Joe Spurgeon, Ph.D., CIH
www.bi-air.com
cih@bi-air.com

WILD FIRE SMOKE

DETECTION OF COMBUSTION PRODUCTS IN RESIDENTIAL PROPERTIES

Property Locations: Six Houses in Texas Exposed to Wild Fire Smoke
Two houses in California Not Exposed to Wild Fire Smoke

Report Date: November 30, 2012

Joe Spurgeon

Joe C. Spurgeon, Ph.D., CIH

SUMMARY OF RESULTS

Summary of Sampling Methods and Assessment Criteria.

SAMPLING METHOD	REPORTED PARAMETER	INDICATOR of CONTAMINATION	ESTIMATED MINIMUM LEVEL
Tape Lift	Soot	Yes	10 % in sample
	Char	Yes	5 % in sample
Wipe Sample	Elemental Carbon	Yes	100 ug/sample
	Organic Carbon	Yes	1,000 ug/sample
	Total Carbon	Yes	NA
Cassette Sample	Elemental Carbon	Yes	25 ug/100 cm^2
	Organic Carbon	Yes	250 ug/100 cm^2
	Total Carbon	Yes	NA
Indoor Air	Acetaldehyde	Yes	0.02 ppm
	Acetone	Yes	0.05 ppm
	Acrolein	Yes	0.15 ppm
	Benzaldehyde	Yes	0.001 ppm
	Formaldehyde	Yes	0.035 ppm
	Hexanal	Yes	0.01 ppm
	Butyraldehyde	No	NA
	Crotonaldehyde	No	NA
	Isovaleraldehyde	No	NA
	Propionaldehyde	No	NA
	Tolualdehyde-o,m,p	No	NA
	Valeraldehyde	No	NA
	2,5-Dimethylbenzaldehyde	No	NA

% Percent
ug Microgram
cm^2 Square centimeter of surface
ppm Parts per million by volume in air

Characterization of the Concentrations of Contaminants in each House.

		HOUSE					
SAMPLER	**ANALYTE**	**1**	**2**	**3**	**4**	**5**	**6**
Tape Lift	Soot	**Pot El**	**Not El**	**Not El**	**Not El**	Elevated	Elevated
Tape Lift	Char	Elevated	Elevated	Elevated	Elevated	Elevated	Elevated
Wipe	Elemental Carbon	Elevated	Elevated	**Not El**	Elevated	Elevated	Elevated
Wipe	Organic Carbon	Elevated	Elevated	**Pot El**	Elevated	Elevated	Elevated
Cassette	Elemental Carbon	Elevated	**Not El**	**Not El**	Elevated	Elevated	Elevated
Cassette	Organic Carbon	Elevated	**Not El**	**Not El**	**Not El**	Elevated	Elevated
Airborne	Aldehydes (ppm)	Elevated	Elevated	Elevated	Elevated	Elevated	Elevated

Not Elevated Not El
Potentially Elevated Pot El

INITIAL CLASSIFICATION OF THE SUBJECT HOUSES

The six smoke-exposed houses had reportedly been cleaned and/or remediated to various degrees prior to the date of the site visit. The presumed status of each property at the time of the site visit is indicated in the following table:
Group I houses had been professionally cleaned, and were presumed to be uncontaminated;
Group II houses had been cleaned by the occupants, and their status was indeterminate;
Group III house had not been cleaned or remediated, and had remained unoccupied; and
Group IV houses were controls, and had not been exposed to wild fire smoke.

These classifications were based on the descriptions in the following table, and were assigned prior to an assessment of the sample data. Therefore, the actual status of a particular house may differ based on an assessment of the sample results.

Group I Houses: Professionally Cleaned.

HOUSE	INTERIOR	CONTENTS	OCCUPANCY
1	Walls painted	Professionally cleaned	Occupied
2	Remodeled	Professionally cleaned	Occupied

Group II Houses: Cleaned by the Occupant.

HOUSE	INTERIOR	CONTENTS	OCCUPANCY
3	Cleaned by occupant	Steam cleaned by occupant	Occupied
4	Cleaned by occupant	Cleaned by occupant	Occupied
5	Cleaned by occupant	Cleaned by occupant	Occupied

Group III Houses: Contaminated.

HOUSE	INTERIOR	CONTENTS	OCCUPANCY
6	Not cleaned	Not cleaned	Not occupied

Group IV Houses: Controls [Not Smoke-Exposed].

HOUSE	INTERIOR	CONTENTS	OCCUPANCY
7	Typical cleaning	Typical cleaning	Occupied
8	Typical cleaning	Typical cleaning	Occupied

INTRODUCTION

Site Visit. A site visit was conducted in July, 2012 to collect preliminary data on wild fire smoke contaminants in six houses in Texas. The site visit was limited to the collection of samples, and did not include an inspection of the properties. Site visits to two houses in California were also conducted in August, 2012. The subject houses in Texas were described as having been substantially impacted by wild fire smoke and combustion products during a wild fire incident that occurred about September 3 & 4, 2011. The site visit occurred about eight months after the wild fire.

Purpose. The purpose of the site visit was to assess the interior space of the six smoke-exposed houses for the presence of residual combustion products typically associated with wild fire smoke. The purpose of this report is to investigate the utility of sampling methods for detecting residual wild fire smoke contaminants following cleaning and/or remediation.

RESULTS AND CONCLUSIONS

Smoke Odors

Smoke-like odors were only detected in one of the six exposed houses (House # 6). This house had been vacated soon after the subject incident, had remained unoccupied, and neither the interior nor the contents had been cleaned or remediated.

Surface Tape-Lift Samples

A tape lift sample was collected from hard surfaces in each of the six smoke-exposed houses by Jim Fields prior to the subject site visit. The samples were analyzed by microscopy for the percentages of Soot and Char in the sample. The percentage of Soot in each sample, and their interpretation, are summarized in Table 1. A Soot concentration of 10 % or more was considered to be indicative of residual contamination. Based on this criterion, evidence of residual contamination was detected in Houses 1, 5 and 6.

Table 1. Concentration of Soot in Surface Tape-Lift Samples (Percent).

HOUSE	GROUP	SOOT (%)	CLASSIFICATION
2	II	0.5	Not Elevated
3	I	0	Not Elevated
4	II	0	Not Elevated
1	I	7.9	Potentially Elevated
6	III	42.5	Elevated
5	II	50	Elevated

Conclusion: Percent Soot from tape lift samples indicated a difference between smoke-exposed houses. Two distinct groups of data [less than 1 % and more than 10 %] are evident.

The percentage of Char in each sample, and their interpretation, are summarized in Table 2. A Char concentration of 5 % or more was considered to be indicative of residual contamination. Based on this criterion, evidence of residual contamination was detected in all six Houses.

Table 2. Concentration of Char in Surface Tape-Lift Samples (Percent).

HOUSE	GROUP	CHAR (%)	CLASSIFICATION
3	II	4.5	Elevated
2	I	10.0	Elevated
4	II	10.5	Elevated
1	I	11.1	Elevated
6	III	13.8	Elevated
5	II	15.0	Elevated

Conclusion: Percent Char was in a narrow range, and did not indicate a difference between the smoke-exposed houses. However, the percent Char exceeded 5 % in all six properties.

The Soot and Char data in Tables 1 and 2 are presented as a log-plot in Figure 1.

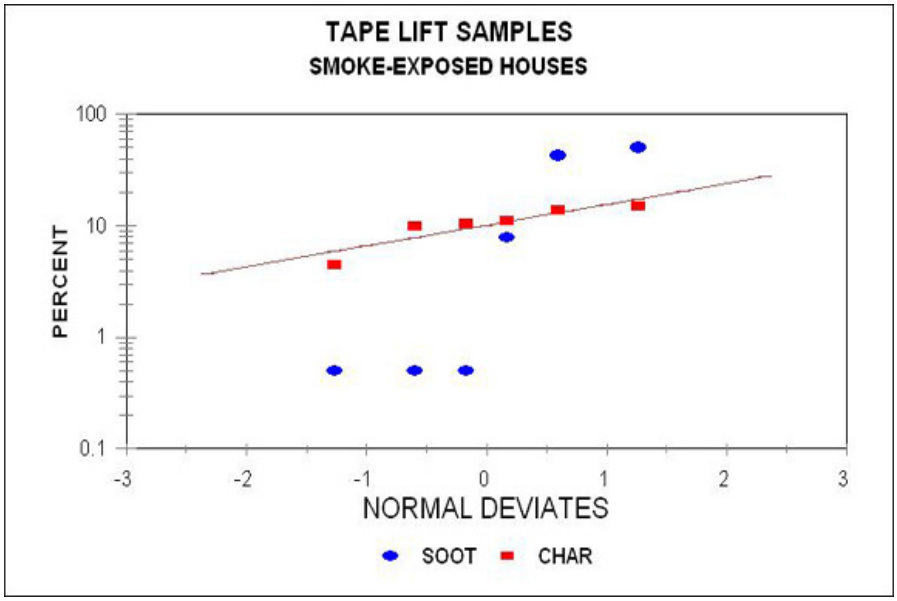

Figure 1. Log-Plots of the Tape-Lift Data.

Samples could have been drawn from two concentration distributions, Uncontaminated and Contaminated. The linear log-plot for the Char data suggest all the samples were collected from the same concentration distribution, which in this case was Contaminated. The Soot data were in two distinct groups, suggesting the samples were collected from both the Uncontaminated and Contaminated distributions.

Surface Wipe Samples

Wipe samples were used to sample hard surfaces, such as window sills, cabinets, dressers, door jambs, etc. The wipe samples were analyzed for Elemental Carbon, Organic Carbon, and Total Carbon [the sum of these two carbons]. Elemental carbon is carbon particulate. Organic carbon is partially oxidized fuel, and includes such chemical compounds as glucosans, diacids, aldehydes, pinenes, polynuclear aromatic hydrocarbons, methoxyphenols, etc.

The concentrations of Elemental Carbon in wipe samples are summarized in Table 3. The results are reported in units of micrograms per sample (ug/sample).Based on a comparison with the data from Group IV control houses, an Elemental Carbon concentration greater than 100 ug/sample was considered to be indicative of residual contamination.

Table 3. Concentration of Elemental Carbon in Wipe Samples (ug/sample).

HOUSE	GROUP	ug/sample	CLASSIFICATION
8	IV	19	Not Elevated
8	IV	33	Not Elevated
7	IV	100	Not Elevated
3	II	100	Not Elevated
2	I	280	Elevated
4	II	330	Elevated
1	I	350	Elevated
6	III	370	Elevated
5	II	1,038	Elevated

Conclusion: Elemental Carbon concentrations from wipe samples indicated a difference between smoke-exposed houses.

The concentrations of Organic Carbon in wipe samples are summarized in Table 4. The results are reported in units of micrograms per sample (ug/sample).Based on a comparison with the data from Group IV control houses, an Elemental Carbon concentration greater than 1,000 ug/sample was considered to be indicative of residual contamination.

Table 4. Concentrations of Organic Carbon in Wipe Samples (ug/sample).

HOUSE	GROUP	ug/sample	CLASSIFICATION
8	IV	330	Not Elevated
8	IV	460	Not Elevated
7	IV	660	Not Elevated
3	II	940	Potentially Elevated
2	I	1,800	Elevated
4	II	2,100	Elevated
1	I	2,450	Elevated
6	III	2,700	Elevated
5	II	4,650	Elevated

Conclusion: Elemental Carbon concentrations from wipe samples indicated a difference between smoke-exposed houses.

The Elemental Carbon and Organic Carbon data in Tables 3 and 4 are presented as a log-plot in Figure 2.

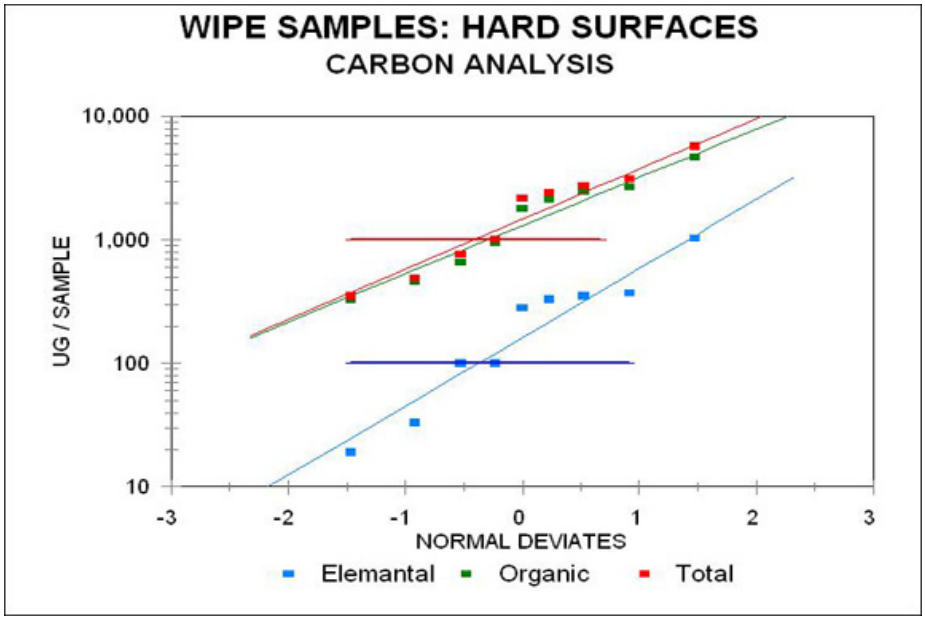

Figure 2. Log-Plots of the Wipe Sample Data.

Surface Cassette Samples

Closed-face cassettes were used to sample soft-surface items (couches, bedding, etc.). The wipe samples were analyzed for Elemental Carbon, Organic Carbon, and Total Carbon [the sum of these two carbons].

The concentrations of Elemental Carbon in cassette samples are summarized in Table 5. The results are reported in units of micrograms per 100 square centimeters (ug/100 cm^2). Based on a comparison with the data from Group IV control houses, an Elemental Carbon concentration greater than 25 ug/100 cm^2 was considered to be indicative of residual contamination.

Table 5. Concentration of Elemental Carbon in Cassette Samples (ug/100 cm^2).

HOUSE	GROUP	Ug/100 cm^2	CLASSIFICATION
8	IV	10	Not Elevated
3	II	15	Not Elevated
7	IV	10	Not Elevated
2	I	16	Not Elevated
4	II	40	Elevated
1	I	41	Elevated
6	III	59	Elevated
5	II	64	Elevated
1 Carpet	- -	360	Contaminated

The carpet in the master bedroom of House # 1 was darkly discolored at the rear entrance door. The discoloration appeared to be a soot-like substance, which was confirmed by the sample results.

Conclusion: Elemental Carbon concentrations from cassette samples indicated a difference between smoke-exposed houses.

The concentrations of Organic Carbon in cassette samples are summarized in Table 6. The results are reported in units of micrograms per 100 square centimeters (ug/100 cm^2). Based on a comparison with the data from Group IV control houses, an Organic Carbon concentration greater than 250 ug/100 cm^2 was considered to be indicative of residual contamination.

Table 6. Concentration of Organic Carbon in Cassette Samples (ug/100 cm^2).

PROPERTY	GROUP	AVERAGE	CLASSIFICATION
3	II	97	Not Elevated
2	I	140	Not Elevated
4	II	180	Not Elevated
1	I	380	Elevated
6	III	420	Elevated
5	II	420	Elevated
1 Carpet	- -	2,800	Contaminated

Conclusion: Organic Carbon concentrations from cassette samples indicated a difference between smoke-exposed houses.

The Organic Carbon and Organic Carbon data in Tables 5 and 6 are presented as a log-plot in Figure 3.

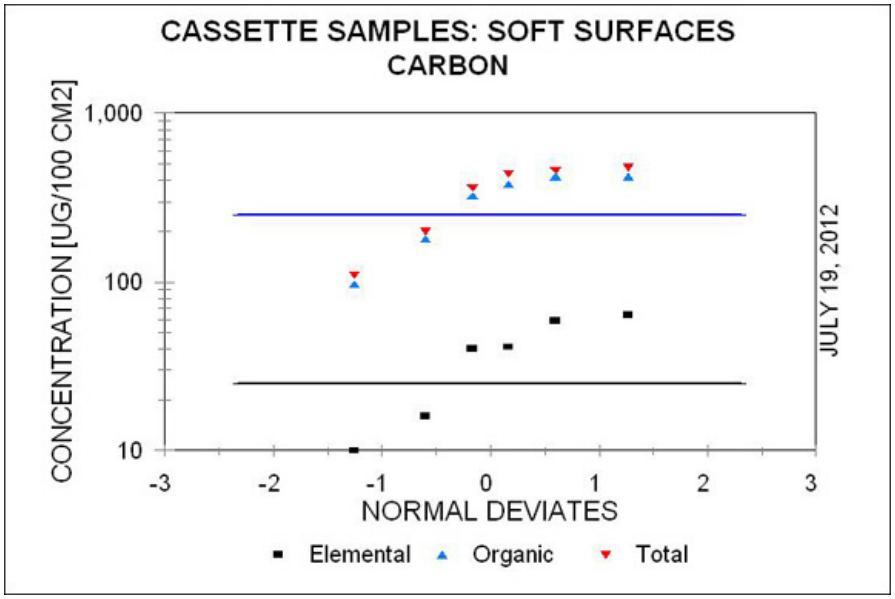

Figure 3. Log-Plot of the Cassette Sample Data.

Airborne Aldehyde Concentrations

The concentrations of aldehydes, in parts per million by volume (ppm), reported in each house are summarized in Table 7. The concentrations in the Limit column were presumed to indicate a difference between uncontaminated and contaminated houses.

Table 7. Concentrations of Selected Airborne Aldehydes in Houses 1-8 (ppm).

HOUSE	LIMIT	1	2	3	4	5	6	7	8
Acetaldehyde	0.02	0.0330	0.0300	0.0370	0.0550	0.0750	0.0210	0.0195	0.0044
Acetone	0.05	0.1400	0.0720	0.0540	0.0900	0.1300	0.0280	0.0465	0.0048
Acrolein	0.15	0.3000	0.3400	0.3000	0.3100	0.2000	0.5400	0.1300	0.1053
Benzaldehyde	0.001	0.0027	0.0011	0.0020	0.0042	0.0050	0.0027	0.0008	0.0008
Formaldehyde	0.035	0.0510	0.0370	0.0760	0.1100	0.0980	0.0800	0.0300	0.0143
Hexanal	0.01	0.0033	0.0019	0.0061	0.0400	0.0330	0.0100	0.0092	0.0011

The interpretation of the concentration data in Table 7 are summarized in Table 8. These interpretations are based on Figures 4 – 7 and similar figures. The difference between "not elevated" and "elevated" is indicated in the following figures by a horizontal dashed line, which conforms to the Limit concentrations in Table 7.

Table 8. Assessment of Airborne Aldehyde Concentrations in each House.

HOUSE	1	2	3	4	5	6	7	8
Acetaldehyde	Elevated	Elevated	Elevated	Elevated	Elevated	Elevated	--	--
Acetone	Elevated	Elevated	Elevated	Elevated	Elevated	--	--	--
Acrolein	Elevated	Elevated	Elevated	Elevated	Elevated	Elevated	--	--
Benzaldehyde	Elevated	Elevated	Elevated	Elevated	Elevated	Elevated	--	--
Formaldehyde	Elevated	Elevated	Elevated	Elevated	Elevated	Elevated	--	--
Hexanal	--	--	--	Elevated	Elevated	Elevated	--	--

Aldehyde concentrations are plotted versus sample number in Figures 4 – 7. A description of the sample numbers is contained in Table 9. Sample numbers 1 – 6 represent the six smoke-exposed houses, in numerical order. Sample numbers 12 and 13 are replicate samples collected in House # 7 following ozonation, while sample number 14 is an outdoor sample.

Table 9. Description of Sample Numbers in Figures 4 – 7.

SAMPLE	HOUSE	LOCATION	SAMPLE	HOUSE	LOCATION
1 [Smoke]	1	Living Room	8 [Control]	7	Master Bedroom
2 [Smoke]	2	Living Room	9 [Control]	8	Kitchen
3 [Smoke]	3	Living Room	10 [Control]	8	Bedroom
4 [Smoke]	4	Living Room	11 [Control]	8	Office
5 [Smoke]	5	Living Room	12 [Control]	7	Kitchen
6 [Smoke]	6	Living Room	13 [Control]	7	Master Bedroom
7 [Control]	7	Kitchen	14 [Reference]	7	Outdoors

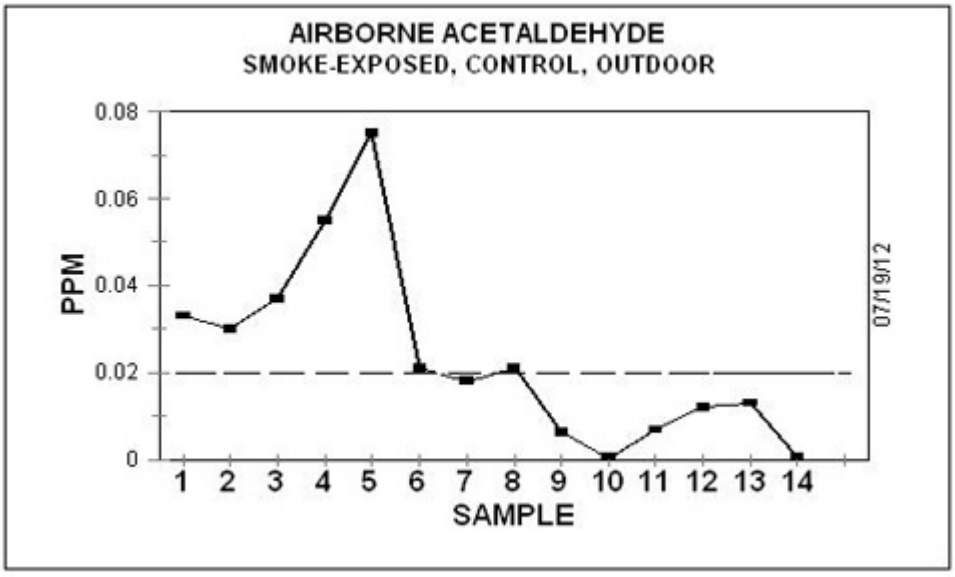

Figure 4. Airborne Acetaldehyde Concentrations

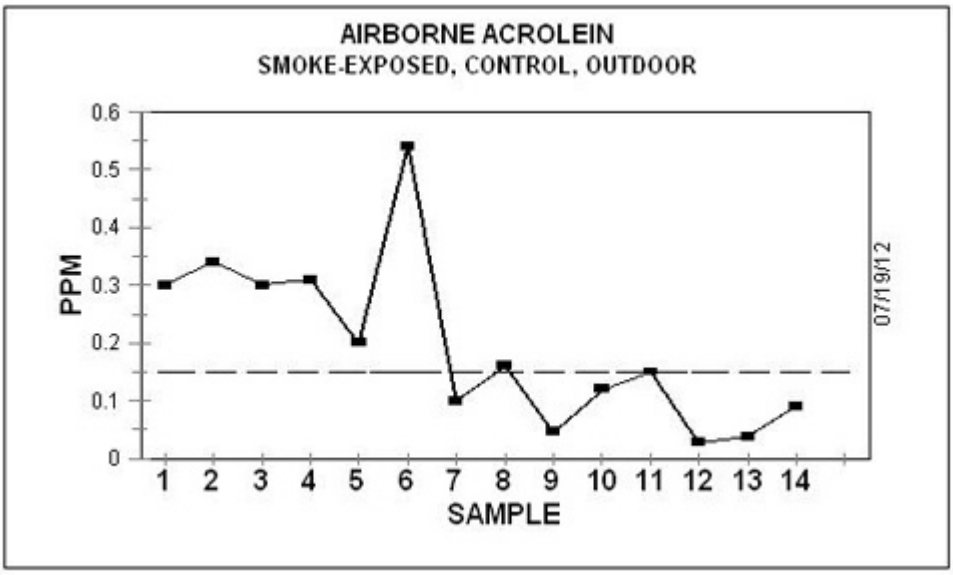

Figure 5. Airborne Acrolein Concentrations

Acrolein is an unsaturated aldehyde. As indicated by a comparison of the concentrations detected in samples 12 & 13 with those detected in samples 7 & 8, treatment of the interior space with ozone reduced the concentration.

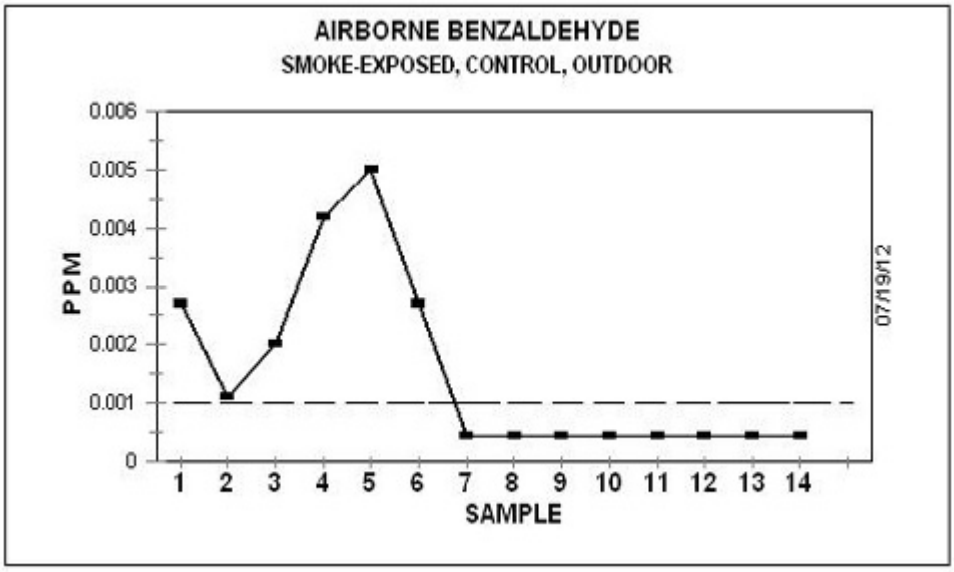

Figure 6. Airborne Benzaldehyde Concentrations

Benzaldehyde was only detected in the smoke-exposed houses. The concentration in both control houses was below the limit of detection.

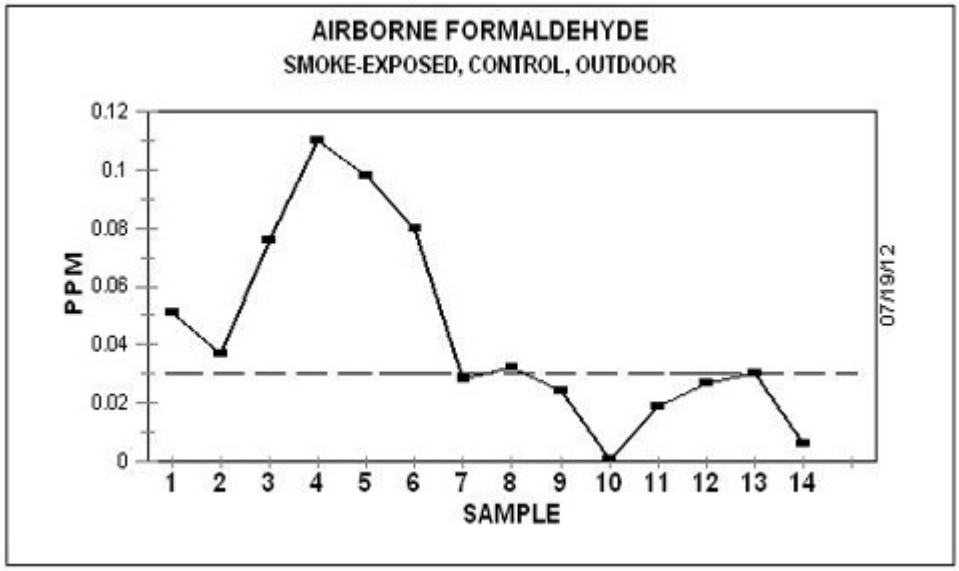

Figure 7. Airborne Formaldehyde Concentrations

Formaldehyde is a saturated aldehyde. Therefore, treatment with ozone did not affect the concentration. The concentrations in samples 12 & 13 were similar to those in samples 7 & 8.

The log-plots for three aldehydes detected in the six smoke-exposed houses are illustrated in Figure 8. All three aldehydes had similar geometric standard deviation values (1.4, 1.5, and 1.7, respectively). The low values for the GSD and the narrow range of values suggest a common source for these aldehydes. It was concluded that these three aldehydes may be the best indicators of residual contamination of those reported by the laboratory.

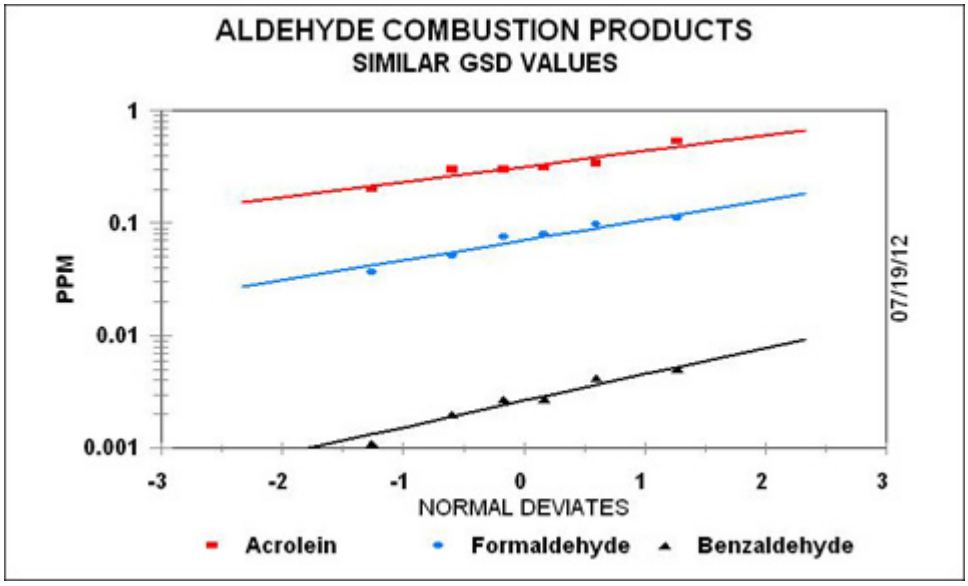

Figure 8. Aldehydes with Similar Geometric Standard Deviations (GSD).

The log-plots for three aldehydes detected in the six smoke-exposed houses and the two control houses are illustrated in Figure 9. The horizontal lines indicate the concentrations denoting contaminated and uncontaminated indoor environments.

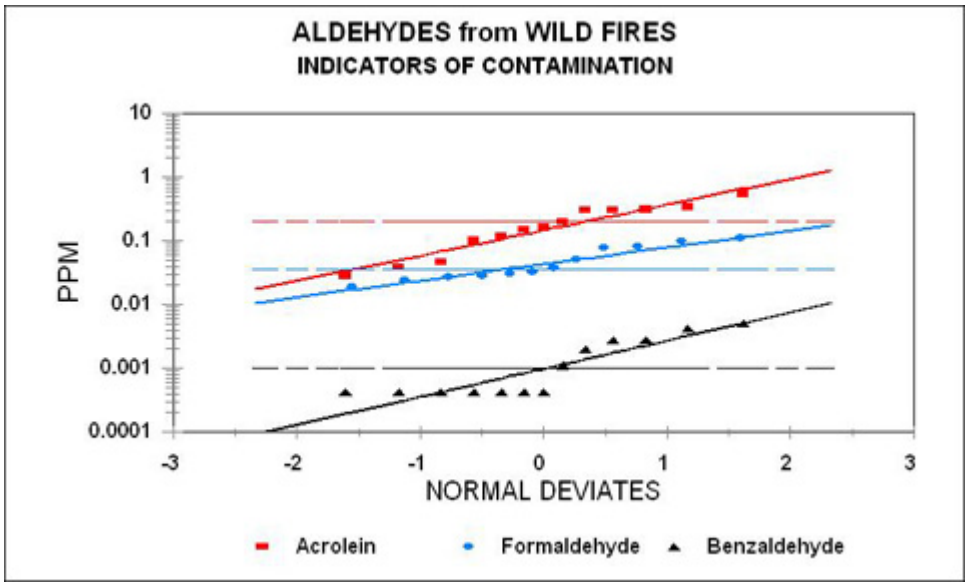

Figure 9. Three Aldehydes with their Limit Concentrations Indicated.

APPENDIX: TOXICITY DATA

Reference: Toxicological Profile for Acrolein [USPHS/CDC/ATSDR]:

Concentrations of Acrolein in Parts per Million by Volume (ppm).

HOUSE	1	2	3	5	4	6	7*	8*
Acrolein (ppm)	0.3000	0.3400	0.3000	0.3100	0.2000	0.5400	0.1300	0.1053
Ratio: Controls*	2.5	2.8	2.5	2.6	1.7	4.5	1.1	0.9

Conclusion: The concentration of acrolein was substantially elevated in all six smoke-exposed houses.

Acrolein is a potent irritant to the mucous membranes. The nasal tissues appear to be the most sensitive target of inhalation exposure, with onset of noticeable irritation occurring in seconds at a concentration of 0.3 ppm. The eyes also rapidly become irritated at a concentration of 0.3 ppm.

The concentration of acrolein equaled or exceeded 0.3 ppm in five of the six houses – and this was a substantial period after the subject incident. Also, acrolein that enters the air as a vapor changes into other chemicals within days. Therefore, there appears to have been a continuing emission source in the six houses since the fire had occurred some time prior to the sampling.

Estimates of exposure levels posing minimal risk to humans (MRLs) have been made for acrolein by CDC/ATSDR. An MRL is defined as an estimate of daily human exposure to a substance that is likely to be without an appreciable risk of (noncarcinogenic) adverse effects over a specified duration of exposure.

MRLs are based on noncancerous health effects only and do not consider carcinogenic effects. MRLs are typically calculated for acute (14 days or less), intermediate (15-364 days), and chronic (365 days or more) exposures.

An MRL of 0.003 ppm has been derived for acute-duration inhalation exposure (14 days or less) to acrolein. A concentration of 0.3 ppm is 100-times this exposure limit, with measured concentrations ranging from 67-times to 180-times this exposure limit.

An MRL of 0.00004 ppm has been derived for intermediate-duration inhalation exposure (15–364 days) to acrolein. A concentration of 0.3 ppm is 7,500-times this exposure limit, with measured concentrations ranging from 5,000-times to 13,500-times this exposure limit.

Reference: Toxicological Profile for Formaldehyde [USPHS/CDC/ATSDR]:

Concentrations of Formaldehyde in Parts per Million by Volume (ppm).

PROPERTY	1	2	3	5	4	6	7*	8*
Formaldehyde	0.051	0.037	0.076	0.11	0.098	0.080	0.030	0.014
Ratio: Controls*	2.3	1.7	3.5	5.7	4.5	3.6	1.4	0.6

Conclusion: The concentration of formaldehyde was substantially elevated in five of the six smoke-exposed houses.

An MRL of 0.04 ppm has been derived for acute-duration inhalation exposure (14 days or less) to formaldehyde.

An MRL of 0.03 ppm has been derived for intermediate-duration inhalation exposure (15–364 days) to formaldehyde.

An MRL of 0.008 ppm has been derived for chronic-duration inhalation exposure (365 days or more) to formaldehyde.