Biomonitoring of Chemical Exposure Among New York City Firefighters

Responding to the World Trade Center Fire and Collapse

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Abbreviations:

WTC – World Trade Center
NYFD – New York Fire Department

CDC – Centers for Disease Control and Prevention

(FDNY-BHS) - New York City Fire Department Bureau of Health Services

NIOSH - National Institute for Occupational Safety and Health

NCEH - National Center for Environmental Health

DLS - Division of Laboratory Sciences

ANCOVA – Analysis of Covariance
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Abstract

The collapse of the World Trade Center (WTC) on September 11, 2001 exposed New York City firefighters to smoke and dust of unprecedented magnitude and duration. The chemicals and the concentrations produced from any fire are difficult to predict, but estimates of internal dose exposures can be assessed by the biological monitoring of blood and urine. Blood and urine specimens obtained from 321 firefighters responding to the WTC fires and collapse were analyzed for 110 potentially fire-related chemicals. Controls consisted of 47 firefighters not present at the WTC. Sampling occurred three weeks after September 11, while fires were still burning. When reference or background ranges were available, most chemical concentrations were found to be generally low and not to be outside these ranges. Compared to controls, the exposed firefighters showed significant differences in adjusted geometric means for six of the chemicals and significantly greater detection rates for an additional three. Arrival time was a significant predictor variable for four chemicals. Special Operations Command firefighters (n=95) compared with other firefighters (n=226) demonstrated differences in concentrations or detection rate for 14 of the chemicals. Special Operations Command firefighters were also significantly different from the control group values for these same chemicals and for two additional chemicals. Generally, the chemical concentrations of the other firefighter group were not different from controls. Biomonitoring was used to characterize firefighter exposure at the WTC disaster. Although some of the chemicals analyzed showed statistically significant differences, these differences were generally small.
Introduction

The catastrophic collapse of the World Trade Center (WTC) on September 11, 2001, resulted in unprecedented fire-related exposures for New York City firefighters. The initial fires, building collapses, and persistent fires that burned for months, while intense rescue and recovery efforts continued, contributed to exposures from a wide variety of pyrolysis, combustion, and pulverized building materials.

Predicting the chemicals and their concentrations produced from a fire is difficult because the composition depends upon the diversity of natural and synthetic fuels, fire temperature and duration, availability of oxygen, compression pressure, atmospheric conditions and the fire’s course relative to surrounding topography. Firefighters and other rescue and recovery personnel may inhale gases or vapors released during a fire or collapse and may inhale and ingest particulates. Hand-to-mouth contamination, contamination inside masks, and dermal absorption also may be important factors affecting chemical absorption. Although, some chemicals are common to most fires (Austin, et al. 2001), neither knowledge of the burning materials, nor environmental measurements can accurately predict the absorbed dose of combustion products. Recent studies have focused on acutely toxic, firefighter exposures and specific aspects of firefighter response (Hartzell 1996); however, there has not been a comprehensive biomonitoring assessment of firefighters following a major incident.

Biomonitoring is the measurement of the internal dose of a chemical or its metabolite in body matrices (such as blood or urine) and provides critical information about the amount of a chemical that actually enters the body from any source, e.g., air, water, dust, soil,
food, and other environmental sources (Sampson, et al. 1994). Biomonitoring is ideally
used in conjunction with measurements of external exposure; however, as in this case,
personal sampling of firefighter external exposures was not possible initially and often is
impractical. The purpose of this study was to characterize internal dose levels of fire-
related (including ancillary exposures to petroleum-powered equipment) chemicals in
NYC firefighters and the relationship of those levels with firefighter activities including
firefighter job task, time of arrival at the site, and number of work days at the site.

Methods

This study was a collaborative effort of the New York City Fire Department Bureau of
Health Services (FDNY-BHS) and the Centers for Disease Control and Prevention
(CDC). Disaster-related logistical limitations delayed the start of blood and urine
collection until October 1, 2001. Search and rescue operations were ongoing at this time
and fires continued to burn at the WTC site. All participants gave informed consent,
approved by Montefiore Medical Center’s Research Review Board. The FDNY-BHS
developed a medical monitoring protocol in collaboration with the CDC’s National
Institute for Occupational Safety and Health (NIOSH). In conjunction with these efforts,
the CDC’s National Center for Environmental Health (NCEH), Division of Laboratory
Sciences (DLS) developed the biomonitoring protocol to quantify 110 chemicals in
firefighters’ blood and urine as markers of exposure (Appendix A).

This was a cross-sectional study using a stratified sample of firefighter units based on
WTC arrival time. FDNY-BHS selected this sample using dispatch records, officer
interviews and a worker questionnaire (the final determinant of arrival time, if
discrepancies arose). Arrival time was categorized as: 1) present at the WTC collapse; 2) arrival on day 1 or 2 but post-collapse; and 3) arrival on days 3—7. Arrival time was of potential interest because exposure opportunity for different chemicals could vary as a function of time from the initial collapse. We also categorized unit assignments as Special Operations Command (i.e., Rescue, Squad and Marine units) or other exposed firefighters (e.g., Ladder, Engine). This grouping was used as a surrogate for job tasks based on the expectation of different assignments for Special Operations Command personnel. Number of work days at the WTC site was categorized as 0-5 days and 6-13 days. More work days at the site could lead to higher internal dose concentrations of chemicals that persist in body. Controls were FDNY firefighters who did not work at or near the WTC because of assignment to office duties as a result of prior injury. All information from the study participants and blood and urine samples were obtained during the week of October 1-5, with nearly equal numbers of participants each day.

**Sample Acquisition and Analytical Methods**

During October 1-5, 2001, firefighters received FDNY-BHS WTC medical evaluation including a self-administered questionnaire (arrival time, work days on site, respirator and other protective equipment use, and symptoms). A DLS response team processed blood and urine samples collected at FDNY-BHS and transported them to DLS in Atlanta for biomonitoring analysis.

Samples from 370 firefighters were analyzed. Because of insufficient volume collection, shortage of some pre-certified collection tubes, failure to pass strict chromatographic quality criteria, or overly dilute urine samples, complete analyses were not available for all participants. Specifically, volatile organic compound measurements were available for
about 67% of the firefighters and dioxin, furan, and PCBs measurements were available for about 90% of the firefighters. All analytic methods have been validated, published (Bernert et al. 1997; Calafat et al. 2002; Cardinali et al. 2000; Chen et al. 1998; Miller et al. 1987; Paschal et al. 1998; Smith et al. 2002; Turner et al. 1997), and are subject to ongoing quality assurance programs. Cotinine, a nicotine metabolite, was used to assess the contribution of tobacco smoke to levels of selected volatile organics compounds (VOCs), cyanide, selected polycyclic aromatic hydrocarbons (PAHs), and selected metals. Urinary creatinine was measured to correct or exclude samples for urinary dilution by standard methods and used as a covariate for chemicals measured in urine.

**Statistical Analyses**

We categorized the firefighters into groups based on arrival time (present during collapse, arrival day 1-2, arrival day 3-7), number of work days at WTC (0-5 days and 6-13 days) and unit assignment (Special Operations Command firefighters, other firefighters, and control firefighters who were not present at WTC). In addition, we defined another category for analysis, the exposed group, as all non-control firefighters. Out of the 110 chemicals, 32 were detectable in more than 60% of the firefighters and subjected to additional analysis. For these 32 chemicals, we performed nonparametric analyses (Kruskal-Wallis, $\alpha = 0.05$) testing for differences in concentrations of each chemical between any two of the firefighter groups. Chemicals that were statistically different by this test were subjected to further analysis by analysis of covariance (ANCOVA).

ANCOVA ($\alpha = 0.01$) analysis of the firefighter groups used the log transformed chemical concentrations as the dependent variable and covariates of age, race (white and other), creatinine, and log cotinine (described below). Number of work days at the WTC was
found not to be a significant predictor of chemical concentrations and was not used in further analysis. Arrival time grouping was changed from three groups to two groups because the number of persons arriving during day 3 through 7 was small. So, further ANCOVA analysis was done on six firefighter groups: the overall exposed group, firefighter groups defined by arrival time (present during collapse, and arrival day 1-2 since collapse), and firefighter groups defined by unit assignment (Special Operations Command firefighters, other firefighters, and control firefighters (those not present at WTC)). As a result, we tested specific hypotheses (ANCOVA contrasts) for the effects of exposure (exposed vs. control); arrival time (present during collapse vs. days 1—2; present during collapse vs. control; days 1-2 vs. control); unit assignment (Special Operations Command firefighters vs. other exposed firefighters; Special Operations Command vs. control; and other exposed firefighters vs. control.

Of the 110 chemicals, 78 had detection rates of less than 60% among individuals tested and were therefore considered as dichotomous variables (i.e., detected or not-detected). These chemicals were examined initially for differences in detection rates among the six firefighter groups described above with Chi-Square tests ($\alpha = 0.05$). Chemicals that were statistically significant were further analyzed by logistic regression ($\alpha = 0.01$) for effects of the six firefighter groups including the same covariates listed above (age, race (white and other), creatinine, log cotinine). The two probabilities used for Type I error rejection are considered lenient because of multiple comparisons at both stages of statistical analysis.

Cotinine from tobacco smoke exposure was an important covariate in most analyses. Tables 1 and 2 report the results of 102 statistical tests examining group differences for
each of the chemicals. Only five of the tests required adjustment for interaction terms among the covariates. Statistical analyses were performed using Statistical Analysis Systems software version 8.0 (SAS Institute, Cary, NC).

Results

A total of 370 firefighters (321 exposed, 47 controls, and 2 with missing data) participated in the biomonitoring study, resulting in 368 firefighters with chemical measurements. One hundred forty eight of the participating firefighters were present during the WTC towers collapse and 142 arrived post-collapse on days 1-2. A significantly greater percentage of Special Operations Command firefighters were present on days 1 and 2 (90.7%) vs. other exposed firefighters (48.2%).

Of the 110 chemicals, 32 were treated as continuous variables and Kruskal-Wallis analysis showed 13 chemicals had statistically significant differences between any two of the six firefighter groups. Results of the ANCOVA analysis for these 13 chemicals is presented in Table 1. For 11 of the 13 chemicals, firefighters in the Special Operations Command had concentrations that were higher (p < 0.01) than those of the other firefighter group. A 12th chemical (1,2,3,4,6,7,8-HCDBD), had higher levels (p < 0.01) for firefighters in the Special Operations Command compared to controls, and also for firefighters in the other firefighter group compared to controls. For only 2 of the 13 chemicals (urinary antimony and urinary cadmium), levels were higher (p < 0.01) in firefighters present at the collapse compared to those who arrived after the collapse during day one or two.
Of the 110 chemicals, 78 had detection rates <60% and were therefore analyzed as dichotomous variables (i.e., detected or not-detected). Chi-square testing showed that four of these 78 chemicals had significantly different detection rates between any two of the six firefighter groups (see Table 2). All four of these chemicals were more likely to be detected in firefighters of the Special Operations Command compared to firefighters in the Other firefighter group. Two of the four chemicals were more likely to be detected in firefighters present at the collapse compared to those who arrived after the collapse during day one or two.

**Discussion**

This was the only biomonitoring study performed after the WTC collapse and during rescue operations. It is also the most extensive biomonitoring study ever performed on any occupational group during the first weeks of exposure to a major fire, building collapse, or urban disaster. We measured up to 110 chemicals in 368 firefighters. As expected, known products of combustion, such as represented by PAH metabolites, were present in greater amounts in exposed firefighters. Unanticipated increases in urinary antimony, serum heptachlorodibenzodioxin, and heptaochlorodibenzofuran also were associated with exposure. Unit assignment was the most predictive variable for the internal dose chemical levels. Arrival time was associated with levels of a few chemicals; duration at the site was not predictive. None of the measured chemicals is presumed to be specific to the WTC and might be seen in firefighters exposed to any structural fire (and collapse) as well as from exposures in the general environment. Although statistically significant elevations were found, their magnitude was not high enough to be of immediate clinical concern.
Interpretation of biomonitoring measurements is most straightforward when recognized guidelines are available that define elevated levels associated with health effects (e.g., blood lead levels $\geq 10$ µg/dL for children, or $\geq 40$ µg/dL for adults). Concentration-related health effects are not established for most chemicals measured in this study. Biomonitoring results of firefighters can be compared with levels observed in other occupational groups or reference ranges for the general population, when available. Reference ranges and tentative occupational guidelines are available for 1-hydroxypyrene, some of the metals, and some volatile organic compounds. Interpretation is also most straightforward when a single known exposure is followed by analysis. In this study, exposures may have continued at varying levels after the initial incident.

We compared exposed firefighters to a firefighter control group to determine how levels compared with those in persons in the same occupation, but who did not respond to the WTC disaster. Although firefighters may have similar fire exposure backgrounds, those assigned to Special Operations Command more often respond to fires of greater intensity and have different job tasks, all of which may have lead to greater exposure to combustion products before and during the WTC disaster. However, it remains unclear for some chemicals whether differences between Special Operations Command firefighters and other exposed firefighters reflect WTC exposures alone or cumulative exposure occurring before the WTC events, or both. Kinetic considerations may be useful in making these distinctions.

**Polycyclic Aromatic Hydrocarbons**

The burning of carbonaceous fuels (any organic matter) produces gases and soot containing polycyclic aromatic hydrocarbons. Our analytical method measured 14

Arrival time, when controlled for other factors (Table 1), was not an independent predictor for urinary 1-hydroxypyrene. However, Special Operations Command firefighters had more than twice the level of urinary1-hydroxypyrene as did other exposed firefighters or control firefighters. The urinary concentrations in the other exposed firefighters were similar to controls. Because of the short half-lives (Heikkila et al. 1995), higher urinary concentrations of 1-hydroxypyrene or other PAHs in the Special Operations Command firefighters may reflect either ongoing higher exposure, larger exposures earlier in the WTC response, or both. The adjusted geometric mean of urinary 1-hydroxypyrene in the Special Operations Command group was 159 ng/L or 0.72 µmol/mol creatinine. This value is similar to median values in another firefighter study (Caux et al. 2002), much less than mean values seen in other occupational studies (Heikkila et al. 1997; Van Schooten et al. 1995; VanRooij et al. 1992; Venier et al. 1985) and similar to reported levels in firefighters during a training exercise (Feunekes et al. 1997). The Special Operations Command values were slightly greater than reported general population background levels (CDC, 2003; Jongeneelen et al. 2001), and only thirteen (4.1%) firefighters had values above the 95th percentile of a nationally
representative sample 20 years and older (CDC, 2003). The values were below a recommended occupational guideline of 2.3 µmol/mol creatinine (Lauwerys et al. 2001).

**Polychlorinated Dibenzofurans, Dibenzodioxins and Biphenyls**

These chemicals are produced when carbon and chlorine combine at high temperatures. Heptachlorodibenzodioxins and heptachlorodibenzofurans were the only polychlorinated dibenzofuran and dibenzodioxin found statistically significant in exposed firefighters when compared with control firefighters. Marklund et al (Marklund et al. 1986), found that heptachlorinated dibenzofurans were the most abundant pyrolytic products in residues of burned plastic material (polyvinylidene chloride–Saran®). They found the content of heptachlorinated dibenzofurans and dibenzodioxins were several orders of magnitude greater than other total congeners (tetra, penta, hexa, octa); however, congener-specific data within the hepta class was not reported. Similar findings have been found in Japanese incinerator workers (Kumagai et al. 2000, Kumagai et al. 2002). Our results demonstrating differences for the two hepta-congeners was not anticipated, but is consistent with other published data and suggest that these analytes may be useful for the detection of exposures to burning plastics containing chlorine. Further kinetic data are needed to understand the relationship of exposure to burning plastics under various exposure conditions with internal dose levels. One report of firefighters after exposures to a transformer fire found 1,2,3,4,6,7,8-heptachlorodibenzofuran and 1,2,3,4,6,7,8-heptachlorodibenzodioxin to have the highest average blood levels with the exception of the fully chlorinated octa class compounds (Kelly et al. 2002). These findings are also consistent with the general U.S. population data showing the octa and hepta congeners to be among the most detectable (CDC, 2003).
Metals

Antimony is generally present in the environment in very low concentrations and has been used in glass as a coloring agent, in non-lead solders, metallurgy, electronics, manufacture of plastics, and other applications. Firefighters present at the collapse had urinary antimony levels that were statistically higher than those of firefighters arriving on days 1—2 and post-collapse or controls (Table 1). The urinary antimony adjusted geometric mean for the Special Operations Command group was two times higher (Table 1) than the other exposed firefighters or controls. Eighteen percent of exposed firefighters had values greater than the 95th percentile of the control group.

Differences between firefighter groups with respect to antimony were unexpected. Antimony in plastics is an integral part of fire retardant formulations (Einhorn 1975; Landrock 1983; Liepins et al. 1976) as a charring agent, and acts with halogenated hydrocarbons to suppress fire. Plastics may have 7-30% antimony by weight. Combustion of plastics or particulate dusts containing antimony from the WTC collapse probably explains this increase in exposed firefighters. Although antimony concentrations were significantly higher in firefighters present during the collapse and in Special Operations Command firefighters, they were well below recommendations for maximum exposure guidelines for workplace antimony exposures (35 µg/g creatinine) or the general population (3 µg/g creatinine) (Lauwreys et al. 2001) and were less than reported industrial exposures (Kentner et al. 1995; Ludersdorf et al. 1987).

Lead levels were statistically higher in exposed firefighters than in control firefighters. Time of arrival was not a significant predictor of adjusted geometric mean blood lead
concentrations, whereas job task group was predictive. For the entire cohort, the highest value was 12.7 µg/dL, with none exceeding the 40 µg/dL adult workplace standard set by U.S. Occupational Safety and Health Administration (US Department of Labor, 2001). Because lead is a cumulative toxic metal in the body, blood lead represents a combination of long-term exposure, compartmental equilibration, and exposure several weeks pre-collection. Although exposed firefighters showed elevations that were statistically significant compared with control firefighters, the increase was small, far below clinically significant levels.

**Mercury** levels were not higher in exposed firefighters but are mentioned because of heightened concern about exposure at WTC (Worth 2002). One control and three exposed firefighters had total blood mercury levels >20 µg/L, a conservative upper reference limit. Because blood inorganic mercury was <1.7 µg/L for all exposed firefighters, these total blood mercury elevated concentrations represent organic mercury contributions from dietary sources (e.g., fish consumption), rather than from exposure at WTC.

We believe our results are comparable to our source population of about 11,000 FDNY firefighters because similar levels were found for blood lead in 9,660 firefighters analyzed by an independent FDNY-BHS contract laboratory. For example, 96% of the firefighters had detectable blood lead, with a geometric mean of 3.21 µg/dL (Prezant D, Personal communication). Neither study identified clinically significant concentrations of metals in firefighters.
Cyanide and Volatile Organic Compounds:

A major cause of mortality from smoke inhalation at structural fires is cyanide intoxication (Baud et al. 1991). Since cyanide kinetics dictate that blood cyanide levels reflect exposure mainly within the past 24 hours, our study shows only that firefighters were not exposed to significant amounts of cyanide proximate to sampling. VOCs also tend to have rapid elimination from the blood. The results for VOCs are presented in Tables 1 and 2; the results suggest that some groups had recent or continual exposures to these compounds. Because of the variety of sources potentially contributing to the low levels measured, including fires, solvents in the debris, indoor air, drinking water, vehicular fuels and exhausts, it is difficult to ascribe a specific source. Only six exposed firefighters had a volatile organic concentration above proposed reference ranges (Ashley et al. 1994).

Study Limitations

Sanderson (Sanderson 1997) outlined the limitations of our knowledge about public health consequences of fires and the difficulties in epidemiologic studies after these incidents. Our study has several limitations. First, biomonitoring measurements were made at only one time-point. Several repeat measurements starting soon after the initial fire and spanning at least 2 weeks would have improved our exposure assessment. This design would have been especially useful for chemicals with short half-lives to determine whether exposure differences were persistent or transient. Second, although the control group was composed of FDNY firefighters, comparability may be limited because most had been assigned office duty due to orthopedic injury and therefore, may have lacked recent fire-related exposures. Lastly, current technology does not allow for
biomonitoring of asbestos, fiberglass, silicates, and other inorganic particulates. Thus, this study cannot provide any information about exposure to, or potential health effects from, these materials.

Conclusions

Biomonitoring of firefighters’ blood and urine is an effective exposure assessment tool that can be used to further understand exposures and evaluate the effectiveness of worker protection strategies. Known products of combustion, such as PAH metabolites, were present in greater amounts in exposed firefighters than controls. Unanticipated increases in urinary antimony, serum heptachlorodibenzodioxin, and heptachlorodibenzofuran were also evident. Comparison of exposed and control groups indicated that levels in exposed firefighters, although statistically elevated, were generally low compared with reference values in the general population or workplace threshold levels (when available). Firefighter exposures during the WTC disaster were unique and extreme; our findings should not be generalized to other populations working or living near WTC.
Reference List


Persistent Pesticides from the Same Serum Sample. Organohalogen Compounds 31(26-31).


Appendix A. 110 Chemicals Measured in the WTC Firefighters

14 Polyaromatic Hydrocarbon Metabolites in Urine
1-hydroxybenzo[a]anthracene
1-hydroxybenzo[c]phenanthrene
1-hydroxyphenanthrene
1-hydroxypyrene
2-hydroxybenzo[c]phenanthrene
2-hydroxyfluorene
2-hydroxyphenanthrene
3-hydroxybenzo[a]anthracene
3-hydroxybenzo[c]phenanthrene
3-hydroxychrysene
3-hydroxyfluoranthrene
3-hydroxyfluorene
3-hydroxyphenanthrene
6-hydroxychrysene

29 Volatile Organics in Blood
Dibromochloromethane
Dibromomethane
Bromodichloromethane
Bromoform
Carbon tetrachloride
1,1-dichloroethane
1,2-dichloroethane
1,1,1-trichloroethane
1,1,2-trichloroethane
1,1,2,2-tetrachloroethane
Hexachloroethane
Trans-1,2-dichloroethylene
Cis-1,2-dichloroethylene
1,1-dichloroethylene
Trichloroethylene
Tetrachloroethylene
1,2-dichloropropane
Chlorobenzene
1,2-dichlorobenzene
1,3-dichlorobenzene
1,4-dichlorobenzene
Benzene
Ethylbenzene
Meta- and para-xylene
Ortho-xylene
Styrene
Toluene
2,5-dimethylfuran
Methyl tertiary butyl ether

3 Coplanar Polychlorinated Biphenyls in Serum
3,3',4',5,5'-hexachlorobiphenyl
3,3',4',5'-pentachlorobiphenyl
3,4',5'-tetrachlorobiphenyl

31 Polychlorinated Biphenyls in Serum (IUPAC nomenclature)
PCB101  PCB172
PCB105  PCB177
PCB110  PCB178
PCB118  PCB180
PCB128  PCB183
PCB138-158  PCB187
PCB146  PCB189
PCB149  PCB196-203
PCB151  PCB201
PCB153  PCB28
PCB156  PCB44
PCB157  PCB49
PCB167  PCB52
PCB170  PCB66
PCB74  PCB87
PCB99

15 Chlorinated Dibenzodioxins and Dibenzofurans in Serum
1,2,3,4,5,6,7,8-octachlorodibenzodioxin
1,2,3,4,6,7,8-heptachlorodibenzodioxin
1,2,3,4,6,7,8-heptachlorodibenzofuran
1,2,3,6,7,8-hexachlorodibenzodioxin
1,2,3,7,8,9-hexachlorodibenzodioxin
1,2,3,7,8,9-hexachlorodibenzofuran
2,3,4,6,7,8-hexachlorodibenzofuran
1,2,3,6,7,8-pentachlorodibenzofuran
1,2,3,7,8-pentachlorodibenzodioxin
1,2,3,7,8-pentachlorodibenzofuran
2,3,4,7,8-pentachlorodibenzofuran
2,3,7,8-tetrachlorodibenzodioxin
2,3,7,8-tetrachlorodibenzofuran

13 Metals in Urine
Total Mercury  Lead
Antimony  Molybdenum
Barium  Platinum
Beryllium  Thallium
Cadmium  Tungsten
Cesium  Uranium
Cobalt

4 Metals in Blood
Cadmium
Inorganic mercury, Total Mercury
Lead

Blood Cyanide
Table 1. Adjusted Geometric Mean Chemical Concentrations and ANCOVA Results

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Units</th>
<th>Exposed</th>
<th>Control</th>
<th>Arrival time</th>
<th>Unit Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>All except controls</td>
<td>Control</td>
<td>Day 1 present at collapse</td>
<td>Unit Assignment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(n = 318)</td>
<td>(n = 47)</td>
<td>(n = 148)</td>
<td>Special Operations (n = 95)</td>
</tr>
<tr>
<td>1-hydroxypyrene</td>
<td>ng/L urine</td>
<td>93.2*</td>
<td>62.5</td>
<td>110*</td>
<td>113*</td>
</tr>
<tr>
<td>1-hydroxyphenanthrene</td>
<td>ng/L urine</td>
<td>186</td>
<td>158</td>
<td>197</td>
<td>206</td>
</tr>
<tr>
<td>2-hydroxyphenanthrene</td>
<td>ng/L urine</td>
<td>164</td>
<td>119</td>
<td>163</td>
<td>191*</td>
</tr>
<tr>
<td>3-hydroxyphenanthrene</td>
<td>ng/L urine</td>
<td>162</td>
<td>127</td>
<td>168</td>
<td>185*</td>
</tr>
<tr>
<td>1,2,3,4,6,7,8-HCDBD</td>
<td>pg/gm lipid</td>
<td>27.8*</td>
<td>19.2</td>
<td>30.1*</td>
<td>26.4*</td>
</tr>
<tr>
<td>1,4-dichlorobenzene</td>
<td>µg/L blood</td>
<td>0.235</td>
<td>0.165</td>
<td>0.274</td>
<td>0.289</td>
</tr>
<tr>
<td>meta/para-xyleneanes</td>
<td>µg/L blood</td>
<td>0.066*</td>
<td>0.051</td>
<td>0.066</td>
<td>0.071</td>
</tr>
<tr>
<td>methyl tertiary butyl ether</td>
<td>µg/L blood</td>
<td>0.124</td>
<td>0.101</td>
<td>0.129</td>
<td>0.138</td>
</tr>
<tr>
<td>lead</td>
<td>µg/dL blood</td>
<td>2.76*</td>
<td>1.93</td>
<td>3.08*</td>
<td>2.98*</td>
</tr>
<tr>
<td>lead</td>
<td>µg/L urine</td>
<td>1.17</td>
<td>1.01</td>
<td>1.44*</td>
<td>1.19</td>
</tr>
<tr>
<td>antimony</td>
<td>µg/L urine</td>
<td>0.203*</td>
<td>0.165</td>
<td>0.271*</td>
<td>0.238*</td>
</tr>
<tr>
<td>cadmium</td>
<td>µg/L urine</td>
<td>0.324</td>
<td>0.377</td>
<td>0.355</td>
<td>0.299</td>
</tr>
<tr>
<td>uranium</td>
<td>µg/L urine</td>
<td>0.00611*</td>
<td>0.00752</td>
<td>0.00643</td>
<td>0.00576*</td>
</tr>
</tbody>
</table>

a To be listed in Table 1, a chemical had to show a difference between any two of the groups by Kruskal-Wallis testing (p < 0.05). All chemicals listed in the table were significant by ANCOVA at p < 0.01, except 1-hydroxyphenanthrene (p = 0.0246) and uranium (p = 0.0273), for differences between any two of the six exposure groups adjusted for covariates of age, race, creatinine, and log cotinine. * Significantly different from controls, p <0.01

HCDBD = heptachlorodibenzodioxin; NS = not significant
Table 2. Adjusted Odds Ratios (95% Confidence Intervals) for the Detection of Significant Chemicals

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Arrival before collapse vs Arrive on days 1-2&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Arrival before collapse</th>
<th>Arrival on days 1-2</th>
<th>Special operations vs Other exposed firefighters&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Special operations</th>
<th>Other</th>
<th>All exposed firefighters vs Controls&lt;sup&gt;d&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,2,3,4,6,7,8-HCDBF</td>
<td>1.48 (0.81-2.70)</td>
<td>6.48 (2.30-18.22)</td>
<td>3.81 (1.39-10.46)</td>
<td>3.25 (1.70-6.21)</td>
<td>9.15 (3.12-26.80)</td>
<td>2.70 (1.02-7.10)</td>
<td>3.54 (1.39-9.01)</td>
</tr>
<tr>
<td>Tetrachloroethylene</td>
<td>1.89 (1.04-3.42)</td>
<td>2.86 (1.17-6.94)</td>
<td>2.06 (0.89-4.79)</td>
<td>2.13 (1.12-4.03)</td>
<td>3.23 (1.30-8.03)</td>
<td>1.82 (0.80-4.13)</td>
<td>2.28 (1.04-5.02)</td>
</tr>
<tr>
<td>Blood cadmium</td>
<td>2.44 (1.42-4.20)</td>
<td>0.72 (0.30-1.73)</td>
<td>0.31 (0.13-0.73)</td>
<td>2.19 (1.23-3.90)</td>
<td>0.70 (0.28-1.71)</td>
<td>0.32 (0.14-0.74)</td>
<td>0.43 (0.19-0.94)</td>
</tr>
<tr>
<td>Ethylbenzene</td>
<td>0.71 (0.36-1.41)</td>
<td>5.85 (1.57-21.83)</td>
<td>8.04 (2.14-30.19)</td>
<td>6.25 (2.99-13.08)</td>
<td>18.14 (4.55-72.28)</td>
<td>2.59 (0.73-9.20)</td>
<td>4.04 (1.25-13.03)</td>
</tr>
</tbody>
</table>

<sup>a</sup> Listed chemicals in Table 2 were initially significant at p < 0.05 for differences between any of the six exposure groups using the Chi Square test. All chemicals listed were also significant at p < 0.01 for differences between any of the six exposure groups by logistic regression adjusted for covariates of age, creatinine, and log cotinine.
<sup>b</sup> Adjusted for job task and other covariates.
<sup>c</sup> Adjusted for arrival time and other covariates. The group having arrival times from 3-7 days was too small for statistical comparison.
<sup>d</sup> Adjusted for covariates of age, creatinine, and log cotinine.

HCDBF = heptachlorodibenzofuran