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I, Michael J Knipp, hereby submit this original work as part of the requirements for the degree of:

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Assessment of Municipal Firefighters’ Dermal Occupational Exposure to Polycyclic Aromatic Hydrocarbons

Student Signature: ________________________________

This work and its defense approved by:

Committee Chair: Erin Nicole Haynes, DrPH

Clara Ross, MD

Charles Stuart Baxter, PhD

Paul Succop, PhD
Assessment of Municipal Firefighters’ Dermal Occupational Exposure to Polycyclic Aromatic Hydrocarbons

A thesis submitted to the
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by

Michael Knipp

B.A. Indiana University, May 2001
M.D. Indiana University, May 2006

Committee Chair: Erin Haynes, DrPH
ABSTRACT

Dermal occupational exposure to polycyclic aromatic hydrocarbons (PAH) in municipal firefighters is not well understood. Two specific aims addressed this lack of knowledge. A systematic literature review of dermal occupational PAH exposure was completed. A pilot study evaluated the feasibility of assessing municipal firefighters’ dermal exposure to PAH.

The results of the literature review and pilot study were used to develop an optimal strategy for assessing the dermal route of PAH exposure in municipal firefighters. This strategy was designed to be effective, simple, and cause minimal interference with firefighters’ duties. Instead of examining the dermal exposure route by relation of dermal and inhalation PAH levels to a biomarker through correlation or regression analysis as done in prior studies, a skin cleaning intervention is deemed more appropriate given the overall goals of work practice change and cancer risk reduction in this worker population.
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INTRODUCTION

Polycyclic aromatic hydrocarbons (PAH) are a large class of compounds that possess two or more fused aromatic rings and are composed of carbon and hydrogen atoms.\(^1\) It is estimated that approximately 5 million workers in the United States may be exposed, with exposure occurring through inhalation of PAH vapors or PAH material adsorbed to particles, ingestion, or skin contamination.\(^2\) The most substantial occupational PAH exposure results from any process involving the incomplete combustion of organic materials, with resulting mixtures of PAH being quite variable (Table 1 and 2 provide a listing of some occupations and industrial processes, respectively, with potential for occupational PAH exposure). Significant non-occupational PAH exposure sources are diet, tobacco smoking, medications, and exposure in the home from wood burning stoves or furnaces.\(^2\)

The harmful effects of PAH have been demonstrated in animal short term and long term toxicity studies, dermal and ocular irritation studies, and reproductive and developmental toxicity studies.\(^1\) Most concerning is that the International Programme on Chemical Safety has designated eighteen PAH compounds as definite mutagens and seventeen PAH compounds as carcinogens based on the animal study literature (see Table 3 and 4, respectively for listings).\(^1\)

1-hydroxypyrene (1-HP) is a urinary metabolite of pyrene, a PAH that is present in relatively high, constant concentrations and in relatively well-described ratios to known carcinogenic PAH such as benzo[a]pyrene in most occupational PAH mixtures.\(^2\) It has been used to study occupational PAH exposure in many occupations. The review by Hansen et al.\(^3\) summarizes 101 studies of over 30 different occupational groups using 1-HP as a biomarker of occupational exposure to PAH, identified through a PubMed search current to 2006. This metabolite has been well-studied in relation to biomonitoring. Its kinetics are known (triphasic elimination with half-lives of 5, 22, and 400 hours),\(^2\) there is a widely
excepted analysis method, it can potentially account for all routes of PAH exposure, and the contribution to measured levels by its effect modifiers has been described (diet and smoking).

Regarding correlation between occupational PAH exposure and urinary 1-HP levels, a recent review by Brandt and Watson of the literature of biomarkers used to monitor PAH exposure concludes that “urinary excretion of 1-hydroxypyrene correlates well with external PAC (polycyclic aromatic compounds) exposure and this compound appears to be a suitable marker for internal exposure.” However, nearly all of the studies included in the review accounted only for the inhalational route of exposure to PAH, even though there is evidence that the dermal route of exposure may be the most important in some occupations, with the contribution to total exposure from the dermal route estimated to be between 25 to 75% based on data from two studies. Therefore the contribution of the dermal exposure route to measured urinary 1-HP levels in occupational PAH exposures is unclear. This is concerning as the dermal exposure route has historically played an important role in the development of occupationally related cancers in certain workers exposed to PAH. The role of PAH and especially the contribution of dermal exposure to the risk of development of occupationally related cancers is not fully understood in exposed worker populations, including municipal firefighters.

Municipal firefighters respond to residential and commercial structural fires and medical emergencies in cities and towns. During a fire event, their duties generally include two phases which may take from minutes to several hours depending on the specific situation: 1. Initial response to and management of the fire is completed ("knockdown") 2. The “overhaul” phase during which they search through the structure seeking to control/put out any remaining smaller fires. The overhaul phase is important as often the firefighters remove some or all of their personal protective equipment (PPE) during it. They are occupationally exposed to complex mixtures of PAH as well as a wide range of other chemical exposures (carbon monoxide, carbon dioxide, sulfur dioxide, hydrogen sulfide, hydrogen cyanide, oxides
of nitrogen, particulates, and other combustion products)\textsuperscript{14} but as a group are relatively unstudied regarding these exposures in the line of duty. Recent epidemiological work has demonstrated that municipal firefighters have an excess risk of several types of cancer\textsuperscript{15-18} leading to the World Health Organization classifying their occupational exposure as Group 2B, “possibly carcinogenic to humans”\textsuperscript{19} based on recognition of the danger posed by municipal firefighters’ exposures.

Given that municipal firefighters are exposed occupationally to mutagenic and carcinogenic PAH compounds, there is a need to characterize these exposures including understanding the relationship between external and internal exposure markers. Historically, assessment of municipal firefighters’ occupational PAH exposure has been difficult, incomplete, and non-standardized. Contributing factors include the variability and complexity of the exposures, as municipal firefighters encounter differing mixtures of compounds from one incident to the next.\textsuperscript{19} Furthermore, municipal firefighters’ PAH exposure is intermittent and at potentially high levels versus other worker populations who are exposed to PAH at a more constant level over a shift. These factors have produced varying and inaccurate exposure estimations in municipal firefighters, including simply using years of employment as a surrogate exposure measure.\textsuperscript{19}

Municipal firefighters’ occupational PAH exposure has an inhalational component, but they also have a potential for high dermal exposure for several reasons. While carrying out their duties firefighters become very dirty and covered with soot. They are exposed to high ambient heat along with increased physiologic demands from wearing heavy PPE and completing physically demanding tasks. These stressors cause a physiologic increase in core temperature, skin temperature, and sweat production.\textsuperscript{20} Firefighters are often unable to clean their skin for several hours during and after a fire event. Finally, being covered with soot and not quickly cleaning oneself has historically been part of municipal firefighter culture as a “badge of honor.” These physiologic responses combined with a prolonged
contact time due to lack of gross removal of soot can result in increased absorption of dermally deposited substances on firefighters’ skin as it is known that increased skin hydration and temperature increase skin permeability.\(^{21}\)

A review of studies published to March 2010 in PubMed to examine the assessment of occupational PAH exposure in municipal firefighters returned only 6 studies (see Table 5).\(^{22-27}\) One study\(^ {26}\) involved wildland firefighters whose duties differ from municipal firefighters, are exposed to PAH mixtures, but are not necessarily to the wider spectrum of chemicals found in residential and commercial structural fires. 1-Hydroxypyrene was the sole marker of occupational PAH exposure used in all except one\(^ {25}\) of the studies retained from the literature review. As only six studies were found, the conclusion that 1-HP is an appropriate biomarker for characterization of municipal firefighters’ occupational exposure to PAH is somewhat weakened. However, this is likely a result of those studies’ authors selecting it due to its advantages as a biomarker discussed above with respect to use in studying other occupational groups’ PAH exposures. Three studies\(^ {22,26-27}\) collected either area or personal air sampling. One study\(^ {27}\) collected dermal exposure to PAH in two different manners and concluded that exposure could be decreased by wearing undergloves during fire training exercises as well as cleaning skin following exposure. No study included correlation of dermal PAH exposure to biomarker levels. It is thought that to date no published study has fully explored how municipal firefighters’ dermal occupational PAH exposure should be assessed. This thesis project was intended to address this gap in knowledge regarding municipal firefighters’ occupational PAH exposure.

**HYPOTHESIS**

Dermal exposure is a significant route of occupational polycyclic aromatic hydrocarbon exposure in municipal firefighters.
**SPECIFIC AIMS**

1. Complete a systematic literature review to examine dermal occupational exposure to polycyclic aromatic hydrocarbons.

2. Conduct a pilot study in order to evaluate the feasibility of assessing municipal firefighters’ dermal exposure to polycyclic aromatic hydrocarbons with 1-hydroxypyrene used as a marker of internal PAH exposure.

**Specific Aim 1**

**Methods**

A literature search was conducted in the *Medline (PubMed)* database using the following search strategy:

"occupational"[All Fields] AND ("PAH"[All Fields] OR "PAHs"[All Fields] OR "polycyclic aromatic hydrocarbons"[All Fields] OR "polycyclic aromatic hydrocarbons"[All Fields]) AND "dermal"[All Fields]

The initial search yielded 58 total references for review. Inclusion and exclusion criteria (See Table 6) were applied. After initial review of papers identified using the search strategies, backward citation searching of the retained articles was completed to identify additional references. Figure 1 summarizes the search process. Twelve articles were ultimately identified for this review.

**Results**

Table 7 provides a summary of the twelve retained articles.\(^8, 27, 28-37\) Specific comparison points include: study population and setting, method used to sample dermal PAH exposure, exposure assessment methodology, study results, factors adjusted for, other data collected, and specific comments on study results/conclusions. Study setting differed among the retained articles. Five studies\(^28, 34-37\) examined road pavers’ exposures. Two studies\(^8, 32\) examined cokery workers’ exposures. Other exposure settings
included: electrode production at an aluminum plant,  
creosote exposed workers, workers in coal liquefaction,  
and carbon black workers. Laitinen et al. examined firefighter trainers at a training facility. Two studies were designed as interventional.

Dermal sampling method varied among the studies. Kuljukka et al. was the only included not to use exposure pads, using a skin wipe of the inside of the left wrist instead. Body sites for exposure pads included: wrist, elbow, neck/jaw, shoulder, ankle, groin, arm, chest, and back. Tsai et al. also sampled the forehead and legs. Jongeneelen et al., Laitinen et al., and Vaananen et al. used hand washing with oil as a dermal sampling method.

Several different exposure assessment strategies were used for dermal exposure. Post shift sampling was the most commonly used both for exposure pads and skin wipe. Pre-shift samples were obtained in two studies. Two of the studies utilizing hand wash collect pre and post shift samples while Laitenen et al. collected mid-shift and post-shift hand wash.

Urine sampling strategy was varied among the studies. Pre and post shift collection was the most common. Other strategies were: post shift only, end of week collection, pre and post shift plus bedtime collection, pre/post/6 hours post/ following morning collection, and 46 hour collection. Van Rooij et al. also collected two samples on two non-working days. Quinlan et al. used the following collection strategy: 24 hour collection on first day of workweek, 4 spot samples during first 24 hours after start of workweek, and end of week spot sample.

Study results and conclusions varied. Seven studies found a significant relationship between dermal pyrene levels and urinary 1-HP levels, with three studies not specifically looking for a relationship, and two being interventional studies. Based on their results, five studies concluded that dermal exposure was the primary route of exposure (as opposed to inhalational) in the studied workers (eleven studies included personal air sampling, with one using area sampling). Both
interventional studies\textsuperscript{30-31} reported decreased post-intervention 1-HP levels. The wrist area was reported as the most contaminated in multiple dermal sampling site studies\textsuperscript{8, 27, 30} with Van Rooij \textit{et al.}\textsuperscript{8} also reporting the jaw/neck area as very contaminated.

\textbf{Limitations}

The retained studies well represented the spectrum of worker groups that have significant dermal occupational PAH exposure. The scope of the review is slightly limited as there were two authors with multiple studies included.

\textit{Specific Aim 2}

\textbf{Methods}

\textit{Partnership Development}

The Cincinnati Fire Department (CFD) was contacted regarding interest in partnership with the University of Cincinnati Department of Environmental Health to develop and participate in interdisciplinary studies involving municipal firefighters’ exposures and health risks. Meetings were held with the District Fire Chief, CFD Training Coordinator, CFD Risk Management Team, Pension Representative for Workers’ Compensation, and Cincinnati Firefighters’ Union Local 48.

Further discussions were held with CFD leadership to identify a cohort and exposure setting for an initial pilot program.
**Sampling Development**

**Component One: Selection of cohort and exposure setting, description of training event**

The 2008-2009 CFD recruit class was identified through mutual discussion with the CFD leadership as an appropriate cohort given several factors. The recruit class had varying prior full time firefighting experience. They were undergoing both classroom and field training over a period of several months at two training locations. As most of the recruits were expected to lack prior full time firefighting experience, it was expected that they would be generally free from previous occupational PAH exposure. Additionally, over their training the recruits were to participate in a series of controlled “training events” at a CFD facility in which they would carry out the normal duties of a municipal firefighter at a structural fire with exposures ostensibly similar to that which municipal firefighters face in the line of duty. Fourteen members of the class agreed to participate in the study.

It was determined that one of the “training fires” would be utilized for study sampling. Using the training event at the CFD facility as a single occupational exposure would be advantageous in allowing for the use of a dermal sampling instrument and biomarker of occupational exposure to PAH in a “best case scenario:” a controlled fire event about which the time, parameters, structural materials, activities, and exposure time would be known. This setting would theoretically eliminate many of the past difficulties encountered with sampling municipal firefighters.

The training event consisted of “controlled” exercises designed to simulate real world conditions that municipal firefighters would face in controlling a structure fire. The training events took place approximately every 2 months at a CFD facility in Colerain Township in the greater metropolitan area of Cincinnati, OH and involved all recruits (twenty-eight on the day of sampling). The CFD recruits arrived at the facility at approximately 8 AM with the training event ending at approximately 4 PM with return to the recruits’ firehouse immediately thereafter.
The recruit class was divided into “districts” for the training event activities. Each district had specific responsibilities during the morning and afternoon training sessions. The recruits wore full personal protective equipment (PPE) which included flame retardant clothing including coat, self-contained breathing apparatus with full facepiece mask, hardhat, boots, etc. during the exercises.

Fires were set inside the three story brick building using kindling and pine board as combustion materials. The recruits carried out their duties just as municipal firefighters would at a structural fire. One “district” was assigned “search and rescue” responsibilities during which they began at the top of the structure and made their way progressively down the floors. The other “district” was assigned to manage the fire engines and water used to put out the fires. Some of the members of this district went inside the structure to put out the fire while others did not. In the afternoon session, the districts switched in their responsibilities and the training exercise was carried out in a similar fashion to the morning session. Specific amount of time doing each activity was not measured. The recruits served as “district members” and carried out those duties for the duration of the morning and afternoon sessions (approximately 4 hours each).

Limitations

The controlled setting may not reflect real-world occupational PAH exposure in municipal firefighters. The study population may not be representative of real-world municipal firefighters.


Component Two: Questionnaires

1. Development

A “baseline” questionnaire was developed to describe PAH exposure biomarker confounders and effect modifiers. Research team members collaborated in developing instrument items that would assess the pertinent information. Specific questions were included regarding: prior experience as a firefighter, smoking history, diet history, and basic demographic information (See Appendix A for full details).

A questionnaire designed to assess both subjective appraisal of environmental conditions at the training fire and subjective report of post-fire symptoms was developed. This questionnaire was adapted from a standard questionnaire that is available to CFD firefighters for voluntary completion after each fire event (See Appendix B for full details). This questionnaire was developed by the Cincinnati Firefighters’ International Association of Firefighters Union Local 48 drawing upon workers’ compensation and police/fire pension system resources.38

2. Collection

The fourteen consented subjects completed the baseline questionnaire at the initial recruitment meeting. Twelve subjects (one subject had been dismissed from the class and one was unable to participate due to illness) filled out the post-exposure questionnaire upon return from the fire training event.

Baseline questionnaires were added to each subject’s study file upon completion on December 19, 2008. Post-exposure questionnaires were added to each subject’s study file upon completion on February 25, 2009. The folders were transported to the University of Cincinnati Department of Environmental Health for secure storage in a faculty office on each of those days.
3. Limitations

The questionnaires used in the controlled event sampling were unvalidated. Formal feedback from the firefighter recruits regarding ease of questionnaire completion was not obtained.

Component Three: Exposure sampling

A. DERMAL

1. Development

An arm template was developed. Vinyl furniture cover material was chosen as it was inexpensive and easy to hand cut into a satisfactory sampling template. The template itself consisted of a rectangular shape with a smaller rectangular area cut out of the middle which formed the sampling area. Double stick tape was placed on the underside of the perimeter. This template was designed to be placed on the ventral, distal forearm with one edge resting on the wrist crease. Total sampling area was approximately 15 x 5 cm, or 75cm².

2. Collection

Fourteen subjects gave a skin wipe sample at the initial recruitment meeting. Twelve subjects gave skin wipe samples immediately upon return to the firehouse from the training event. They were instructed not to wash their hands until they had given the skin wipe sample.

The skin template was adhered to the subject’s ventral distal forearm with the edge of the template resting at the wrist crease. A study team member used a prepackaged wipe to collect dust from the designated portion of the template. Sampling technique involved folding the wipe so that it covered the proximal (near the elbow) portion of the sampling area and then wiping the sampling area in an S-shaped fashion one time. The wipe was then placed in a prelabeled container and into a cooler with ice-packs (temperature unknown) which was transported to the
University of Cincinnati Department of Environmental Health for storage in a secure laboratory.

A clean field blank wipe was also included in the samples.

3. Results

Table 8 summarizes demographic, occupational history, and diet data.

4. Limitations

Skin wipe data was not analyzed. During post-training event sampling it was noticed that there was no visible contamination on any subject’s arm area which would have led to clean samples. Additionally, no pre event skin wipe was collected. It was assumed that the subjects’ arms were clean, but theoretically a portion of the dermal PAH could be from contaminated clothing or gear as these can be a source of dermal exposure. This is less likely as the subjects’ arms were grossly uncontaminated after the fire training event.

B. Urine

1. Development

Non-clean catch samples were to be obtained on several occasions. Specimen containers were prepared by labeling them and instilling approximately 5 mL of a 1% glycerol solution preservative.

2. Collection

Study subjects used a prelabeled, sealed collection cup to give a non-clean catch urine sample of approximately 50 mL at the recruitment meeting, in the morning before the fire training event, and immediately upon return to the firehouse after the fire training event.
The collected samples were placed in a cooler containing ice-packs (temperature unknown) and transported to the University of Cincinnati Department of Environmental Health where they were placed in a freezer for storage inside a secured laboratory.

3. Results

Urinary 1-HP data is summarized in Table 9 and statistical analysis in Table 10. There was no statistically significant difference in pre and post-training fire levels in the study subjects.39

4. Limitations

Data regarding dietary ingestion of PAH on the day of the fire event was not collected. This prevented adjustment for dietary PAH contribution to urinary 1-HP levels and should be collected in a future study as same-day meal ingested doses could affect monitored 1-HP levels.2 Study subjects did not wash their hands prior to giving post-exposure urine samples which could lead to sample contamination. This occurred as some subjects gave their skin wipe samples after giving the urine samples. However, a clean-catch sample was not required and contamination of the sample would not affect measured 1-HP levels.

Please see Figure 2 for a succinct overview of the data collection process.
OPTIMAL DESIGN FOR DERMAL EXPOSURE ASSESSMENT

Specific Aims and Hypothesis

The importance of the dermal route of PAH exposure in multiple worker groups has been established through direct data analysis\textsuperscript{8,27,29,34-35} or inference from data results in other studies.\textsuperscript{40-41} However, additional work must be completed in order to develop an optimal assessment strategy to understand the importance of this exposure route in municipal firefighters. It is possible that data regarding the dermal route in other workers cannot be generalized to municipal firefighters as the mixtures and exposure settings they encounter may significantly differ from other worker populations. Laitenen \textit{et al.}\textsuperscript{27} do conclude that the dermal route is primary in municipal firefighters’ PAH exposure, but the study is limited by small sample size, being conducted in a controlled setting, and ability to generalize to real-world municipal firefighter exposures. Additionally, use of knowledge gained from establishment of the importance of the dermal PAH exposure route in other worker populations, must be informed by first considering the municipal firefighter population itself and most importantly the purpose for understanding their PAH exposure in general and the dermal component specifically. These two considerations should inform development of an optimal assessment strategy. Regarding the specifics of municipal firefighters, any sampling may cause interference with their daily occupational duties. As opposed to a coke oven worker whose production may be slightly affected, any interfering sampling may affect the ability of firefighter to carry out their critical and often life-saving work. Realistically and appropriately, a firefighter will likely just not complete any sample collection that has the potential to interfere with their work. Subsequently, an optimal assessment strategy for municipal firefighters dermal PAH exposure must be effective, simple and cause the \textit{least interference possible} with their duties. Its success will be encouraged by obtaining frank, continuous feedback from the firefighters. Therefore, the purpose of this study is to implement an optimal assessment strategy that will demonstrate the importance of the dermal route in municipal firefighter occupational PAH exposure.
hypothesize that municipal firefighter occupational exposure to PAH as measured by urinary 1-hydroxypyrene levels will be significantly decreased after a skin cleaning intervention.

**Specific Aim 1:** Determine the effect of smoking, diet, and hygiene on measured levels of urinary 1-HP by obtaining diet, demographic, occupational, hygiene habit, and health history information from municipal firefighters.

**Specific Aim 2:** Assess the effectiveness of a skin cleaning intervention by collecting pre and post fire event biological and environmental samples.

**Background and Significance**

Much recent increased interest in municipal firefighters’ occupational PAH exposure derives from epidemiological evidence of cancer excess (as well as other health effects). This is an issue that reaches beyond the academic realm and into the clinical. As such, it impacts choice of study type so that future work should seek to make a strong difference in municipal firefighters’ health outcomes regarding prevention of future cancers. Specifically, it requires a decision as to what questions to address regarding dermal exposure. On one hand, sampling strategy could be optimized to examine if the dermal route is primary using characterization techniques relating dermal and inhalation PAH levels to a biomarker through correlation or regression analysis as was carried out in several of the studies in the current literature search.\(^8, 28-29, 33-35, 37\) However, an interventional study such as in Van Rooij *et al.*\(^{30}\) and Quinlan *et al.*\(^{31}\) is more appropriate given the concern for the clinical outcome of cancer risk reduction.

A study designed to show effectiveness of an exposure reduction intervention may help to change work practices that lead to increased dermal PAH exposure in municipal firefighters and end the decades entrenched culture of soot=honor among firefighters. This study type may also indirectly indicate the
primacy of the dermal route if an intervention designed to decrease dermal exposure results in significantly decreased level of the biomarker of internal exposure when no intervention was used to decrease inhalational exposure (in reality an inhalational exposure intervention is usually in place in the form of the SCBA that municipal firefighters wear).

**Preliminary Studies**

The pilot study described above allowed development and testing of collection strategy and instruments in a “controlled” setting. The current literature review results demonstrate wide use of dermal PAH sampling with a biomarker of internal exposure in multiple worker groups, show a strong correlation between dermal exposure levels and a biomarker of internal PAH exposure even with variation in urine collection strategy, and demonstrate how a decrease in dermal exposure can lead to a subsequent decrease in internal exposure as measured by biomarker levels in two interventional studies. Most importantly, the data demonstrate the importance of the dermal route of occupational PAH exposure in multiple worker populations. Discussions with CFD firefighters have provided feedback regarding sampling design. They have indicated that the jaw, neck, and forehead would be the most appropriate dermal sampling areas as per them these anatomical regions become the most contaminated during their duties as opposed to the wrist region sampled in studies of other worker groups and in the current pilot study (which was grossly uncontaminated).

**Methods**

*Study Population, Exposure Setting, and Study Duration:*

The study population should consist of municipal firefighters participating in real-world fire events. Exposure assessment during controlled fires could be utilized to initially to practice sampling technique, but ultimately dermal exposure must be assessed during actual fire events to understand what the
actual exposure is. Exposure during the overhaul phase must also be captured as many firefighters do not wear all (or any) of their PPE during this part of the fire event while still being exposed to deleterious substances. Sampling should be done for one month without and then with the intervention. This timeframe is initially chosen to allow for enough time for several fire events to occur. The shift length at the participating fire station should be 24 hours on and 48 hours off. Multiple crews could be sampled during their working shifts.

Specific Aim 1: Determine the effect of smoking, diet, and hygiene on measured levels of urinary 1-HP by obtaining diet, demographic, occupational, hygiene habit, and health history information from municipal firefighters.

Non-intervention period (One month)

Subjects will complete a baseline questionnaire (See Appendix A) to provide information about their health and occupational history. Subjects will complete a post-exposure questionnaire (See Appendix B) shortly after each fire event. Subjects will complete a questionnaire regarding recent diet, smoking, and personal hygiene history (See Appendix C) and Section F of the post exposure questionnaire (See Appendix B) at the beginning of each shift. Subjects will also complete the questionnaire regarding recent diet, smoking, and personal hygiene history at the end of each shift during which they participated in a fire event.

Intervention period (One month)

This period will immediately follow the non-intervention month. Subjects will complete a post-exposure questionnaire (See Appendix B) after each fire event. Subjects will complete a questionnaire regarding recent diet, smoking, and personal hygiene history (See Appendix C) and Section F of the post exposure
questionnaire (See Appendix B) at the beginning of each shift. Subjects will also complete the questionnaire regarding recent diet, smoking, and personal hygiene history at the end of each shift during which they participated in a fire event.

Specific Aim 2: Assess the effectiveness of a skin cleaning intervention by collecting pre and post fire event biological and environmental samples.

Non-intervention period (One month)
Subjects will give a 50mL non-clean catch urine sample at the beginning of each shift and at the end of each shift if there was a fire event. Subjects will be trained on proper use of and wear personal air sampling devices during all fire events. A research assistant will be present at the beginning of each shift and shortly after the end of each shift during which there was a fire event to collect urine samples.

Intervention period (One month)
Subjects will give urine samples and wear personal air sampling devices in the same manner as during the non-intervention period. Subjects will be instructed on proper collection of a dermal wipe sample (thoroughly cleaning AT LEAST the jaw, neck, and forehead regions). A research assistant will be present at the beginning of each shift and at the scene of every fire event during their shift to reinforce cleaning technique and to collect the dermal wipe samples.

Figure 3 provides an overview of the sampling strategy
**Sample Analysis:**

Urine samples will be analyzed for 1-HP according to established methodology.\(^5\) Skin wipe samples will be analyzed for pyrene and total PAH, air samples for pyrene according to accepted methodology.\(^32\)

**Statistical Analysis:**

End of shift, post fire event 1-HP levels during the non-intervention and intervention periods will be examined for a statistically significant difference. Correlation coefficients between air pyrene levels and 1-HP as well as between dermal pyrene and 1-HP levels will be determined.

**Expected Results:**

Measured levels of post-fire event 1-HP during the intervention period will be significantly less than those measured during the non-intervention period. A strong correlation between dermal pyrene levels and 1-HP levels is expected.

**Future Directions:**

Other sampling strategy components could be considered for eventual inclusion. To adjust for the contribution of smoking to 1-HP levels, a biomarker could be added to the sampling strategy. Cotinine, a metabolite of nicotine, has been measured in plasma in prior firefighter studies.\(^25,42\) Less invasive measurement of cotinine levels is possible in urine and saliva.\(^43\)

The ability to reliably assess the contribution of dermal PAH exposure to municipal firefighters’ occupational PAH exposure will allow for greater understanding regarding the pathway from occupational exposure to clinical outcome. This could eventually include examination of the relationship between dermal exposure levels and markers of biological effect such as DNA adducts, sister chromatid exchange, and micronucleus formation.
BIBLIOGRAPHY

10. Pott P. Chirurgical observations relative to the cataract, the polypus of the nose, the cancer of the scrotum, the different kinds of ruptures, and the mortification of the toes and feet. London: Hawkes, Clarke, and Collins, 1775.


Table 1

Occupations with Potential Exposure to PAH Mixtures

<table>
<thead>
<tr>
<th>Occupation</th>
<th>Occupation</th>
<th>Occupation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coke oven workers</td>
<td>Aluminum/iron/steel foundry workers</td>
<td>Refuse workers</td>
</tr>
<tr>
<td>Petroleum refinery workers</td>
<td>Automobile mechanics</td>
<td>Construction workers</td>
</tr>
<tr>
<td>Rubber workers</td>
<td>Railroad workers</td>
<td>Firefighters</td>
</tr>
<tr>
<td>Waste oil workers</td>
<td>Creosote workers</td>
<td>Shipyard workers</td>
</tr>
<tr>
<td>Pitch workers</td>
<td>Asphalt workers</td>
<td>Plumbers</td>
</tr>
</tbody>
</table>
Table 2
Industrial Processes Involving Exposure to PAH Mixtures

<table>
<thead>
<tr>
<th>Processing coal, crude oil, natural gas</th>
<th>Aluminum production</th>
<th>Refuse incineration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power plant operations</td>
<td>Dye manufacture</td>
<td>Pigment manufacture</td>
</tr>
<tr>
<td>PVC/plasticizers manufacture</td>
<td>Pesticide manufacture</td>
<td></td>
</tr>
</tbody>
</table>
### Table 3

<table>
<thead>
<tr>
<th>PAH Compounds Designated as Mutagens by the International Programme on Chemical Safety¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benz[a]anthracene</td>
</tr>
<tr>
<td>Benzo[ghi]perylene</td>
</tr>
<tr>
<td>Cyclopenta[cd]pyrene</td>
</tr>
<tr>
<td>Fluoranthene</td>
</tr>
<tr>
<td>Perylene</td>
</tr>
</tbody>
</table>

Table 4

PAH Compounds Designated as Carcinogens by the International Programme on Chemical Safety

<table>
<thead>
<tr>
<th>Anthanthrene</th>
<th>Benz[a]anthracene</th>
<th>Benzo[b]fluoranthene</th>
<th>Benzo[j]fluoranthene</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzo[k]fluoranthene</td>
<td>Benzo[c]phenanthrene</td>
<td>Benzo[a]pyrene</td>
<td>Chrysene</td>
</tr>
<tr>
<td>Cyclopenta[cd]pyrene</td>
<td>Dibenzo[a,h]anthracene</td>
<td>Dibenzo[a,e]pyrene</td>
<td>Dibenzo[a,h]pyrene</td>
</tr>
<tr>
<td>Dibenzo[a,i]pyrene</td>
<td>Dibenzo[a,l]pyrene</td>
<td>Fluoranthene</td>
<td>Indeno[1,2,3-cd]pyrene</td>
</tr>
<tr>
<td>5-Methylchrysene</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Table 5

Summary of Firefighter Studies Using 1-HP as a Marker of Internal PAH Exposure

<table>
<thead>
<tr>
<th>Reference, location</th>
<th>Study population and setting</th>
<th>Biomarker(s) of PAH exposure used</th>
<th>Exposure Assessment</th>
<th>Study results</th>
<th>Adjustment</th>
<th>Other data collected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feunekes et al. (1997), Nimjmenen, the Netherlands</td>
<td>33 firefighters, 14 controls; Firefighting training school, controlled fire events</td>
<td>1-HP²</td>
<td>Pre-shift sample in all after 3-4 week vacation One firefighter group A: end-of-week, 16-20h post-last training exercise One firefighter group B: 2-4h post last exercise of a day</td>
<td>Pre-shift levels similar amongst groups, higher in smokers; Levels in group A elevated compared to pre-shift, but due to smoking; Levels in group B elevated compared to pre-shift, smoking and fire smoke exposure significant</td>
<td>smoking</td>
<td>Personal PAH² sampling, job duty, age, smoking habits, diet, use of medication, contact with tar products</td>
</tr>
<tr>
<td>Moen et al. (1997), Bergen, Norway</td>
<td>9 military recruits undergoing a one-week training course, 4 trainers; Firefighting school</td>
<td>1-HP</td>
<td>During training week: Monday: all subjects gave urine sample before start of course Tuesday: all subjects gave urine sample 6-7h post-lesson Wednesday &amp; Thursday: trainers gave urine sample 6-7h after end of lesson</td>
<td>Significant increase in levels after training</td>
<td>smoking</td>
<td>Smoking habits, diet</td>
</tr>
<tr>
<td>Caux et al. (2002), Toronto, Ontario, Canada</td>
<td>43 City of Toronto firefighters</td>
<td>1-HP</td>
<td>1. All urine produced for 20h following end of an exposure 2. Control sample after at least 4 days without firefighting activity</td>
<td>38% of maximum of all samples from each firefighter and 1 control sample exceeded 95&lt;sup&gt;th&lt;/sup&gt; percentile of reference population</td>
<td>Fire phase, use of protective equipment</td>
<td>Report of duties during fires and protective equipment use; muconic acid, smoking, lifestyle</td>
</tr>
<tr>
<td>Edelman et al. (2003), New York City, New York, United States</td>
<td>318 New York City firefighters at World Trade Center, 47 firefighter controls not present at World Trade Center</td>
<td>1-HP and 13 other PAH metabolites³</td>
<td>One-time sample on October 1-5, 2001</td>
<td>1-HP levels significantly different from controls</td>
<td>smoking</td>
<td>Report of arrival time at site, total number of worksite days, protective equipment use; plasma cotinine, metals, VOCs⁴, PCBs⁵, CDBDs⁶, serum cyanide</td>
</tr>
<tr>
<td>Robinson et al. (2008), Arizona, United States</td>
<td>21 wildland firefighters</td>
<td>1-HP</td>
<td>Pre-shift (first morning void), end of prescribed burn shift, morning following prescribed burn (first morning void); 5 total prescribed burns</td>
<td>No significant change in 1-HP levels following prescribed burn exposure</td>
<td>diet, home fuel use</td>
<td>Personal and area sampling for total &amp; respirable dust, particulates, &amp; PAHs; pulmonary function testing, respiratory symptoms, job duties</td>
</tr>
<tr>
<td>Laitinen et al. (2010), Kuopio, Finland</td>
<td>4 firefighter trainers</td>
<td>1-HP</td>
<td>Before exposure, immediately after exposure, 6h after end of exposure, morning following exposure; 3 training fires</td>
<td>Highest 1-HP excretion following burning of conifer wood and chipboard, lowest with pure pine and spruce</td>
<td>Type of material burned</td>
<td>Muconic acid, 1-naphthol, dermal exposure, area air concentrations of PAH, hydrogen cyanide, cyanides, formaldehyde, VOCs</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reference, location</th>
<th>Study population and setting</th>
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</tr>
</tbody>
</table>

27
Table 5 (Continued)- Summary of firefighter studies using 1-HP as a marker of internal PAH exposure

1-HP: 1-hydroxypyrene

PAH: polycyclic aromatic hydrocarbons


VOCs: volatile organic compounds

PCBs: polychlorinated biphenyls

CDBs: chlorinated dibenzodioxins
Table 6

Inclusion and Exclusion Criteria for Literature Review

<table>
<thead>
<tr>
<th>Inclusion</th>
<th>Exclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peer reviewed study in English</td>
<td>Non-peer reviewed</td>
</tr>
<tr>
<td>Adult human subjects</td>
<td>Not in English</td>
</tr>
<tr>
<td>1-hydroxypyrene used as a biomarker of occupational PAH(^1) exposure</td>
<td>Mortality or morbidity study</td>
</tr>
<tr>
<td>Dermal sampling for occupational PAH exposure used</td>
<td>Workers’ compensation data used</td>
</tr>
<tr>
<td>Any sampling strategy</td>
<td>Animal subjects</td>
</tr>
<tr>
<td>Any confounders or effect modifiers adjusted for Interventional/non-interventional study</td>
<td></td>
</tr>
<tr>
<td>Controls used/not used</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)PAH: Polycyclic aromatic hydrocarbon
<table>
<thead>
<tr>
<th>Reference, Location</th>
<th>Study Population and Setting</th>
<th>Dermal Sampling Method</th>
<th>Exposure Assessment</th>
<th>Study Results</th>
<th>Adjustment</th>
<th>Other Data Collected</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jongeneelen et al. (1988) Nijmegen, Netherlands</td>
<td>Surface dressing workers at 4 paving sites</td>
<td>Exposure pads on: wrist, elbow, neck, shoulder, ankle Hand washing with sunflower oil</td>
<td>Pre and post shift hand washing for pyrene Post shift exposure pads for pyrene Pre and post shift urinary 1-HP&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Increased levels of 1-HP found, highest levels of 1-HP in post-shift samples Significant positive correlation between: pyrene on wrist pad and end of shift urinary 1-HP, pyrene on hands and end of shift urinary 1-HP, two skin contamination variables</td>
<td>Breathing zone airborne particulates</td>
<td>Wrist pads most contaminated</td>
<td></td>
</tr>
<tr>
<td>Van Rooij et al. (1992) Nijmegen, Netherlands</td>
<td>20 workers in electrode production of aluminum reduction plants</td>
<td>Exposure pads on: wrist, jaw/neck, groin</td>
<td>End of shift, pre next shift, weekly increase for: urinary 1-HP, dermal pyrene, pyrene in air</td>
<td>Correlation coefficients between dermal contamination and urinary 1-HP equal/higher than that of pyrene in air and urinary 1-HP</td>
<td>Personal air sampling for pyrene</td>
<td>Total skin contamination estimated more than 3 times higher than intake per inhalation -&gt; significant dermal contribution to total PAH body burden</td>
<td></td>
</tr>
<tr>
<td>Van Rooij et al. (1993) Nijmegen, Netherlands</td>
<td>10 creosote exposed workers</td>
<td>Exposure pads on: jaw/neck, shoulder, upper arm, wrist, groin, ankle</td>
<td>Post shift exposure pads for pyrene on 2 Mondays after weekend off work Urine from Sunday 8AM to Tuesday 6AM for urinary 1-HP coincident with exposure pads On one sampling day, workers wore coveralls under clothes</td>
<td>Coveralls reduced skin contamination by 35% on average, but no significant reduction at jaw/neck, ankle, groin Significant decrease in excreted 1-HP with use of coveralls</td>
<td>Breathing zone air for pyrene Interview for alcohol, smoking, height, weight, age</td>
<td>Regression analysis showed skin PAH contamination main determinant of internal exposure dose in creosote workers Without protective clothing, wrist had highest contamination</td>
<td>Interventional Study</td>
</tr>
<tr>
<td>Van Rooij et al. (1993) Nijmegen, Netherlands</td>
<td>12 coke plant workers</td>
<td>Exposure pads on: jaw/neck, shoulder, upper arm, wrist, groin, ankle</td>
<td>Post shift exposure pads for pyrene on 5 consecutive 8 hour shifts Pre and post shift urinary 1-HP; also two day period during weekend after workweek</td>
<td>Average of 75% of absorbed pyrene through skin Variation in excreted 1-HP varied more with dermal dose than respiratory</td>
<td>Smoking, alcohol Airborne particulates in breathing zone Interview for age, height, weight, smoking habits, alcohol</td>
<td>Highest contamination of jaw/neck and wrist Skin is main route of uptake of PAH</td>
<td></td>
</tr>
<tr>
<td>Quinlan et al.</td>
<td>10 coal</td>
<td>Exposure pads</td>
<td>Post shift exposure pads for</td>
<td>55% reduction in 1-HP</td>
<td>Weekly self-</td>
<td>Exposure to PAH may</td>
<td></td>
</tr>
</tbody>
</table>

Table 7
Summary of Retained Articles from Literature Review
<p>| (1995) Birmingham, England | liquefaction factory; crossover design of 2 weeks’ duration | on: groin, ankle pyrene on first day of workweek. One week using intervention coveralls, one without 24 hour urine on first day of week; 4 spot samples during first 24 hours after start of week; spot sample at end of week | excreted on first day of intervention phase (CI 9.5–40.8 nmol) 82% reduction in skin pad deposition of pyrene on first day of intervention (CI 7.3–26.4 ng/cm²) Reduction in excreted 1-HP over working week during intervention phase, not significant at 5% level | administered diary card for age, health status, smoking habits, medication use, diet, workwear nature occur from workers’ own clothes Interventional Study |
| Kuljukka et al. (1996) Kohtla-Jarve, Estonia | 49 cokery workers, 10 controls | Skin wipe of left inside wrist with Smear Tab Pre and post shift skin wipes for pyrene and BaP 4 times in workers with 1 corresponding sample in controls Post shift urine for 1-HP | Visible skin contamination, in 60% of samples, post-shift value higher Correlation between pyrene in air and 1-HP (r=0.56) Correlation between BaP in air and 1-HP (r=0.63) | Personal air sampling for pyrene and BaP Interview for work history, smoking habits, health status Unable to control for handwashing in skin wipe sampling |
| Tsai et al. (2002) Taiwan | 30 carbon black workers | Exposure pads on: front head, neck/back, neck/front, back, chest, upper arm, lower arm, upper leg, lower leg Post shift exposure pads for PAH on 5 consecutive days (only 4 workers gave samples) Pre and post shift on first day, post shift on fifth day for 1-HP | Post shift 1-HP on day 5 regression model and regression coefficients for gaseous PAH concentration, particle bound inhalable PAH, and dermal PAH concentration were significant | Personal air sampling for 8h on 5 consecutive days for inhalable particle bound PAH and gaseous PAH concentration Interview for smoking habits, age, sex, body weight, height Authors conclude post shift 1-HP on 5th working day possible suitable indicator for PAH exposure in carbon black workers if respiratory and dermal PAH exposures are assessed |
| McClean et al. (2004) Boston, United States | 26 construction workers (20 paving and 6 milling) | Exposure pad on wrists Two post shift exposure pads on 2 or 3 consecutive days (millers, pavers respectively) Pre shift, post shift, bedtime, and additional pre shift on final day urine for 1-HP for 2 or 3 days (millers, pavers respectively) | Paving workers had higher inhalational and dermal exposures to pyrene No difference between groups in 1-HP level after weekend away from work Mean 1-HP increased pre to post shift on each workday for pavers Increase in pre shift 1-HP levels in pavers through | Questionnaire for age, height, weight, smoking, diet Personal air sampling for pyrene Dermal contact is primary exposure route Cumulative exposure to PAH will be underestimated if dermal measure not included |</p>
<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Contact</th>
<th>Exposure</th>
<th>Post-shift exposure</th>
<th>PAH results</th>
<th>Significance</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vaananen et al. (2005) Helsinki, Finland</td>
<td>29 road pavers, 4 traffic controllers</td>
<td>Exposure pad on wrists</td>
<td>Post shift exposure pads x2 on 8 total days for PAH</td>
<td>PAH results between exposure pads and hand washing equivalent and strong correlation (r=0.757, p&lt;0.001)</td>
<td>Significant difference between pre and post shift handwashing samples</td>
<td>Variation in PAH contamination on skin explained more of variation in 1-HP levels than did respiratory PAH concentrations</td>
<td>Breathing zone personal air sampling for PAH</td>
</tr>
<tr>
<td>Vaananen et al. (2006) Helsinki, Finland</td>
<td>16 asphalt workers, 2 traffic controllers</td>
<td>Exposure pad on wrists</td>
<td>Post shift exposure pads x2 on 4 total days for PAH</td>
<td>Dermal deposition of PAH low</td>
<td>Work related uptake of PAH low in all pavers, significantly higher in smokers</td>
<td>Breathing zone air for total particulates, bitumen fume/vapor, 16 PAH, four methylated PAH, 11 aldehydes/resin acids</td>
<td>Questionnaire for sex, age, eye/skin/respiratory irritation, staining, odor, protective clothing use</td>
</tr>
<tr>
<td>Sobus et al. (2009) Boston, United States</td>
<td>20 road pavers</td>
<td>Exposure pad on wrists</td>
<td>Post shift exposure pads x2 for 3 consecutive days for particulate PAH</td>
<td>Both air and dermal levels of PAH were significant predictors of post shift urine levels of 1-HP</td>
<td>Dermal levels were</td>
<td>Urinary creatinine, smoking status, age, body mass index, timing of sample</td>
<td>Personal air sampling for particulate PAH</td>
</tr>
</tbody>
</table>

1-HP can be used as marker of exposure to particulate asphalt emissions Given significant
| Laitinen et al. (2010) | 4 firefighter trainers | Exposure pads on chest and back <br>Hand wash with sunflower oil | Post training day exposure pads <br>Hand wash before lunch and at end of training day <br>Pre training, immediately after training day end, 6h post training end, following morning urine for 1-HP, muconic acid, 1-naphthol | Highest 1-HP, benzene, hydrogen cyanide levels 6h post burning of conifer plywood and chipboard <br>Highest dermal whole body PAH in firehouse simulator (average 1200 ng/cm²) versus container training sessions (average 760 ng/cm²) <br>PAH on hands decreased 80% when they used undergloves (average 8.7 ng/cm²) versus not (average 48.4 ng/cm²) <br>No difference in protection efficiency based on type of tested fire suits | Type of material burned during training exercises | Area air sampling for PAH, hydrogen cyanide, cyanides, formaldehyde, volatile organic compounds | Authors conclude that dermal is main route of PAH exposure |

1-HP: 1-hydroxypyrene

2PAH: polycyclic aromatic hydrocarbons

3BaP: benzo[a]pyrene
Table 8
Demographic, Smoking, Diet Data

<table>
<thead>
<tr>
<th>Average Years of Prior Firefighting Experience</th>
<th>0.66 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smoking</td>
<td></td>
</tr>
<tr>
<td>Never smoker</td>
<td>9</td>
</tr>
<tr>
<td>Former smoker</td>
<td>2</td>
</tr>
<tr>
<td>Current smoker</td>
<td>1</td>
</tr>
<tr>
<td>Race</td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>12</td>
</tr>
<tr>
<td>African American</td>
<td>0</td>
</tr>
<tr>
<td>American Indian</td>
<td>0</td>
</tr>
<tr>
<td>Pacific Islander</td>
<td>0</td>
</tr>
<tr>
<td>Asian</td>
<td>0</td>
</tr>
<tr>
<td>Ethnicity</td>
<td></td>
</tr>
<tr>
<td>Hispanic or Latino</td>
<td>0</td>
</tr>
<tr>
<td>Not Hispanic or Latino</td>
<td>12</td>
</tr>
<tr>
<td>Average age</td>
<td>25.92 years</td>
</tr>
<tr>
<td>Number of subjects that consumed PAH containing foods</td>
<td>2</td>
</tr>
</tbody>
</table>
Table 9

Pre and Post Training Fire Urinary 1-Hydroxypyrene Levels

<table>
<thead>
<tr>
<th>Subject ID</th>
<th>Pre 1-HP (µg/L)</th>
<th>Post 1-HP (µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.201</td>
<td>LOD¹</td>
</tr>
<tr>
<td>2</td>
<td>0.0988</td>
<td>LOD</td>
</tr>
<tr>
<td>3</td>
<td>0.122</td>
<td>0.0861</td>
</tr>
<tr>
<td>4</td>
<td>subject left study</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.121</td>
<td>0.199</td>
</tr>
<tr>
<td>6</td>
<td>LOD</td>
<td>0.110</td>
</tr>
<tr>
<td>7</td>
<td>LOD</td>
<td>LOD</td>
</tr>
<tr>
<td>8</td>
<td>0.119</td>
<td>0.0969</td>
</tr>
<tr>
<td>9</td>
<td>0.143</td>
<td>0.159</td>
</tr>
<tr>
<td>10</td>
<td>0.134</td>
<td>0.0932</td>
</tr>
<tr>
<td>11</td>
<td>0.181</td>
<td>0.258</td>
</tr>
<tr>
<td>12</td>
<td>subject left study</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>LOD</td>
<td>0.259</td>
</tr>
<tr>
<td>14</td>
<td>0.119</td>
<td>0.106</td>
</tr>
<tr>
<td>Mean</td>
<td>0.113</td>
<td>0.124</td>
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</tbody>
</table>

¹LOD= limit of detection, 0.0387 µg/L
Table 10

Statistical Analysis of 1-HP Data

<table>
<thead>
<tr>
<th>Exposure Groups</th>
<th>N</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>95% CI lower</th>
<th>95% CI upper</th>
<th>T-value</th>
<th>Two Tailed P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre - Post</td>
<td>12</td>
<td>-0.0109587</td>
<td>0.0945227</td>
<td>-0.07102</td>
<td>0.049099</td>
<td>-0.40162</td>
<td>0.6957</td>
</tr>
<tr>
<td>Pre-Shift</td>
<td>12</td>
<td>0.11286857</td>
<td>0.0527765</td>
<td>0.079336</td>
<td>0.146401</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-Shift</td>
<td>12</td>
<td>0.12382724</td>
<td>0.0790921</td>
<td>0.073574</td>
<td>0.17408</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1

Summary of Literature Search

58 articles identified by search strategy

13 articles excluded based on title review

23 articles excluded based on abstract review with application of inclusion/exclusion criteria

22 potentially relevant papers retrieved, 12 excluded following full review

2 articles identified through backward citation search

12 studies included in final review
Figure 2

Data Collection Overview¹

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Baseline Questionnaire</td>
<td>• Urine sample</td>
<td>• Post-exposure questionnaire</td>
</tr>
<tr>
<td>• Skin wipe</td>
<td>• Saliva sample</td>
<td>• Blood sample</td>
</tr>
<tr>
<td>• Urine sample</td>
<td>• Area environmental sampling</td>
<td>• Urine sample</td>
</tr>
<tr>
<td>• Saliva sample</td>
<td></td>
<td>• Skin wipe</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Mask wipe</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Saliva sample</td>
</tr>
</tbody>
</table>

¹Saliva, blood, mask wipe, and area environmental sampling was completed as part of other research team members’ projects
Overview of Optimal Assessment Strategy

**Non-intervention period (one month)**
- Urine
  - Pre-shift and post if fire event
- Air
  - Personal air sampling during fire events
- Questionnaire
  - Baseline
  - Pre-shift
    - Recent habits
  - Post-exposure for each fire event
  - Recent habits
  - Incident details

**Intervention period (one month)**
- Dermal
  - Pre-shift and after each fire event during a shift
- Urine
  - Pre-shift and post if fire event
- Air
  - Personal air sampling during fire events
- Questionnaire
  - Pre-shift
    - Recent habits
  - Post-exposure for each fire event
    - Recent habits
    - Incident details
APPENDIX A:

BASELINE QUESTIONNAIRE

SUBJECT ID#: _________

Section A. – **Firefighting History**

1. What year did you begin working as a firefighter (include part time and volunteer)?
   ________

   Since you began working as a firefighter, how many fires have you participated in extinguishing?

   O  0 (none)

   O  1-5

   O  6-20

   O  21-49

   O  >50

2. When was your last fire? ______________________

3. In the past 3 months, how many fires have you participated in extinguishing?
Section C. – Medical History

1. Smoking status (circle one):

   a. Never smoked

   b. Former smoker

   When did you quit? ______

   How many cigarettes did you smoke:

      Per day? ______
      Per week? ______
      Per month? ______
      Don’t know? ______

   c. Current smoker

   How many cigarettes do you smoke:

      Per day? ______
      Per week? ______
      Per month? ______
      Don’t know? ______

2. Have you eaten any of these foods in the past 8 hours? (circle all that apply)
Section C. - Demographic Information

3. What is your birthdate? ____/____/______  
Mo/ day/year

4. How best would you describe your ethnicity?  
○ Hispanic or Latino (0)  
○ Not Hispanic or Latino (1)

5. How best would you describe your race?  
○ White/Caucasian (0)  
○ Black/African American (1)  
○ American Indian (2)  
○ Pacific Islander (3)  
○ Asian (4)  
○ Other ____________________________  
○ Don’t know (6)

12. Age: _______
APPENDIX B

POST-EVENT QUESTIONNAIRE

SUBJECT ID#: __________

1. Incident Date ___/___/_____
2. Alarm Time ______ AM  PM

Section A. – Incident Type (select one)

0 Trash/Dumpster  0 Vehicle fire  0 Food on Stove  0 Residential Fire
0 Industrial Fire  0 Commercial Fire  0 Marine Fire  0 Railroad Fire
0 Water/Rescue  0 Hazmat  0 EMS

0 Other (describe in one or two words): ________________________________

Type Occupancy (describe in one or two words):

________________________________________

Section B. – Length of Exposure by Fire Stage/Activity

1. Fire Stage

<table>
<thead>
<tr>
<th></th>
<th>&lt; 1 hour</th>
<th>1-2 hours</th>
<th>2-3 hours</th>
<th>3+ hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incipient</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Free burning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## 2. Activity

<table>
<thead>
<tr>
<th>Activity</th>
<th>&lt; 1 hour</th>
<th>1-2 hours</th>
<th>2-3 hours</th>
<th>3+ hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extinguishment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entry/Ventilation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rescue</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light Overhaul</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavy Overhaul</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EMS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Investigation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Section C. – Personal Protective Equipment Use

#### 1. Fire Stage

<table>
<thead>
<tr>
<th>Fire Stage</th>
<th>Turnout Gear</th>
<th>SCBA</th>
<th>HEPA Filter</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incipient</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Free burning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smoldering</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-fire</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
1A. If SCBA used, how many Bottles? (circle one): 1  2  3  >3  N/A

2. Activity

<table>
<thead>
<tr>
<th>Activity</th>
<th>Turnout Gear</th>
<th>SCBA</th>
<th>HEPA Filter</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extinguishment</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Entry/Ventilation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rescue</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light Overhaul</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Heavy Overhaul</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>EMS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Investigation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2A. If SCBA used, how many Bottles? (circle one): 1  2  3  >3  N/A

Section D. — Smoke Exposure

1. Smoke Conditions

   0 Light  0 Medium  0 Heavy  0 None

2. Smoke Colors __________________________________________

Section E. -- Symptoms
(Check all that apply)

<table>
<thead>
<tr>
<th></th>
<th>At incident</th>
<th>After incident</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyes burning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cough</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coughing blood</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nose bleed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nose irritation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lung irritation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nausea</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dizziness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ears ringing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Headache</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skin irritation/rash</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loss of consciousness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other (describe)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Section F. – Exposure Reduction

Which parts of your body were contaminated with soot? Please darken in on the diagram below:

Please check here if you could not see any soot on your body_______________
Did you clean any part of your body? Circle below.

FACE  JAW/NECK  HEAD/HAIR  ARMS  CHEST  BACK  LEGS

OTHER: ____________________________________________
APPENDIX C

Recent Habits Questionnaire

SUBJECT #: ______________  DATE AND TIME: ____________________________

1. Have you eaten any of these foods in the past 8 hours? (circle all that apply)
   grilled meat, barbecue, smoked meats, chicory (aka endive/radicchio), olives

2. When was the last time you used tobacco? _______________________

   When was the last time you showered or took a bath? _______________________
