ppm over 2min. 4-10 ppm over 7 min. 5-12 ppm over 4 min. 5-529 ppm over 4 min STEL 26 ppm ave. over 4 min.
12/21/2009	17 mins	Residential	Contents fire. Chair, human, clothing, personal effects	52° F, humidity 86%, wind 11.5 mph	Well ventilated, PPV	NO_2: 15.6 ppm, Aldehydes 18.0 ppm, O_3: 0.9 ppm	CO 6-14 ppm over 2 min
1/12/2010	22 mins	Residential	Kitchen fire with structure, mostly contents consumed	48.9° F, humidity 93%, wind 0 mph	PPV fan ventilation	Mercury: 0.035 ppm, NO_2: up to 40 ppm, Acrolein 1.7 ppm	CO 6-30 ppm over 4 min. 20-69 ppm over 31 min STEL ave. over 21 min
1/18/2010	49 mins	Motor Home / Trailer	Contents and minor structure	52.5° F, humidity 63%, wind 10.4 mph	Little ventilation. No PPV	Benzene: 1.58 ppm, Benzyl Chloride: 0.062, Phenol: 0.1 ppm	Not analyzed
1/31/2010	17 mins	Residential	Fire through roof, large fire including kitchen contents	67° F - 90° F Depending on location. 70% humidity throughout	PPV at front of garage. Natural including missing roof at kitchen at balance of structure	Benzene: 2.04 ppm, Naphthalene 0.645 ppm, SO_2: 0.2 ppm	CO 5-42 ppm. STEL high 23 ppm. 6-44 ppm. STEL 23 ppm over 16 min.
2/2/2010	0 minutes	Residential	Deck, structure, dining area and ceiling spaces	53° F, humidity 66%, wind 5.8 mph	PPV at end of fire	Benzene: 1.96 ppm, O_3: 0.367 ppm, NO_2: 10.8 ppm	CO 16-610 ppm STEL 148 ppm over 11 min. 25-75 ppm. STEL 152 ppm over 16 min.

APPENDIX D

Potentially Harmful and Carcinogenic Chemicals Studied

Chemical	**Cancer status/reference**	**skin designation**	**method of detection**	**Mean concentration detected (ppm) (when calculated)/fires detected**
Acrolein	No	Skin	Tubes/GasTec	4 of 12 fires
Acetaldehyde	2B/IARC-NTP		UV spec/GC-MS	Present 12 of 12 fires
Arsenic	1/IARC-NTP		TIMs spectrophotometer/Micro-5	3 of 9 fires (including 1 additional test fire)
Benzene	1/IARC-NTP	Skin	UV spec/GC-MS/CMS	10 of 29 fires
Benzyl chloride	2A/IARC		UV spec/GC-MS	0.022/3 of 3 fires
1,3 Butadiene	1/IARC-NTP		GC-MS/UV spec	0.074/3 of 3 fires
Benzofuran	2B IARC		GC-MS	Present/1 of 3 fires
Carbon disulfide	No	Skin	UV Spec/GC-MS	0.016/3 of 3 fires
Carbon tetrachloride	2B/IARC-NTP		GC-MS	0.00021/1 of 3 fires
Coal Tar pitch	1/IARC-NTP		Reference only[1]/light scattering particulate meter	possible at 26 of 26 fires
1,4 Dichlorobenzene	2B NTP		GC-MS	trace/2 of 3 fires
1,2 dichloroethane	2B		GC-MS	0.013/2 of 3 fires
1,3 dichloropropane	2B/IARC		GC-MS	Present/1 of 3 fires
Diesel Exhaust	2A/IARC	Skin	GC-MS mixture by species	38 of 38 fires
Ethyl benzene	2B/IARC		GC-MS	0.051/4 of 4 fires
Formaldehyde	1/IARC-NTP		UV spec/CMS	4 of 29 fires
Furan	2B/IARC-NTP		GC-MS	Present/2 of 3 fires
Furfural	Possible (CPDB)	Skin	GC-MS	Present/2 of 3 fires
Glutaraldehyde	No	Skin (sensitizer)	UV Spec/GC-MS	Present/12 of 12 fires
Hydrogen chloride	No	Skin (Acid)	Drager electrochemical	8 of 37 fires
Hydrogen cyanide	No	Skin	Micro5 electrochemical	6 of 25 fires
Mercury	No	Skin	UV Spec/colorimetry	5 of 31 fires (including 2 additional test fires)
Naphthalene	2B/IARC-NTP	Skin	UV spec/GC-MS	11 of 37 fires
N-Nitrosodimethylamine	2A/IARC-NTP	Skin	GC-MS	Present/1 of 4 fires
Phenol	No	Skin	UV spec/GC-MS	9 of 29 fires
Styrene	2B IARC		GC-MS/UV spec/CMS	25 of 29 fires
Tetrahydrofuran	No	Skin	GC-MS	0.009/1 of 3 fires
Toluene	No	Skin	GC-MS/UV spec/CMS	25 of 29 fires
Vinyl Chloride	1 IARC/NTP		GC-MS	0.014/1 of 3 fires

IARC: International Agency for Research on Cancer
Group 1 carcinogens: known human carcinogens
Group 2 carcinogens: a) probable human carcinogen b) possible human carcinogen
NTP: National Toxicology Program
CPDB: Carcinogenic Potency Database

APPENDIX E

Average CO levels at time range and ventilation

Time	OverAll	Ventilation Level			Percentage reduction	
> or =	Average	0	1	2	1 over 0	2 over 1
0:15	43.84	113.33	51.19	10.07	54.8%	80.3%
0:20	49.92	496.00	28.46	16.85	94.3%	40.8%
0:25	27.71	78.75	29.88	12.79	62.1%	57.2%
0:30	43.60	6.00	65.46	18.70	0.0%	71.4%
0:35	5.88	0.00	5.75	5.97	0.0%	0.0%
0:40	12.81	0.00	17.27	7.23	0.0%	58.1%
0:45	0.00	0.00	0.00	0.00	0.0%	0.0%
0:59	20.34	6.00	30.47	9.62	0.0%	68.4%

Average Ozone* levels at time range and ventilation

Time	OverAll	Ventilation Level			Percentage reduction	
> or =	Average	0	1	2	1 over 0	2 over 1
0:15	0.87	1.10	0.63	0.00	42.4%	0.0%
0:20	0.75	0.00	0.87	0.81	0.0%	6.9%
0:25	0.94	0.37	0.41	0.00	0.0%	0.0%
0:30	0.89	0.00	1.04	0.00	0.0%	0.0%
0:35	0.71	0.00	0.75	0.00	0.0%	0.0%
0:40	0.48	0.00	0.54	0.00	0.0%	0.0%
0:45	0.00	0.00	0.00	0.00	0.0%	0.0%
0:59	0.66	0.00	0.00	0.81	0.0%	0.0%

Average Acrolein levels at time range and ventilation

Time	OverAll	Ventilation Level			Percentage reduction	
> or =	Average	0	1	2	1 over 0	2 over 1
0:15	2.50	0.00	2.50	0.00	0.0%	0.0%
0:20	1.90	0.00	1.90	0.00	0.0%	0.0%
0:25	0.00	0.00	0.00	0.00	0.0%	0.0%
0:30	0.00	0.00	0.00	0.00	0.0%	0.0%
0:35	0.00	0.00	0.00	0.00	0.0%	0.0%
0:40	0.00	0.00	0.00	0.00	0.0%	0.0%
0:45	0.00	0.00	0.00	0.00	0.0%	0.0%
0:59	4.00	0.00	0.00	4.00	0.0%	0.0%

Average PID levels at time range and ventilation

Time	OverAll	Ventilation Level			Percentage reduction	
> or =	Average	0	1	2	1 over 0	2 over 1
0:15	24.87	11.10	3.95	0.00	64.4%	0.0%
0:20	4.54	0.00	5.58	0.00	0.0%	0.0%
0:25	177.88	0.00	8.00	0.00	0.0%	0.0%
0:30	11.18	0.00	2.25	0.00	0.0%	0.0%
0:35	10.38	0.00	13.67	0.00	0.0%	0.0%
0:40	3.75	0.00	4.50	0.00	0.0%	0.0%
0:45	0.00	0.00	0.00	0.00	0.0%	0.0%
0:59	8.78	0.00	8.33	9.23	0.0%	0.0%

Average Arsenic levels at time range and ventilation

Time	OverAll	Ventilation Level			Percentage reduction	
> or =	Average	0	1	2	1 over 0	2 over 1
0:15	3.80	0.00	3.80	0.00	0.0%	0.0%
0:20	3.80	0.00	3.80	0.00	0.0%	0.0%
0:25	0.95	0.00	0.00	0.95	0.0%	0.0%
0:30	0.00	0.00	0.00	0.00	0.0%	0.0%
0:35	0.00	0.00	0.00	0.00	0.0%	0.0%
0:40	0.00	0.00	0.00	0.00	0.0%	0.0%
0:45	0.00	0.00	0.00	0.00	0.0%	0.0%
0:59	0.88	0.00	1.00	0.76	0.0%	23.8%

Average PID~ levels at time range and ventilation

Time	OverAll	Ventilation Level			Percentage reduction	
> or =	Average	0	1	2	1 over 0	2 over 1
0:15	14.75	27.00	0.00	2.50	0.0%	0.0%
0:20	215.00	0.00	215.00	0.00	0.0%	0.0%
0:25	0.00	0.00	0.00	0.00	0.0%	0.0%
0:30	68.00	0.00	68.00	0.00	0.0%	0.0%
0:35	0.00	0.00	0.00	0.00	0.0%	0.0%
0:40	0.00	0.00	0.00	0.00	0.0%	0.0%
0:45	0.00	0.00	0.00	0.00	0.0%	0.0%
0:59	68.00	0.00	0.00	2.50	0.0%	0.0%

Average Benzene* levels at time range and ventilation

Time	OverAll	Ventilation Level			Percentage reduction	
> or =	Average	0	1	2	1 over 0	2 over 1
0:15	0.80	1.79	0.46	0.88	74.6%	0.0%
0:20	0.69	0.69	0.00	0.00	0.0%	0.0%
0:25	2.30	2.30	0.00	0.00	0.0%	0.0%
0:30	0.60	0.51	0.62	0.00	0.0%	0.0%
0:35	0.35	0.00	0.35	0.00	0.0%	0.0%
0:40	0.51	0.00	0.65	0.23	0.0%	65.4%
0:45	0.00	0.00	0.00	0.00	0.0%	0.0%
0:59	0.50	0.51	0.53	0.23	0.0%	57.7%

Average Toluene*, ** levels at time range and ventilation

Time	OverAll	Ventilation Level			Percentage reduction	
> or =	Average	0	1	2	1 over 0	2 over 1
0:15	0.88	0.00	0.60	1.09	0.0%	0.0%
0:20	1.48	2.29	1.76	1.06	23.2%	39.5%
0:25	1.74	0.00	2.54	0.94	0.0%	63.2%
0:30	1.39	0.00	1.73	0.36	0.0%	79.2%
0:35	0.96	0.00	0.96	0.00	0.0%	0.0%
0:40	1.11	0.00	1.11	0.00	0.0%	0.0%
0:45	0.00	0.00	0.00	0.00	0.0%	0.0%
0:59	1.08	0.00	1.25	0.32	0.0%	74.5%

Average Formaldehyde* levels at time range and ventilation

Time	OverAll	Ventilation Level			Percentage reduction	
> or =	Average	0	1	2	1 over 0	2 over 1
0:15	0.47	0.00	0.00	0.47	0.0%	0.0%
0:20	0.39	0.00	0.58	0.20	0.0%	65.5%
0:25	0.00	0.00	0.00	0.00	0.0%	0.0%
0:30	0.00	0.00	0.00	0.00	0.0%	0.0%
0:35	0.63	0.00	0.63	0.00	0.0%	0.0%
0:40	0.35	0.00	0.35	0.00	0.0%	0.0%
0:45	0.00	0.00	0.00	0.00	0.0%	0.0%
0:59	0.49	0.00	0.49	0.00	0.0%	0.0%

Average Total Aliphatic Aldehydes*, * levels at time range and ventilation**

Time	OverAll	Ventilation Level			Percentage reduction	
> or =	Average	0	1	2	1 over 0	2 over 1
0:15	18.45	57.60	15.90	14.47	72.4%	9.0%
0:20	18.07	0.00	19.88	15.35	0.0%	22.8%
0:25	18.00	0.00	17.55	18.90	0.0%	0.0%
0:30	17.38	0.00	18.00	15.50	0.0%	13.9%
0:35	14.21	0.00	14.21	0.00	0.0%	0.0%
0:40	19.87	0.00	23.15	16.59	0.0%	28.3%
0:45	0.00	0.00	0.00	0.00	0.0%	0.0%
0:59	17.08	0.00	17.46	16.22	0.0%	7.1%

Average Glutaraldehyde* levels at time range and ventilation

Time	OverAll	Ventilation Level			Percentage reduction	
> or =	Average	0	1	2	1 over 0	2 over 1
0:15	0.71	0.89	0.56	0.83	36.5%	0.0%
0:20	1.11	0.00	0.71	1.50	0.0%	0.0%
0:25	2.50	2.50	0.00	0.00	0.0%	0.0%
0:30	1.37	0.00	1.37	0.00	0.0%	0.0%
0:35	2.37	0.00	1.60	3.13	0.0%	0.0%
0:40	1.79	0.00	3.13	0.46	0.0%	85.1%
0:45	0.00	0.00	0.00	0.00	0.0%	0.0%
0:59	1.68	0.00	2.31	1.06	0.0%	54.0%

Average HCL^ levels at time range and ventilation

Time	OverAll	Ventilation Level			Percentage reduction	
> or =	Average	0	1	2	1 over 0	2 over 1
0:15	0.00	0.00	0.00	0.00	0.0%	0.0%
0:20	0.00	0.00	0.00	0.00	0.0%	0.0%
0:25	0.00	0.00	0.00	0.00	0.0%	0.0%
0:30	0.00	0.00	0.00	0.00	0.0%	0.0%
0:35	0.00	0.00	0.00	0.00	0.0%	0.0%
0:40	0.00	0.00	0.00	0.00	0.0%	0.0%
0:45	0.00	0.00	0.00	0.00	0.0%	0.0%
0:59	3.30	0.00	3.30	0.00	0.0%	0.0%

Average HCN levels at time range and ventilation

Time	OverAll	Ventilation Level			Percentage reduction	
> or =	Average	0	1	2	1 over 0	2 over 1
0:15	2.33	0.00	2.50	2.00	0.0%	20.0%
0:20	0.00	0.00	0.00	0.00	0.0%	0.0%
0:25	0.30	0.00	0.30	0.00	0.0%	0.0%
0:30	0.20	0.00	0.20	0.00	0.0%	0.0%
0:35	0.50	0.00	0.50	0.00	0.0%	0.0%
0:40	0.00	0.00	0.00	0.00	0.0%	0.0%
0:45	0.00	0.00	0.00	0.00	0.0%	0.0%
0:59	0.35	0.00	0.35	0.00	0.0%	0.0%

Average NH3* levels at time range and ventilation

Time	OverAll	Ventilation Level			Percentage reduction	
> or =	Average	0	1	2	1 over 0	2 over 1
0:15	0.00	0.00	0.00	0.00	0.0%	0.0%
0:20	0.38	0.00	0.00	0.38	0.0%	0.0%
0:25	0.00	0.00	0.00	0.00	0.0%	0.0%
0:30	0.00	0.00	0.00	0.00	0.0%	0.0%
0:35	0.00	0.00	0.00	0.00	0.0%	0.0%
0:40	0.00	0.00	0.00	0.00	0.0%	0.0%
0:45	0.00	0.00	0.00	0.00	0.0%	0.0%
0:59	0.00	0.00	0.00	0.00	0.0%	0.0%

Average Mercury* levels at time range and ventilation

Time	OverAll	Ventilation Level			Percentage reduction	
> or =	Average	0	1	2	1 over 0	2 over 1
0:15	0.43	0.52	0.34	0.00	34.6%	0.0%
0:20	0.25	0.00	0.00	0.25	0.0%	0.0%
0:25	0.00	0.00	0.00	0.00	0.0%	0.0%
0:30	0.00	0.00	0.00	0.00	0.0%	0.0%
0:35	0.00	0.00	0.00	0.00	0.0%	0.0%
0:40	0.00	0.00	0.00	0.00	0.0%	0.0%
0:45	0.00	0.00	0.00	0.00	0.0%	0.0%
0:59	0.00	0.00	0.00	0.00	0.0%	0.0%

Average Styrene*, ** levels at time range and ventilation

Time	OverAll	Ventilation Level			Percentage reduction	
> or =	Average	0	1	2	1 over 0	2 over 1
0:15	0.00	0.00	0.00	0.00	0.0%	0.0%
0:20	0.00	0.00	0.00	0.00	0.0%	0.0%
0:25	0.00	0.00	0.00	0.00	0.0%	0.0%
0:30	0.00	0.00	0.00	0.00	0.0%	0.0%
0:35	0.00	0.00	0.00	0.00	0.0%	0.0%
0:40	0.00	0.00	0.00	0.00	0.0%	0.0%
0:45	0.00	0.00	0.00	0.00	0.0%	0.0%
0:59	2.03	0.00	0.25	3.80	0.0%	0.0%

Average NO2* levels at time range and ventilation

Time	OverAll	Ventilation Level			Percentage reduction	
> or =	Average	0	1	2	1 over 0	2 over 1
0:15	4.91	1.70	7.03	4.40	0.0%	37.4%
0:20	4.63	0.00	5.34	1.47	0.0%	72.5%
0:25	3.82	0.40	4.20	4.40	0.0%	0.0%
0:30	1.30	0.00	0.70	1.60	0.0%	0.0%
0:35	2.60	0.00	2.60	0.00	0.0%	0.0%
0:40	4.20	0.00	0.00	4.20	0.0%	0.0%
0:45	0.00	0.00	0.00	0.00	0.0%	0.0%
0:59	2.20	0.00	1.65	2.48	0.0%	0.0%

Average Particulates (In Mg/M3) levels at time range and ventilation

Time	OverAll	Ventilation Level			Percentage reduction	
> or =	Average	0	1	2	1 over 0	2 over 1
0:15	1.95	1.21	5.12	0.84	0.0%	83.6%
0:20	2.85	0.00	3.54	2.25	0.0%	36.5%
0:25	1.18	0.57	2.25	0.88	0.0%	60.7%
0:30	1.71	0.86	2.44	0.32	0.0%	86.9%
0:35	1.54	0.00	0.68	2.18	0.0%	0.0%
0:40	0.86	0.00	1.17	0.48	0.0%	58.8%
0:45	0.00	0.00	0.00	0.00	0.0%	0.0%
0:59	0.17	0.86	1.45	0.97	0.0%	33.2%