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Pilot study on the efficiency of water-only decontamination for firefighters' turnout gear

Anthony Calvillo¹, Erin Haynes¹, Jeff Burkle¹, Kenny Schroeder², Angelo Calvillo³, Julie Reese⁴, Tiina Reponen^{1,*}

¹Center for Health-Related Aerosol Studies, Department of Environmental Health, College of Medicine, University of Cincinnati, 160 Panzeca Way, Cincinnati, OH 45267-0056

²Independence Fire District, P.O. Box 175 1980 Delaware Crossing, Independence, KY 41051

³Cleveland Fire Headquarters, 1645 Superior Ave, Cleveland, OH 44114

⁴City of Cincinnati, 805 Central Avenue, Cincinnati, Ohio 45202

Abstract

Firefighters are exposed to toxic environments upon entering burning structures. Many structures contain synthetic materials which release toxic chemicals when on fire. These chemicals can enter the body through multiple routes of exposure, including inhalation and skin absorption. Thus, according to the fire departments included in this study, firefighters now conduct on-site decontamination procedures to remove hazardous chemicals, including polycyclic aromatic hydrocarbons from the surface of firefighter turnout gear. Several methods are being practiced at the local level, including decontamination with soap and water, and decontamination with water alone. The water-only decontamination method requires less time and supplies yet has not been investigated as a suitable method for removing polycyclic aromatic hydrocarbons from turnout gear. Therefore, we evaluated the efficiency of this method by measuring polycyclic aromatic hydrocarbon (PAH) concentration levels before and after water-only decontamination. The calculated efficiency displays the percentage of PAHs removed (or not removed) at post-decontamination in relation to the initial sample collected at pre-decontamination. The turnout gear was sampled after live residential structure fires. Firefighter turnout gear was worn throughout Attack, Overhaul Search and Rescue, and Rescue from Fire operations. All firefighters came to a central location for sampling after completing their job responsibilities. Water only decontamination did not appear to be effective, resulting in an overall 42% increase in PAH contamination. The unexpected increase may have been due to disparate pre and post-decontamination sampling sites on turnout gear.

Keywords

Contamination; washing; PAHs; volatile organic compounds; firefighting; personal protective equipment

* Author to whom correspondence should be addressed: Tel: +1-513-558-0571; fax: +1- 513-558-2263; Tiina.Reponen@uc.edu.

INTRODUCTION

Firefighters are exposed to numerous toxic chemicals during firefighting activity and overhaul. Fires occur in buildings filled with furniture, carpet, insulation, and other items containing synthetic materials. Toxic fumes are emitted when synthetic materials burn and have the potential to lead to serious health impacts.^[12] Polycyclic aromatic hydrocarbons (PAHs) and volatile organic compounds (VOCs) are known byproducts from burning synthetic materials. A study characterizing smoke exposure during various structural firefighting activities showed that firefighters are exposed to toxic gases. The study identified several chemical species that are either known or suspected potential carcinogens.^[5]

PAHs are molecules composed of linked benzene rings with H-atoms or other radicals saturating the outer bonds of peripheral carbon atoms.^[3] Heavy exposure to PAHs has been linked to an increased risk of developing lung, skin, and bladder cancer.^[2] Studies have found PAH carcinogens on firefighters' body surfaces and personal protective equipment. Skin absorption is thought to be a major exposure route for PAHs.^[11]

Firefighters are at increased health risks of simultaneous exposure to multiple chemicals.^[1] Therefore, fire departments have implemented post-fire decontamination procedures. The decontamination procedures are designed to reduce the concentration levels of contaminants, such as PAHs from the surface of firefighter turnout gear.

Decontamination options include wet decontamination, air decontamination, and dry decontamination methods. Fent et al. recently studied the efficiency of these three decontamination methods. The study determined that decontamination conducted by using soap and water mixture was effective at removing 85% of contaminants. Dry brush decontamination was found to be effective at removing 24% of contaminants, while air-based decontamination resulted in an increase of 0.5% of contaminants. Dish soap is known to contain surfactants. The surfactants in the dish soap surround lipid molecules which allow water to remove contaminants from the turnout gear effectively.^[6] Many fire departments have implemented water-only decontamination procedure because it requires less time and supplies than the other methods. No studies to date have evaluated the efficiency of water only decontamination procedures.

The purpose of this study was to determine the efficiency of water-only decontamination method on firefighters' turnout gear. This study used firefighting turnout gear that had recently been in live structure fires. The study focused on PAHs for surface testing.

METHODS

Study Population

Data collection took place between February and March of 2018. Data were collected in two different cities with the aid of two separate fire departments. The participating fire departments included Cleveland, OH and Independence, KY. All firefighting turnout gear used in this study came from live structure fires. Twenty-four suits and two fire hoods were

sampled for PAHs before and after water-only decontamination. This study was determined to be non-human subject by the University of Cincinnati IRB.

Decontamination

Participating fire departments notified the study team when they had post-fire gear ready for decontamination. Each department had their gear removed from service. The gear was brought to a nearby central location (respective fire station) for decontamination and sampling.

The decontamination procedure used in this study was the same at both fire departments. The gear was placed on the ground and thoroughly rinsed with water from a gardening hose. Firefighters did not wear the gear during decontamination.

Wipe Sampling

Wipe samples were analyzed using U.S. Environmental Protection Agency method 8270. Wipe samples (10 cm × 10 cm) were collected using cotton gauze wetted with hexane before and after water-only decontamination. The PAH compounds tested for included 1-methylnaphthalene, 2-methylnaphthalene, acenaphthene, acenaphthylene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, carbazole, chrysene, dibenzo(a,h)anthracene, dibenzofuran, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, naphthalene, phenanthrene, and pyrene. Pre-decontamination samples were collected from the forearm area of firefighter turnout gear. Post-decontamination samples were collected from the right shoulder of firefighter turnout gear.^[4]

Two fire hoods were also included in this process. Pre-decontamination samples were collected from the right of the hood's neck. The fire hoods were then decontaminated with water. Post-decontamination samples were collected from the middle of the hood's neck after decontamination. All samples collected from the hoods were below the detection limit.

Fifty-two wipe samples were collected between pre-decontamination and post-decontamination wipes. All analyzed PAH species were non-detectable in 11 pairs of pre- and post-decontamination samples. This resulted in 22 of the 52 wipe samples being below the detection limit.

Efficiency of Water-only Decontamination

Firefighter turnout gear was wiped before and after decontamination. The firefighters responsible for extinguishing the structure fires (n=24) were equipped with the turnout gear that was sampled. Three separate job tasks were completed: 1. Attack Line, 2. Overhaul/Search and Rescue, and 3. Rescue from Fire. Each firefighter had varying responsibilities depending on their assigned job tasks. Table 1 provides a summary of information for samples collected during stage one.

Firefighters on Attack Lines were responsible for making the initial entry and extinguishing the fire from the inside. Two hoods worn by members of an Attack Line team were also sampled. Overhaul/Search and Rescue teams entered the structures after the fire had been

extinguished. The overhaul team searched for additional flames that may be an extension from the fire. This group also managed search and rescue operations. The Rescue from Fire team entered the structure fire before the fire had been extinguished. They were responsible for rescuing civilians still trapped in the structure. Structure fires utilized in this study occurred at residential locations. Firefighters reported dense smoke and heat throughout residences in each of the fires.

Twenty-one pre-decontamination and post-decontamination samples were collected from Cleveland, OH. Samples from Cleveland were collected within one hour after live structure fires had been extinguished. Firefighter turnout gear from Cleveland is regularly washed. Each station within this department is equipped with an industrial washer in the event firefighters need to clean their gear more regularly.

Three pre-decontamination and post-decontamination samples were collected from the Independence Fire District. Samples were collected 24 hours after a structure fire was extinguished. Firefighter turnout gear at the Independence Fire District is industrially washed after every fire.

Data Treatment

Percent change in total PAH was calculated to determine the efficiency of the water-only decontamination procedure. Turnout gear with PAH concentrations below the detection limit before decontamination were not used in the percent change calculation. Percent change was calculated using equation 1.

$$\frac{(Post\ Decontamination\ concentration) - (Pre\ Decontamination\ concentration)}{(Pre\ Decontamination\ concentration)} * 100 \quad (1)$$

Total PAHs were calculated by summing up all the concentrations of individual PAHs separately for pre-decontamination and post-decontamination data.

Only PAHs that had detectable concentrations were included in the calculation of total PAHs. When evaluating the concentrations of calculated total and individual PAHs, data points below the detection limit ($LOD = 0.20 \mu g/100 \text{ cm}^2$) were substituted with $LOD/2$.^[8]

RESULTS

A median reduction of 76% and 5% of PAH contamination was observed for firefighters' gear on Attack Line teams (three sets of gear) and Overhaul Search and Rescue teams (six sets of gear), respectively. However, a median increase of 170% was found for the gear on the Rescue from Fire team (six sets of gear). The overall percent difference was found to be a 42% increase in PAH contamination (Table 2).

Total PAH concentration values were calculated for each job task. Total PAH contamination from highest to lowest by job task are as follows: Rescue from Fire, Overhaul Search and Rescue, and Attack Line.

Figure 1 provides a summary of median total PAH concentrations by job task. Results from gear worn by firefighters responsible for Rescue from Fire operations showed a median pre-decontamination concentration of $0.91 \mu\text{g}/100 \text{ cm}^2$ and a median post-decontamination concentration of $3.3 \mu\text{g}/100 \text{ cm}^2$. Results from Overhaul Search and Rescue gear showed a median pre-decontamination concentration of $0.39 \mu\text{g}/100 \text{ cm}^2$ and a median post-decontamination concentration of $0.14 \mu\text{g}/100 \text{ cm}^2$. The respective results from Attack Line gear were $0.18 \mu\text{g}/100 \text{ cm}^2$ and $0.14 \mu\text{g}/100 \text{ cm}^2$.

The median total PAH increased by $2.4 \mu\text{g}/100 \text{ cm}^2$ after the water-only decontamination on the gear used by the Rescue from Fire teams (six sets of gear; zero initial non-detects). The decontamination of the gear on Overhaul Search and Rescue teams (12 sets of gear; 6 initial non-detects) resulted in a median total PAH decrease of $0.25 \mu\text{g}/100 \text{ cm}^2$. The decontamination of the gear on Attack Line teams (six sets of gear; three initial non-detects) resulted in a median total PAH decrease of $0.03 \mu\text{g}/100 \text{ cm}^2$.

Differing job tasks had similar composition of PAHs in the wipe samples collected from firefighter turnout gear (Figure 2). The individual PAH concentrations for the gear on the Attack Line team showed a minor decrease after decontamination (Figure 2A). No observable change was seen in the PAH concentrations for the gear on the Overhaul Search and Rescue team (Figure 2B). In contrast, almost all displayed PAH concentrations increased in the gear worn by the Rescue from Fire team (Figure 2C).

DISCUSSION

The goal of this study was to investigate if water-only decontamination was effective at removing PAH contamination from the surface of firefighter turnout gear. Results from gear that was worn during Overhaul Search and Rescue and Attack Line procedures showed a decrease in the PAH concentration. However, the Rescue from Fire group results showed a substantial increase in PAH concentration. An overall median increase was 42% when data from all procedures were included.

Rescue from Fire turnout gear had a higher total PAH concentration compared to the other two groups both before and after decontamination. While the median percent decrease calculated for the gear worn by the Attack Line team was efficient (-75%), only three sets of turnout gear were included in the analysis. Furthermore, the total PAH concentration levels on the gear worn by the Attack Line team was less than half of that compared to the gear worn by the two other types of teams before the decontamination.

Fent *et al.* showed that on-site decontamination procedure using soap and water reduced PAH contamination on firefighter's jackets by a median of 85%.^[6] Dry brush decontamination resulted in 23% reduction whereas blowing air on the gear resulted in 0.5% increased contamination. In their study, the median PAH concentrations before the decontamination ranged from 0.31 to $9.3 \mu\text{g}/100 \text{ m}^2$, depending on the type of activity and number of fires. These are comparable to the levels measure in our study.

Firefighters are reportedly positive about the notion associated with post-fire decontamination processes.^[7] These positive reports were mainly referring to showering

after a fire. The extra time the decontamination process would take was a reported concern.^[7] The soap-water decontamination would take minimal extra time compared to water-only decontamination. It is recommended that firefighters should include soap during on-site decontamination procedures.

Fire departments have their gear laundered for a more complete decontamination process. Depending on the fire department, firefighters have their gear laundered at different time intervals, varying from after every live fire response to biannually. Some fire departments give firefighters the option to have their gear washed on a more regular basis. Firefighters often exercise this option if they had recently faced an especially hazardous fire.

A study conducted by Stull et al. determined that the laundering procedure affects the ability of the gear to resist water penetration for a non-breathable moisture barrier material.^[13] Thus, the more frequent laundering could directly affect the service life of the gear. On-site decontamination methods are useful in that they offer a level of decontamination without reducing the functional ability of the gear.

Our results show that the water-only decontamination is not an efficient method to remove contamination from firefighter turnout gear. This was most evident with the most contaminated gear. While it is not likely that water increased the contamination level, it likely did not remove much or any contamination from the gear. The observed increase between pre and post wipes could be explained by the disparate locations from which the samples were collected.

Chemicals that appeared in each group include pyrene, phenanthrene, chrysene, fluoranthene, benzo(a)anthracene, and benzo(b)fluoranthene. Each of the listed PAHs can pose serious health hazards, including bronchitis, irritation, dyspnea, and potentially cancer. Chrysene and benzo(a)anthracene are both suspected carcinogens. While benzo(b)fluoranthene is a possible carcinogen, and it is recommended that fluoranthene be regulated as a carcinogen.^[9]

A limitation of this study is that it is currently unknown if certain areas of firefighter turnout gear have higher chemical concentrations than others. The increased levels post-decontamination could be due to the spatial variability in contamination in the two sample locations. The forearm was selected as the primary wiping zone because if the hexane from the wetted wipes dripped onto the sleeve, it would further remove PAH contamination from the gear. There is a likelihood that the shoulder area on the turnout gear has a higher concentration of chemicals compared to that of the forearm. However, the same sampling procedure was used throughout this study to avoid bias.

Another limitation of this study is the unknown efficiency of the sampling method used. The surfaces sampled were not from a flat or solid surface. It is possible that not all PAHs were collected from the wiped surfaces. However, both pre-decontamination and post-decontamination wipes had this same limitation.

CONCLUSIONS

The water-only decontamination procedure is not an effective on-site decontamination method. In contrast, using soap and water has been shown to be successful at removing PAH contamination from firefighter turnout gear.^[6] Soap contains surfactants which are effective at removing lipid soluble PAHs. Future studies should include examination of the hot spots of chemical concentrations on firefighter turnout gear.

RECOMMENDATIONS

Fire departments should adopt a soap and water decontamination method instead of water-only. Further research should be conducted to determine if certain areas on firefighter turnout gear are more heavily contaminated with chemicals than others. This information would help to target the decontamination onto high areas with the highest contamination.

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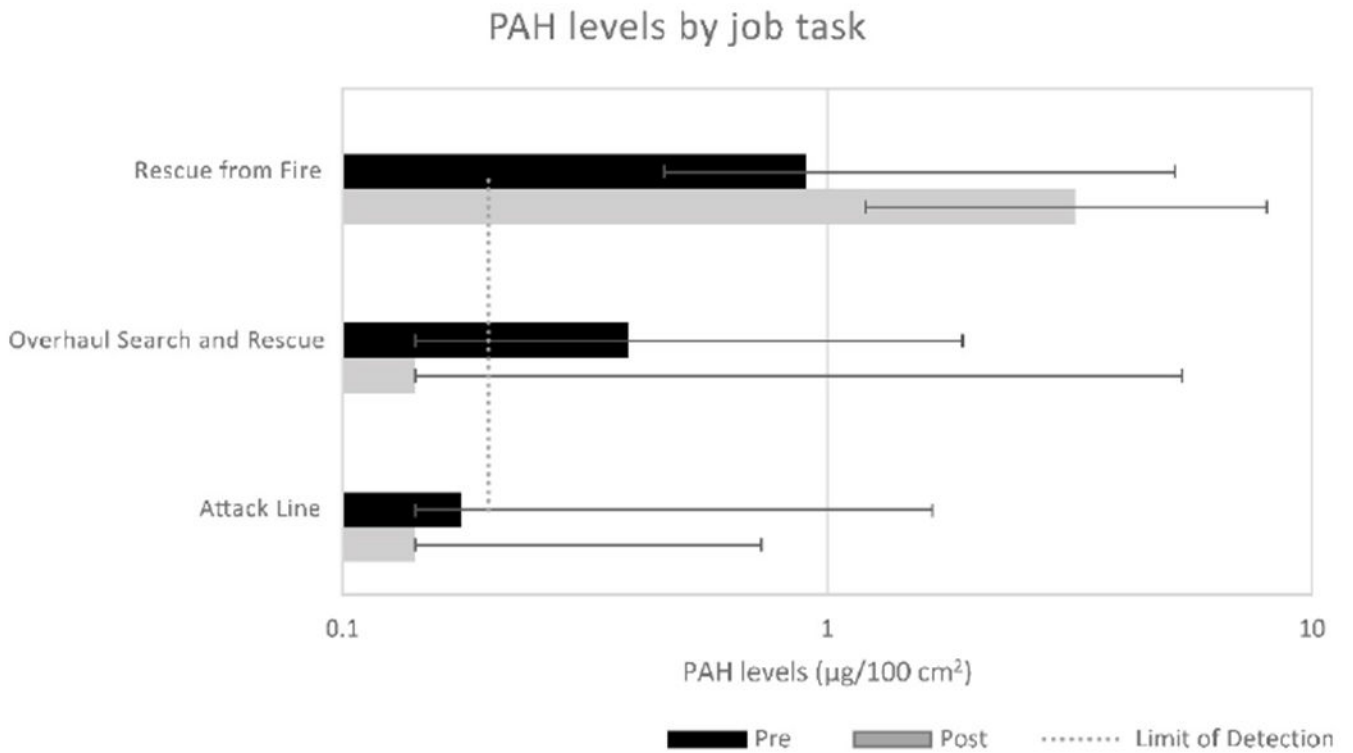


Figure 1: Summary of median total PAH concentration of analyzed contaminants organized by Attack Line firefighters (n = 6); Overhaul Search and Rescue firefighters (n = 12); Rescue from Fire firefighters, (n = 6). The median, and maximum values are displayed for concentration measured before and after the decontamination.

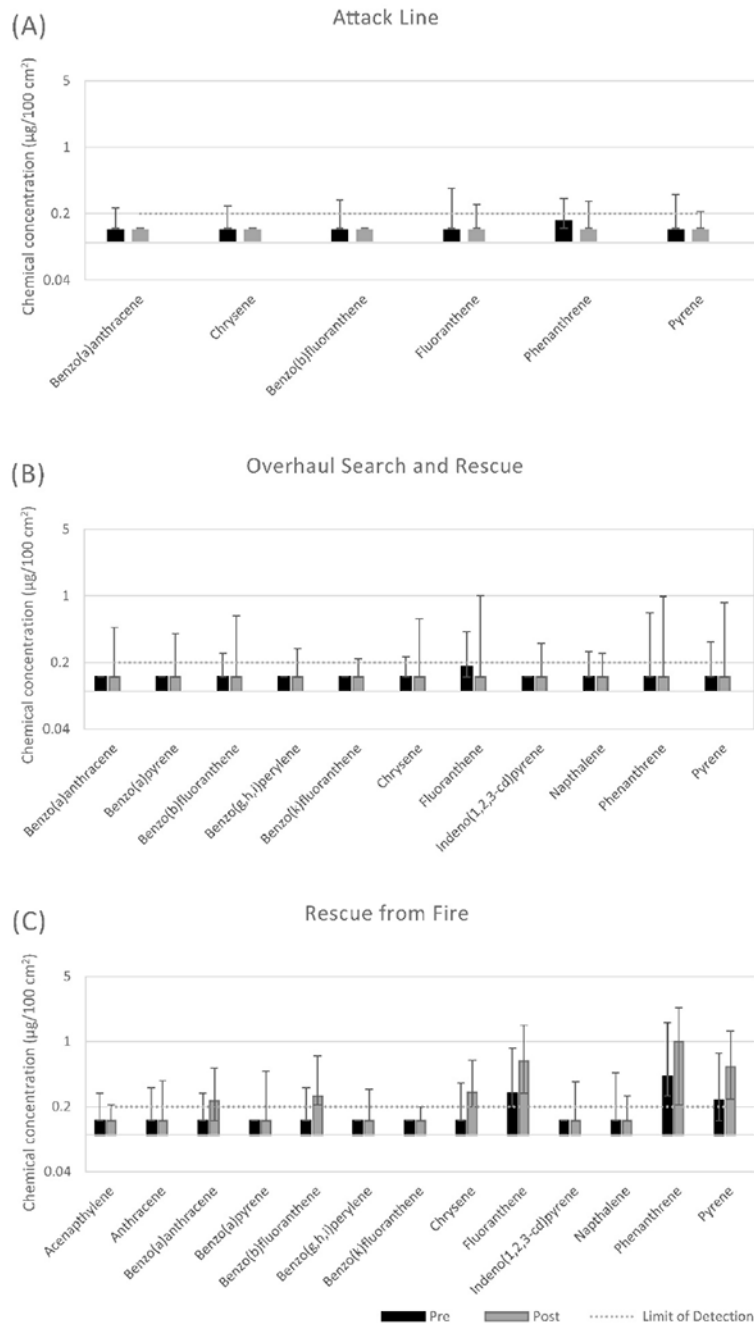


Figure 2: Summary of median PAH levels for the occurring chemicals collected from the gear worn by (A) the Attack Line firefighters (n = 6); (B) Overhaul Search and Rescue firefighters (n = 12); (C) Rescue from Fire firefighters (n = 6). The median and maximum values are displayed for chemical concentrations before and after the decontamination.

Table 1.

Description of wipe samples.

Sampling information	Sampling periods	Number of samples	Analytes	Sampling method
Efficiency of water-only decontamination (wipe samples)				
Attack Line	Pre-decon	6	PAHs	EPA method 8270
	Post-decon	6		
Overhaul/Search and rescue	Pre-decon	12	PAHs	EPA method 8270
	Post-decon	12		
Rescue from Fire	Pre-decon	6	PAHs	EPA method 8270
	Post-decon	6		
Fire hoods	Pre-decon	2	PAHs	EPA method 8270
	Post-decon	2		

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Table 2.

The percent difference (%) in total PAH concentrations in firefighters' gear between pre and post decontamination.

Job assignment	N	Median	Maximum decrease	Maximum increase
Attack line	6	-76	-248	100
Overhaul search and rescue	12	-5	-744	100
Rescue from fire	6	170	-1159	38
All tasks combined	24	42	-1159	100

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