# Understanding Firefighter's Dermal PAH Exposure on Hands During Demobilization Based on Various Types of Gloves

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## Abstract

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In June 2022, the International Agency for Research on Cancer (IARC) classified firefighting as a carcinogenic occupation due to strong evidence linking it to increased cancer in humans, with exposure to polycyclic aromatic hydrocarbons (PAHs) identified as a likely contributor. Although PAH exposure during fire suppression is well-documented, less is known about exposure during demobilization tasks like rolling hoses, cleaning, and stowing contaminated gear. Current best practices lack clear PPE guidelines for these activities, especially regarding glove use. This study evaluated dermal PAH exposure on firefighters' hands during demobilization and compared effectiveness of structural, leather and nitrile layered leather gloves. Dermal samples from 45 firefighters were collected during live fire training at WA State Fire Training Academy using 70% isopropyl alcohol wipes and analyzed by GC-MS/MS. Nitrile layered gloves were the most effective during demobilization, limiting on-hand PAH exposure to 0.33 $\mu g/m^2$, compared to significantly higher exposures with leather gloves (1.31 $\mu g/m^2$) and structural gloves (2.56 $\mu g/m^2$). Cross contamination from structural gloves contributed to increased PAH levels, emphasizing the importance of using clean gear after gross decontamination. Thorough gross decontamination reduced PAH exposure by an average of 1.92 $\mu g/m^2$, underscoring the role of best practices in minimizing dose and duration of exposure. Nitrile layered leather gloves reduced lifetime cancer risk associated with benzo(a)pyrene, a Group 1 carcinogen, to 0.15 per million, significantly lower than leather glove (0.74 per million) and structural gloves (1.45 per million). Although dermal PAH exposures measured during demobilization were lower than during fire suppression, firefighters still face exposure to carcinogenic PAHs. These findings highlight the protective benefits of nitrile layered leather gloves and the importance of effective

decontamination practices. To mitigate PAH exposure and associated cancer risks, fire departments can consider adopting nitrile layered leather gloves and implementing training and oversight to ensure effective and consistent implementation of gross decontamination procedures. Recognizing variability in exposure levels, broader engagement with fire services is also essential to refine and implement these recommendations at scale.

## Dedication

I would like to dedicate this work to my parents for their unconditional love and sacrifice for me and because of you I was able to finish my academic journey successfully. My deepest appreciation to my parents. I will be thankful forever.

## Acknowledgment


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Thank you for the opportunity join the live fire training. You welcomed us and helped us in the field for dermal sampling in every aspect.

<u>Department of Environmental and Occupational Health Science (DEOHS)</u>

I am grateful to Elena Austin, my research mentor, for helping me get through and finish my master's program.

Thanks to Marty and Chris for helping me whenever I need some advice since my undergraduate at University of Washington. I am grateful for both of you serving as my thesis committee.

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# 1. Introduction

## 1.1 Firefighters' Elevated Cancer Risk

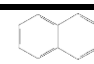
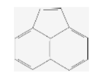
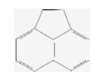
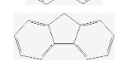
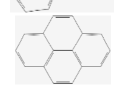
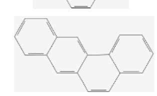
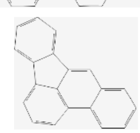
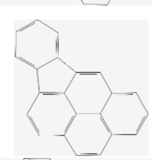
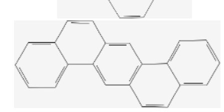
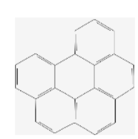
In June 2022, the International Agency for Research on Cancer (IARC) classified occupational exposure of firefighters as carcinogenic to humans (Group 1) [1]. Numerous studies in the United States and internationally have reported an elevated risk among firefighters, linked to the complex nature of their occupational exposure [1–6]. The exposure involves chemical, biological, physical, and psychological hazards arising from the diverse activities in which firefighters engage [7].

*Lee et al.* analyzed 38 published research papers from 1978 to 2022 and found that firefighters face a significantly higher incidence of cancer such as skin melanoma, other skin cancers, and prostate cancer [6]. Similarly, *LeMaster et al.* reviewed 32 studies and reported elevated risks of multiple myeloma, lymphoma, and testicular cancers compared to the general population [3]. These findings underscore the multiple and often life-threatening hazards faced by firefighters directly related to the performance of their professional duties.

## 1.2 The Role of Polycyclic Aromatic Hydrocarbons (PAHs)

Among these hazards, polycyclic aromatic hydrocarbons (PAHs) are a major contributor to cancer risk of firefighters [1,7]. PAHs are chemical compounds composed sorely of carbon and hydrogen, structured as two to six fused aromatic rings [8]. They are formed through the incomplete combustion of organic materials such as coal, gas, wood, and solid waste. While over 100 PAHs have been identified [9], the United States Environmental Protection Agency (EPA) has designated 16 PAHs as high-priority pollutants due to their hazardous properties. The International Agency for Research on Cancer (IARC) further categorized these

**Table 1**: List of 16 Priority Polycyclic Aromatic Hydrocarbons (PAHs) and their carcinogenic group classified by IARC. Group 1: Carcinogenic to humans; Group 2A: Probably carcinogenic to humans; Group 2B: Possibly carcinogenic to humans; Group 3: Not classifiable as to its carcinogenicity to humans. [10–13]

| | **PAHs** | **PAH Abbreviation** | **Carcinogenicity Group by IARC** | **Molecular Weight (g/mole)** | **Structure** |
|---|---|---|---|---|---|
| 1 | Naphthalene | NPH | 2B | 128 |  |
| 2 | Acenaphthylene | ACY | 3 | 152 |  |
| 3 | Acenaphthene | CAN | 3 | 154 |  |
| 4 | Fluorene | FLU | 3 | 166 |  |
| 5 | Phenanthrene | PHN | 3 | 178 |  |
| 6 | Anthracene | ATR | 3 | 178 |  |
| 7 | Fluoranthene | FLT | 3 | 202 |  |
| 8 | Pyrene | PYR | 3 | 202 |  |
| 9 | Benzo(a)anthracene | B(a)A | 2B | 228 |  |
| 10 | Chrysene | CRY | 2B | 228 |  |
| 11 | Benzo(b)Fluoranthene | B(b)F | 2B | 252 |  |
| 12 | Benzo(k)Fluoranthene | B(k)F | 2B | 252 |  |
| 13 | Benzo(a)pyrene | B(a)P | 1 | 252 |  |
| 14 | Indeno(1,2,3-cd)pyrene | I(123cd)P | 2B | 276 |  |
| 15 | Dibenzo(a,h)anthracene | D(ah)A | 2A | 278 |  |
| 16 | Benzo(g,h,i)perylene | B(ghi)P | 3 | 276 |  |

PAHs into Group 1 (carcinogenic to humans), Group 2A (probably carcinogenic to humans), and Group 2B (possibly carcinogenic to humans) carcinogens [11,12]. Detailed information about these PAHs is presented in Table 1.

### 1.3 PAH Exposure in Firefighters

Firefighters are exposed to PAHs throughout their working hours. PAHs, as byproducts of combustion, are predominantly encountered at fire scenes during fire suppression and related activities [7]. However, exposure persists even outside of active operations, as PAHs are semi-volatile or non-volatile chemicals [14], that can remain on the skin and surfaces for extended periods.

During fire suppression operations, firefighters wear personal protective equipment (PPE) or turnout gear to protect themselves, such as self-contained breathing apparatus (SCBA), helmet, hood, structural firefighting gloves, and insulation of multiple layers of clothing [7,15–17]. Despite this, multiple studies have identified PAH accumulation on firefighters' skin, particularly on the hands, wrists, neck, and face even with PPE in use [18–23]. In addition, there are concerns related to cross contamination from used gear as various studies found elevated concentrations of PAHs on the gear of firefighters after fire suppression [18–20].

Contamination is not limited to gear. PAHs have been detected in fire engines [19,24,25] and fire stations [25] with sources including diesel exhaust and inadequately decontaminated firefighting equipment. This cross contamination may contribute to prolonged PAH exposure during non-fire suppression activities [19,24]. Biomarker studies have confirmed PAH absorption in firefighters, detecting metabolites in urine samples even when full protective ensembles were used during fire suppression [20,23,26,27]. These findings suggest dermal absorption as a critical pathway for PAH exposure, underscoring the importance of mitigating skin contact to reduce cancer risk. [20,23,26].

### 1.4 Post Fire Suppression Activities and Protocols

Post fire suppression contamination of turnout gear and equipment exacerbates dermal PAH exposure, necessitating decontamination measures. It also may contribute to prolonged PAH exposure in firefighters [18–26]. Gross decontamination removes hazardous contaminants with water or brushes before firefighters take off their turnout gear [15,16,28]. Demobilization follows, encompassing tasks such as cleaning contaminated equipment, rolling hoses, and reloading firefighting gear into fire engines. [29,30].

Despite the importance of these post fire suppression activities, research on PAH exposure has predominantly focused on the fire suppression phase. This leaves a significant knowledge gap regarding the best practices to reduce risks associated with gross decontamination and demobilization. These phases are critical, as firefighters often handle contaminated equipment without the respiratory protection used during active fire suppression.

Reflecting this lack of research focus, existing protocols for demobilization lack clear guidelines on the selection of PPE. The Washington State Council of Fire Fighters (WSCFF) recommends removal of structural gloves after gross decontamination and utilization of medical or nitrile gloves for subsequent tasks [16]. Nitrile gloves are specifically recommended for use during packaging of firefighting gear after fire suppression and cleaning PPE in fire stations to reduce dermal PAH exposure; however, the recommendations do not extend to demobilization [16]. Similarly, the National Fire Protection Association (NFPA) provides general guidance for demobilization but does not specify the appropriate glove types for mitigating dermal PAH exposure [29]. The absence of detailed and evidence-based recommendations leaves firefighters vulnerable to continued PAH exposure during this critical phase.

To address these deficiencies, the study aims to investigate dermal PAH exposure on firefighters' hands during demobilization. It evaluates the protective effectiveness of different types of gloves: structural, leather, and nitrile layered leather gloves. It also provides evidence-based recommendations to mitigate dermal PAH exposure and associated health risks.

### 1.5 Preliminary Studies

Two studies were conducted concurrently with this research, which aimed to investigate the optimal practices for glove usage to mitigate firefighters' cancer risk during demobilization. *Gilbertson's* study investigated the current glove usage practices in Washington State. It revealed that firefighters used a variety of gloves, including structural, leather, and nitrile gloves, during the demobilization process, likely due to ambiguous standards and the absence of clear recommendations regarding the most appropriate glove type for this phase [30]. The study also found that increased awareness through education and explicit guidelines could promote the use of suitable gloves by firefighters during demobilization [30].

*Lykins'* study investigated the usability of different types of gloves for demobilization tasks, focusing on structural, leather, and nitrile layered leather gloves. The nitrile layered leather gloves were not a single glove but consisted of two layers: nitrile gloves worn underneath leather gloves. This layered glove approach provided better performance in terms of dexterity, control and comfort for the tasks simulating demobilization compared to structural gloves in laboratory settings [31]. The study concluded that nitrile layered leather gloves performed best in these controlled conditions and their implementation is likely feasible, given the familiarity and availability of leather and nitrile gloves [31].

Together, the findings of *Gilbertson* and *Lykins* identified a lack of clarity in existing protocols for selecting appropriate gloves during demobilization. They also emphasize the absence of definitive recommendations for gloves that offer superior protection from dermal PAH exposure. Notably, nitrile layered leather gloves had better usability and comfort than structural gloves in laboratory settings and were the most effective among the options tested. Building on these results, this research investigates dermal PAH exposure during demobilization, evaluates the impact of various glove types (structural, leather, and nitrile layered leather gloves) on exposure, and aims to determine the most suitable gloves for demobilization tasks by addressing the following research questions (RQ):

**RQ1: Are firefighters exposed to dermal PAHs during demobilization?**

**RQ2: Is dermal PAH exposure different based on the selection of gloves?**

**RQ3: What type of gloves are appropriate for demobilization tasks?**

### 1.6 Significance of the Study

This research addresses a critical gap in firefighter safety protocols by quantifying dermal PAH exposure during demobilization and assessing the protective efficacy of different glove types. The study's findings will provide evidence-based recommendations for glove selection for demobilization tasks, contributing to the reduction of cancer risks associated with occupational PAH exposure. By focusing on a previously overlooked phase of firefighting, this research enhances our understanding of cumulative exposure risks and offers practical solutions to improve firefighters' health outcomes.

## 2. Methods

### 2.1 Recruitment and Initial Screening

The University of Washington (UW) research team collaborated with the Pierce County Fire Training Consortium (PCFTC), which comprises five fire departments in Pierce County, Washington [32]. The PCFTC is responsible for training newly hired firefighters and conducting live fire training exercises. The training took place at the Washington State Fire Training Academy (FTA) near North Bend, Washington. The FTA is a facility that offers fundamental and essential training for newly recruited firefighters to attain the National Fire Protection Association (NFPA) 1001 Firefighter Professional Qualifications [29].

Live fire training exercises are critical for preparing recruits to handle real-world fire scenarios. The FTA features burn buildings designed to replicate residential and commercial buildings, [33] which are intentionally ignited using wood pallets for controlled training purposes. The live fire training lasts for two days per academy, with each day divided into an AM and PM session. During each training session, participating firefighters were divided into squads which consisted of approximately four trainees. Each squad was assigned to a different type of building, either commercial or residential. Instructors oversaw fire suppression procedures and demobilization, while each trainee squad was rotated through the tasks. Gross decontamination and demobilization activities were performed at the end of each session.

The PCFTC worked closely with the research team to plan the study, organizing key aspects of the procedures for this study including training date, participant roster, training location, squad formation and assigning tasks, and many other critical aspects of live fire training. To plan for each data collection event, the UW research team was provided with information from the PCFTC including number of participants in the training, the detailed schedule of the training, and the glove sizes of the participants.

To recruit participants and to obtain consent, the research team provided an initial recruitment email template and a link to Research Electronic Data Capture (REDCap) platform [34,35] hosted at the UW Institute of Translational Health Sciences [36]. These materials were shared with the firefighter Chief overseeing the training, who then disseminated the recruitment emails to trainees. The recruitment materials included details about the UW research team, objectives and procedures of the study, potential risks and benefits of participation, measures for maintaining confidentiality, funding sources for the research, and reminders on the voluntary nature of participation (Appendix A).

To be eligible to participate, fire training academy recruits were required to meet the following criteria:

- Be at least 18 years old.
- Be affiliated with fire departments in Pierce County and PCFTC, with current or future full-time employment status.
- Not have smoked cigarettes containing tobacco in the seven days prior to sampling.

Participants who had smoked cigarettes were excluded because smoking generates PAHs that can persist on hands, potentially interfering with accurate assessment of dermal PAH exposure during demobilization [37,38]. Eligible participants completed the REDCap survey and provided informed consent electronically (Appenix B). To ensure study procedures and risks were fully understood, on the first day of live fire training at FTA, the UW research team had the opportunity to verbally explain the research to the firefighters. At the end of the briefing, it was emphasized that participation in the research was voluntary.

The study procedures and REDCap survey components were reviewed by the UW Institutional Review Board (IRB). The IRB determined that the research posed minimal risk to participants and therefore did not require written consent forms. Despite this, comprehensive information about the study was communicated with firefighters through multiple channels to ensure participants understood their rights and could decline participation if desired.

### 2.2 Dermal Wipe Sample Strategy

To quantify on-skin PAH exposure during demobilization activities, a wet sampling method was employed to enhance collection efficiency [39]. Previous studies investigating dermal PAH exposure also utilized wet sampling media [40–44]. These studies used either 70% isopropyl alcohol [40,41,43] or corn oil [42,44] as the wetting media. Although there are many advantages to corn oil as a wetting agent, *Fent et al.* reported that due to the complex chemical matrix of corn oil, several peaks generated by corn oil overlapped with the peaks produced by PAHs. Consequently, the researchers were unable to analyze for total PAHs and had to select six PAHs as a metric for the dermal wipe samples [44]. One concern in using isopropyl alcohol is the relatively low solubility of PAHs in alcohol [45]. However, despite this, 70% isopropyl alcohol was selected for this study because the focus was on the 16 PAHs designated as primary pollutants by the EPA [12], and this approach had been previously reported in this context. The samples were collected using Medique Medi-First™ Alcohol Prep-Pad Wipes (70% isopropyl alcohol), with pre-analysis of the wipes to ensure no background interference (LOT number JT18520 and 306724).

The UW research team collaborated with the PCFTC to conduct dermal sampling during two live fire training sessions at the FTA in North Bend, Washington. The first training occurred on February 4$^{th}$-5$^{th}$, 2023, with 21 firefighters participating, and the second training on August 7$^{th}$-8$^{th}$, 2024, involving 24 newly recruited firefighters.

Each training spanned two days, with multiple fire suppression evolutions conducted during four sessions. After each session, participants performed gross decontamination and demobilization procedures. The key objective of the research during training sessions included:

1) Investigating dermal PAH contamination from cross contamination caused by used structural gloves.

2) Assessing the efficacy of gross decontamination procedures.

3) Evaluating dermal PAH exposure during demobilization tasks performed with structural, leather, and nitrile layered leather gloves.

To address these objectives, the research design incorporated specific sampling stages targeting cross contamination, decontamination efficacy, and glove performance during multiple live fire training sessions.

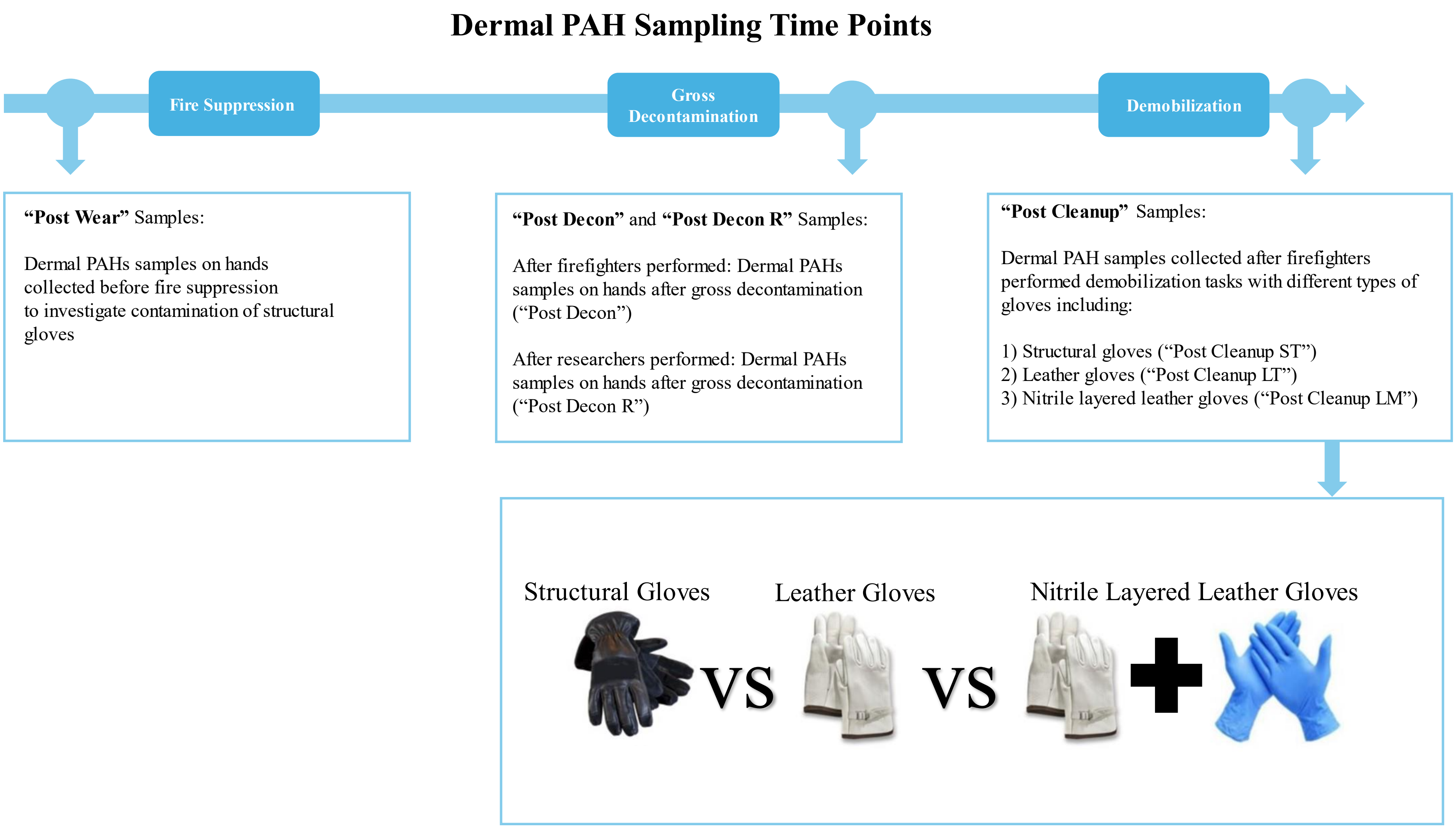
Cross contamination of the structural gloves was suspected, as it was observed that the same structural gloves were continuously worn during demobilization following fire suppression activities [46]. *Lykins* discovered that in a laboratory setting, nitrile layered leather gloves worked best for firefighters during demobilization compared to structural gloves or leather gloves [31] informing the investigation of this PPE option as existing dermal PAH exposure data for nitrile layered leather gloves were not available for firefighters performing demobilization tasks.

Details of the collected samples, including the number of samples obtained and their labeling are summarized in Table 2. The sampling time points, along with the description and labeling of the collected samples from two live fire trainings, are illustrated in Figure 1. Additionally, Figure 1 displays the three types of gloves—structural, leather, and nitrile layered leather gloves—used during demobilization tasks.

**Table 2**: Description, count, and label of the samples collected from live fire training

| Dates | Session | Sample Counts | Sample Description | Label |
|---|---|---|---|---|
| 2/4/23 | 1 | 10 | After gross decontamination | "Post Decon" |
| | | 10 | After wearing of used structural gloves without activities | "Post Wear" |
| | 2 | 6 | After gross decontamination | "Post Decon" |
| | | 6 | After demobilization tasks with structural gloves | "Post Cleanup ST" |
| 2/5/23 | 3 | 21 | After gross decontamination | "Post Decon" |
| | | 21 | After demobilization tasks with structural gloves | "Post Cleanup ST" |
| | 4 | 21 | After gross decontamination | "Post Decon" |
| | | 21 | After demobilization tasks with leather gloves | "Post Cleanup LT" |
| 8/7/24 | 1 | 5 | After additional decontamination with premoistened wipes by researcher | "Post Decon R" |
| | | 10 | After Demobilization Tasks with nitrile layered leather gloves | "Post Cleanup LM" |
| 8/8/24 | 2 | 2 | After additional decontamination with premoistened wipes by researcher | "Post Decon R" |
| | | 8 | After Demobilization Tasks with nitrile layered leather gloves | "Post Cleanup LM" |

**Figure 1**: Dermal PAH sampling time points, along with description and labeling of the collected samples from two live fire trainings and photos of three types of gloves utilized for demobilization tasks by firefighters



During the training occurred in February 2023, gross decontamination and dermal sampling were conducted after each session, while demobilization tasks followed in later sessions. Initially, randomization of glove assignments for demobilization tasks was planned. However, the structured nature of the training schedule and limited flexibility made randomization infeasible. Distributing specific gloves to firefighters during training was logistically challenging and risked disrupting the schedule. Consequently, a simplified approach was adopted: all firefighters in a given session wore the same type of gloves for demobilization. Structural gloves were used in Session 2 and 3, and new leather gloves were in Session 4. Participants were provided with new leather gloves of appropriate size (Majestic 1509 Cowhide Drivers Glove with Wrist Strap).

The sampling that occurred in August 2024 was built on findings from the first sampling, incorporating additional decontamination methods and nitrile layered leather gloves to expand the dataset. Gross decontamination and demobilization tasks were performed only at the end of each day, per instructions from training instructors. Researchers also administered additional decontamination using premoistened wipes, and samples collected at this stage were labeled as "Post Decon R". To streamline the process and maximize efficiency, only the dominant hand of firefighters was sampled, reducing collection time without compromising data quality. Additional samples were collected after firefighters performed demobilization tasks while wearing nitrile layered leather gloves (Leather gloves were Majestic 1509 Cowhide Drivers Gloves with Wrist Strap and nitrile gloves were Fisherbrand Comfort Nitrile Gloves with 9.5 inch of length, 2.8 mil of palm thickness and 3.5 mil of finger thickness). These samples, labeled as "Post Cleanup LM", provided data on dermal PAH exposure associated with this specific glove type. By incorporating nitrile layered leather gloves into the study, the research team addressed a gap existing data on the efficacy of these gloves in mitigating dermal PAH exposure during demobilization tasks.

These procedural adaptations across both training sessions enabled the collection of a comprehensive dataset on dermal PAH exposure while addressing practical limitations of live fire training.

### 2.3 Quantification of Dermal PAH Samples

The collected dermal PAH samples were submitted to the Environmental Health Laboratory at the University of Washington (UW) Department of Environmental and Occupational Health Science (DEOHS) for quantification of PAHs. At the sampling site, the collected samples were stored in a temperature-controlled container with dry ice, transported to the University of Washington, and stored in a freezer at -20 degrees Celsius to maintain sample integrity [47].

Quantitative analysis of collected dermal PAH samples was conducted using methods similar to those described by *Cherry et al.* Dermal samples were placed in amber salinized glass vials with 4 mL of hexane/acetone (3:1 v/v) and subjected to sonication for 30 minutes to extract PAHs [40]. The extract was filtered using a 0.2 µm PTFE filter disc and transferred to 2 mL salinized GC vials for analysis by GC-MS/MS [40]. *Stec et al.* also employed a comparable methodology for the quantification of dermal PAH samples, which included extraction of samples via hexane/acetone solution (3:1 v/v), sonication for 30 minutes, and analysis by GC-MS [43].

Sonication for 30 minutes in hexane/acetone extraction solution (3:1 v/v) was employed because it had acceptable extraction efficiency, proved more cost-effective, and offered greater operational simplicity compared to the Soxhlet extraction, which is one of the primary standard methods for extracting PAHs [48,49]. Furthermore, *Yamaguchi et al.* revealed that ultrasonic extraction is an efficient, reliable, and environmentally sustainable approach for recovering PAHs from a solid matrix compared to the Soxhlet extraction technique. Additionally, they found that a solvent mixture of acetone and hexane provided adequate extraction efficiency [49]. Following a comprehensive review of relevant studies, we established our methodology for extracting dermal PAH samples. The protocol involved utilizing an extraction solution comprising hexane and acetone (3:1 v/v), subjecting the samples to sonication for 30 minutes, filtering them through a 0.2 µm PTFE filter disc, and conducting analysis via GC-MS/MS.

To ensure the precision and accuracy of the analysis, comprehensive quality assurance (QA) and quality control (QC) measures were implemented. Field blanks were collected at the sampling sites to ascertain the absence of background PAHs. A minimum of one blank field sample was obtained for each live fire training session. Along with the dermal PAH samples, the field blank and matrix blank, which were 70% isopropyl alcohol wipes without sampling, were analyzed to ensure absent of background PAH concentrations. Dermal PAH samples were adjusted by subtracting the values of the field blank or matrix blank from the values of the samples. Moreover, spike QC samples and internal standard solutions were analyzed. The percent recovery and coefficient of variance for the 16 PAHs were calculated to ensure the validity of the analysis. Linearity of the internal standard solutions was determined to validate the analysis. The QA/QC values are presented in the Results section to ensure the validity of the GC/MS-MS analysis and integrity of dermal PAH exposure data.

## 2.4 Statistical Analysis

The Environmental Health Laboratory at UW DEOHS conducted an analysis of dermal PAH samples and reported a mass of 16 PAHs in nanograms. These results were utilized to calculate dermal PAH concentrations in units of $ng/cm^2$ and converted to $\mu g/m^2$. The total PAH concentrations were calculated as the sum of the 16 PAHs detected from the hands of the firefighters divided by the hand surface area of the participants. This calculation was based on the specific occasion on which the sample was collected, whether after wearing used structural gloves ("Post Wear"), after gross decontamination ("Post Decon"), or after performing demobilization tasks ("Post Cleanup").

The Environmental Health Laboratory established a reporting limit for 16 PAHs. Analyte masses below the reporting limit were designated as below reporting limit (BRL). For example, the reporting limit for benzo(a)pyrene is two nanograms. For statistical analysis, data values below the reporting limit were treated as zero, which may introduce a potential low bias in the dataset. The reporting limits for PAHs analyzed by the Environmental Health Laboratory are presented in Table 3.

**Table 3**: Reporting limits of PAHs

| **Analyte** | **Reporting Limits (ng)** |
|---|---|
| Naphthalene | 4 |
| 2-Methylnaphthalene | 3 |
| 1-Methylnaphthalene | 3 |
| Acenaphthylene | 0.4 |
| Acenaphthene | 0.4 |
| Fluorene | 0.4 |
| Phenanthrene | 1 |
| Anthracene | 0.4 |
| Fluoranthene | 1 |
| Pyrene | 6 |
| Benz(a)anthracene | 2 |
| Chrysene | 0.4 |
| Benzo(*)fluoranthene | 0.8 |
| Benzo(a)pyrene | 2 |
| Indeno(1,2,3-cd)pyrene | 0.4 |
| Dibenz(a,h)anthracene | 0.4 |
| Benzo(g,h,i)perylene | 0.4 |

The "Post Wear" and "Post Decon" datasets were compared to assess the cross contamination from used structural gloves. The "Post Wear" and "Post Decon" datasets were also compared with "Post Decon R" to evaluate the effectiveness of gross decontamination and the difference in the efficiency of gross decontamination performed by firefighters and by researchers. The datasets of "Post Cleanup ST", "Post Cleanup LT", and "Post Cleanup LM" were compared to examine the efficacy of gloves in mitigating dermal PAH exposure during the demobilization process. For comparison, a two-tailed t-test was performed using Microsoft Excel software. Statistical significance was determined utilizing a probability threshold of $P < 0.05$. The mean difference (MD) and its 95% confidence intervals (95% CI) were calculated as well to examine relationship between the datasets.

### 2.5 Dermal Sampling Procedures

The objective of dermal PAH sampling was to ensure that the entire surface area of participants' hand was thoroughly sampled to maximize capture of PAHs. The Surface Sampling Guidance published by the National Institute for Occupational Safety and Health (NIOSH) recommends conducting surface sampling in a "Z or S" pattern, repeated two or three times, with the sampling media folded between iterations to prevent loss of analyte and to utilize the entire surface of the media for sampling [39]. When the participants were ready for dermal sampling, they were instructed to remove their gloves according to their standard departmental procedures and to place their hands flat in front of their body, with palms facing upward. The hand surface was sampled using 70% isopropyl alcohol wipes employing an overlapping "S" pattern with horizontal strokes. The identical surface was wiped again using vertical "S" patterns to encompass the entire surface area of the hand, from the wrist to the tip of the participant's longest finger. The participants were requested to invert their hands over, and the researchers sampled the opposite side of the hand using the same technique with the folded alcohol wipes. Following the completion of sampling, we folded the wipe again, wrapped the sample in aluminum foil, and placed it in a resealable polyethylene bag. The samples were then stored in a cooler box containing dry ice and transferred to the laboratory. Prior to submission to the Environmental Health Laboratory at UW DEOHS, the samples were stored in a freezer at a temperature below -20 degrees Celsius. *Galea et al.* reported that crude oil dermal samples, including hydrocarbon samples, can be stored for up to 54 days without influencing the results, even at ambient and elevated temperatures [47]. Based on these findings, we stored the samples in a freezer upon their submission to the laboratory.

To calculate dermal PAH concentrations, it was necessary to determine the surface area of participants' hand. *Lee et al.* established a formula to calculate hand surface area based on hand length and hand circumference as presented in Eq. 1 [50]. Before

$$[\text{Eq. 1}]\ HSA = 1.219 \ * HL\ (cm) \ * HC\ (cm)$$

*HSA=Hand Surface Area; HL=Hand Length (a); HC=Hand Circumference (b)*

the training began, the participants' hand length and circumference were measured to calculate the hand surface area of all participants. The estimated hand surface area was calculated, and the results were utilized to estimate dermal PAH concentration on hands of firefighters in the data analysis.

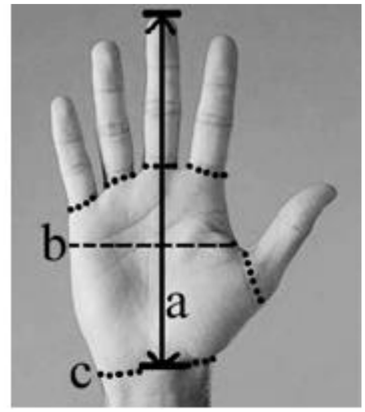



**Figure 2:** Anthropometric lines on the hand. a=Hand length (from the wrist circumference to the tip of the middle finger), b=hand circumference (Metacarpal-Phalangeal Joint Circumference), c=Wrist circumference [50]

**2.6 Lifetime Cancer Risk**

Dermal PAH exposure data were used to calculate the lifetime cancer risk associated with exposure to PAHs during demobilization for structural, leather, and nitrile layered leather gloves. Data were collected for dermal exposure to 16 PAHs. Among theses PAHs, the exposure data for benzo(a)pyrene was selected to calculate the lifetime cancer risk associated with exposure to the analyte during demobilization. Benzo(a)pyrene was selected due to its classification as Group 1 carcinogen by IARC, which indicates that the compound is carcinogenic to humans [11]. The first step in the calculation of lifetime cancer risk involved estimating the dose. The absorbed dose through dermal PAH exposure was estimated with the following formula (Eq. 2) [51]:

$$[\text{Eq. 2}]\ AD(mg/kg/day) = ((MSE\ (mg/cm^2) \ * \ HSA\ (cm^2) * AF \ * D))/(BW\ (kg))$$

*AD=Absorbed Dose; MSE=Measured Skin Exposure; HSA= Hand Surface Area; AF=Absorption Factor D=Duration (hrs) in one day; BW=Body Weight*

Measured skin exposure to benzo(a)pyrene and surface area were obtained through dermal PAH sampling during the live fire training. According to the EPA, the dermal absorption factor of benzo(a)pyrene and other PAHs from soil is 0.13 [52]. Exposure duration was defined as the number of hours of exposure per day. It was assumed that the demobilization process takes approximately one hour. *Gilbertson* conducted a survey of firefighters in Washington State, inquiring about the frequency of their dispatch for fire suppression activities within a month. The results are presented in Table 4.

**Table 4**: Average Fire Calls of Washington State Firefighters [46]

| Fire Calls | |
|---|---|
| 0-2 per month | 144 (39.6%) |
| 3-5 per month | 116 (31.9%) |
| 6-8 per month | 39 (10.7%) |
| 9+ per month | 63 (17.3%) |
| Unspecified | 2 (0.5%) |

The mean frequency of fire calls was four times per month [46]. If a firefighter is dispatched to fire calls four times a month and spends about an hour for demobilization, the firefighter is exposed to benzo(a)pyrene for about 0.13 hours a day from performing demobilization tasks. This value was used as the exposure duration in the calculations. Due to limitations in data collection, the body weights of the live fire training participants were unavailable. Consequently, an assumption was made based on the statistical average body weight of individuals in the United States aged 20 to 29. This age range was selected because the participants were firefighters in the early stages of their careers and were recently recruited for the occupation. The average body weight for males between the ages of 20 and 29 in the United States was 85.5 kg, while for females in the same age range, it was 74.9 kg [53].

After the absorbed dose was estimated, we calculated work-related lifetime cancer risk utilizing the following formula (Eq. 3) [54]:

$$[\text{Eq. } 3]\ LCR = AD\ (mg/kg/day) * CSF\ (mg/kg/day)^{-1} * D\ (yrs)/(70\ yrs)\ [3]$$

*LCR=Life Cancer Risk; AD=Absorbed Dose; CSF=Cancer Slope Factors; D=Duration*

The Cancer Slope Factor (CSF) is derived from toxicological studies and represents the cancer risk per unit dose of a carcinogen [54]. According to the Environmental Health Agency (EPA), the cancer slope factor for benzo(a)pyrene is 1 [55]. An exposure duration of 25 years within a lifespan of 70 years was assumed. The calculated lifetime cancer risk was compared with a cancer risk level of 1 in 1,000,000, which is considered an acceptable risk by the EPA [56,57]. Moreover, lifetime cancer risk was evaluated in comparison to the National Institution of Occupational Safety and Health (NIOSH) minimum level of protection for workers from carcinogens. The NIOSH considers the risk estimate of one additional cancer case per 10,000 workers over a 45 years of working period as the minimum level of protection for workers exposed to carcinogens [58]. When the calculated cancer risk resulting from exposure to benzo(a)pyrene during demobilization exceeds the acceptable cancer risk defined by the EPA or the minimum level of protection established by the NIOSH, it may indicate that such exposure poses a significant risk to firefighters and require urgent efforts to mitigate exposure [56].

Lifetime cancer risks calculated from dermal PAH exposure during demobilization were compared across the types of gloves utilized (structural, leather, and nitrile layered leather gloves). Statistical analysis was performed using two-tailed t-test in Microsoft Excel. A P-value $< 0.05$ was considered statistically significant. To further examine the relationship between the datasets, the mean difference (MD) and its 95% confidence intervals (95% CI) were calculated.

These measures provided additional insight into the magnitude and variability of differences in lifetime cancer risks associated with each glove type.

# 3. Results

## 3.1 Study Population and its Demographic Information

The University of Washington (UW) research team participated in two live fire trainings hosted by the Pierce County Fire Training Consortium (PCFTC) on February 4$^{th}$ and 5$^{th}$ of 2023 and on August 7$^{th}$ and 8$^{th}$ of 2024 to collect dermal PAH samples from firefighters to assess PAH exposure of firefighters' hands after gross decontamination and during demobilization.

A total of 45 firefighters participated in the study, consisting of 38 males and 7 females, which reflected the distribution of male and female recruits of the PCFTC (Table 5). All participants were over 18 years of age and affiliated with Pierce County Fire Departments, members of the PCFTC. One firefighter reported smoking cigarettes within a week of the live fire training; consequently, the individual was excluded from the dermal PAH exposure data analysis.

Most of the participants were right-handed (N=42), while three were left-handed. Hand measurements, including hand length and circumference, were collected to estimate the hand surface area, which was used to calculate dermal PAH concentrations. Summary statistics of participants demographic and hand measurements are presented in Table 5, and raw data can be found in Appendix C.

**Table 5**: Participants demographic information (N=45)

| | | N |
|---|---|---|
| Gender | Male | 38 |
| | Female | 7 |
| Ages over 18 | Yes | 45 |
| | No | 0 |
| Affiliated with Pierce County Fire Departments | Yes | 45 |
| | No | 0 |
| Smoking within one week of dermal PAH sampling | Yes | 1 |
| | No | 44 |
| Dominant Hand | Right | 42 |
| | Left | 3 |
| Hand Surface Area ($cm^2$) | Average | 1082.9 |
| | Range | 707.6 - 1718.8 |
| Hand Length (cm) | Average | 19.8 |
| | Range | 13.5 - 30 |
| Hand Circumference (cm) | Average | 23.3 |
| | Range | 18.5 - 25.5 |

### 3.2 Cross Contamination and Gross Decontamination

Dermal PAH samples collected from the hands of firefighters at different stages to evaluate contamination due to cross contamination from used structural gloves ("Post Wear") and the effectiveness of gross decontamination performed by firefighters ("Post Decon") and by researchers ("Post Decon R").

**Table 6**: Concentrations of dermal PAH exposure after wearing used structural gloves and gross decontamination

| | **Post Wear (N=10)** | **Post Decontamination by Firefighters (N=56)** | **Post Decontamination by Researcher (N=7)** |
|---|---|---|---|
| Mean ($\mu g/m^2$) | 3.51 | 2.60 | 0.68[a, b] |
| Median ($\mu g/m^2$) | 2.52 | 1.78 | 0.56 |
| Standard Deviation | 5.03 | 6.57 | 0.11 |

[a]Statistical significant from "post wear" data set by two-tailed t-test ($P < 0.01$)
[b]Statistical significant from "post decontamination" data set by two-tailed t-test ($P < 0.01$)

For "Post Wear" samples, the mean on-skin PAH concentration was 3.51 $\mu g/m^2$ (n =10). The mean dermal PAH exposure of "Post Decon" samples were 2.60 $\mu g/m^2$ (n = 56). We further investigated whether decontamination by researchers produced different on-skin PAH exposure compared to decontamination by firefighters. We found significantly lower concentrations on their hands after decontamination performed by researchers ("Post Decon R") with mean on-skin PAH concentrations of 0.68 $\mu g/m^2$ (n = 7). The results of these tests, along with the associated sample sizes and statistical significance testing results are presented in Table 6.

Statistical analyses were performed to compare the dermal PAH concentrations across these datasets. A two tailed t-test comparing "Post Wear" and "Post Decon" datasets showed no statistically significant difference in PAH concentrations on hands after wearing used structural gloves and after gross decontamination conducted by firefighters ($p > 0.05$, MD = 0.91 μg/m$^2$, 95% CI [-2.96, 4.78]). This finding suggests that gross decontamination performed by firefighters slightly reduced dermal PAH exposure, but the reduction was not statistically significant.

Comparisons involving “Post Decon R” samples, however, revealed significant reductions in dermal PAH concentrations. Two-tailed t-test supported the conclusion that PAH concentrations after gross decontamination performed by researchers (“Post Decon R”) were significantly lower than those in the “Post Wear” dataset ($p < 0.001$, MD = 2.83 μg/m$^2$, 95% CI [-0.77, 6.43]) and the “Post Decon” dataset ($p < 0.001$, MD = 1.92 μg/m$^2$, 95% CI [0.16, 3.68]). These results demonstrate the greater efficacy of gross decontamination conducted by researchers in reducing dermal PAH exposure compared to gross decontamination performed by firefighters.

In summary, the findings indicate that while gross decontamination conducted by firefighters provided some reduction in dermal PAH exposure, it was not statistically significant. By contrast, gross decontamination performed by researchers resulted in a substantial and statistically significant reduction in dermal PAH concentrations, emphasizing the need for improved decontamination protocols to better mitigate dermal PAH exposure after fire suppression activities.

### 3.3 Dermal PAH Exposure During Demobilization

Dermal PAH samples were collected during demobilization from two live fire trainings to evaluate dermal PAH exposure while firefighters wore different glove types, including structural, leather, and nitrile layered leather gloves. A total of 25 samples were obtained for structural gloves ("Post Cleanup ST), 20 samples for leather gloves ("Post Cleanup LT") and 18 samples for nitrile layered leather gloves ("Post Cleanup LM").

The mean concentration of dermal PAH exposure during demobilization while wearing structural gloves was 2.56 $\mu g/m^2$. For leather gloves, the mean concentration was 1.31 $\mu g/m^2$, and for nitrile layered leather gloves, it was significantly lower at 0.33 $\mu g/m^2$. The detailed descriptive statistics for dermal PAH exposure during demobilization based on glove type, including median values and standard deviations, are presented in Table 7.

**Table 7**: Concentrations of dermal total PAH exposure during demobilization based on the different glove types

| | **Structural Gloves (N=25)** | **Leather Gloves (N=20)** | **Nitrile Layered Leather Gloves (N=18)** |
|---|---|---|---|
| Mean ($\mu g/m^2$) | 2.56 | 1.31$^{c}$ | 0.33$^{c, d}$ |
| Median ($\mu g/m^2$) | 2.50 | 0.79 | 0.27 |
| Standard Deviation | 1.33 | 1.38 | 0.03 |

$^{c}$Statistical significant from structural glove data set by two-tailed t-test ($P < 0.001$)
$^{d}$Statistical significant from leather glove data set by two-tailed t-test ($P < 0.01$)

Two-tailed t-tests were conducted to compare the dermal PAH exposure across the different glove types during the demobilization process, and dermal PAH exposure while wearing nitrile layered leather gloves was significantly lower than that of structural gloves ($p < 0.001$) and leather gloves ($p < 0.01$). The mean difference in dermal PAH exposure between structural gloves and nitrile layered leather gloves was 2.23 μg/m$^2$ (95% CI [1.68, 2.78]). The difference between leather gloves and nitrile layered leather gloves was 0.98 μg/m$^2$ (95% CI [0.34, 1.63]). These findings conclude that there are significant differences in dermal PAH exposure associated with wearing nitrile layered leather gloves compared to structural and leather gloves during demobilization. A box plot (Figure 3) was generated using the dermal PAH exposure data for the structural, leather, and nitrile layered leather gloves to visually represent these differences.

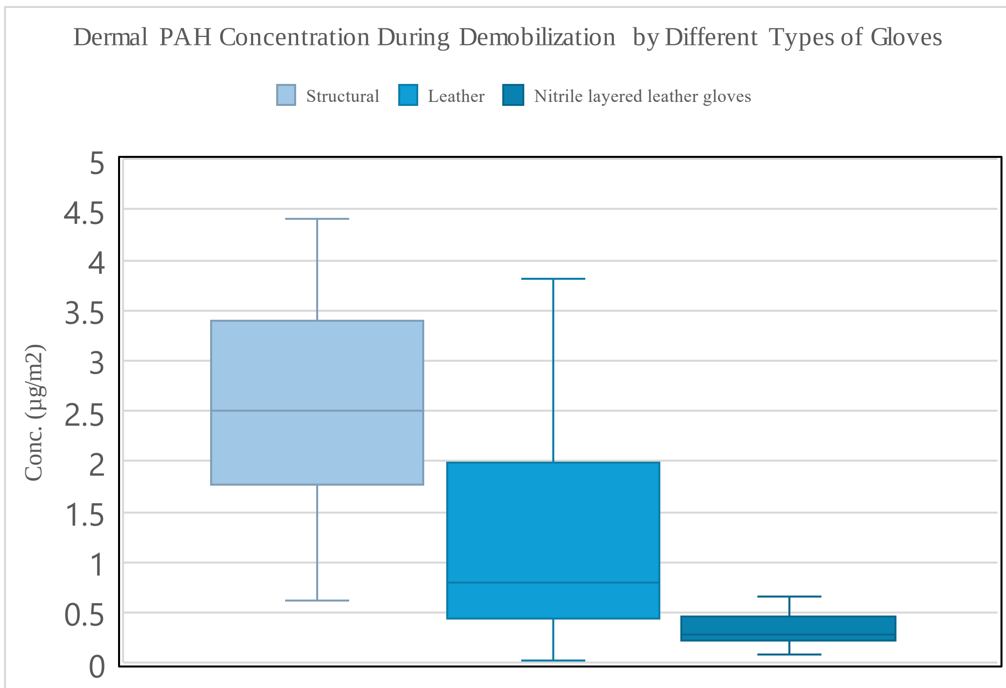


**Figure 3**: Box Plot for Dermal PAH Concentration During Demobilization Performed by Different Types of Gloves

### 3.4 Lifetime Cancer Risk

Lifetime cancer risk was calculated to estimate the risk of firefighters' dermal exposure to benzo(a)pyrene during demobilization in relation to the types of gloves worn during the process. The risk is presented as risk per one million.

The lifetime cancer risk associated with wearing structural gloves during demobilization was 1.45, while the risk for leather gloves was 0.74. The lifetime cancer risk for nitrile layered leather gloves was significantly lower at 0.15. Descriptive statistics of lifetime cancer risk based on different types of gloves are presented in Table 8.

The lifetime cancer risk from wearing structural gloves during demobilization exceeded the acceptable cancer risk set by the EPA, though it remained below the minimum level of protection for workers established by NIOSH. In contrast, the lifetime cancer risks associated with wearing leather gloves and nitrile layered leather gloves were below the standards set by both the EPA and NIOSH [56–58].

**Table 8**: Lifetime cancer risk from exposure to benzo(a)pyrene during demobilization based on different glove types (Risk is presented as a risk per one million)

| | **Structural Gloves (N=25)** | **Leather (N=20)** | **Nitrile layered leather gloves (N=18)** |
|---|---|---|---|
| Mean | 1.45 | 0.74[e] | 0.15[e, f] |
| Median | 1.48 | 0.46 | 0.14 |
| Standard Deviation | 0.45 | 0.37 | 0.0081 |

[e]Statistical significant from structural glove data set by two-tailed t-test ($P < 0.001$)
[f]Statistical significant from leather glove data set by two-tailed t-test ($P < 0.001$)

To further assess the differences in lifetime cancer risk across the glove types, statistical comparisons were conducted using two-tailed t-tests. A significant difference in lifetime cancer risk was found between structural gloves and leather gloves ($p < 0.001$), with the risk associated with structural gloves being higher by 0.71 (95% CI [0.47, 0.96]). Similarly, the lifetime cancer risk associated with nitrile layered leather gloves was significantly lower than that of both structural gloves ($p < 0.001$) and leather gloves ($p < 0.001$). The difference in lifetime cancer risk between structural gloves and nitrile layered leather gloves was 1.3 (95% CI [1.11, 1.49]), while the difference between leather gloves and nitrile layered leather gloves was 0.59 (95% CI [0.42, 0.76]).

The results highlight the reduction in lifetime cancer risk achieved by wearing nitrile layered leather gloves compared to structural or leather gloves during demobilization. This finding underscores the effectiveness of nitrile layered leather gloves in mitigating cancer risks associated with dermal exposure to benzo(a)pyrene from performing demobilization tasks.

To further illustrate the differences in lifetime cancer risk across glove types, a box plot (Figure 4) was generated using the dermal exposure data for structural, leather, and

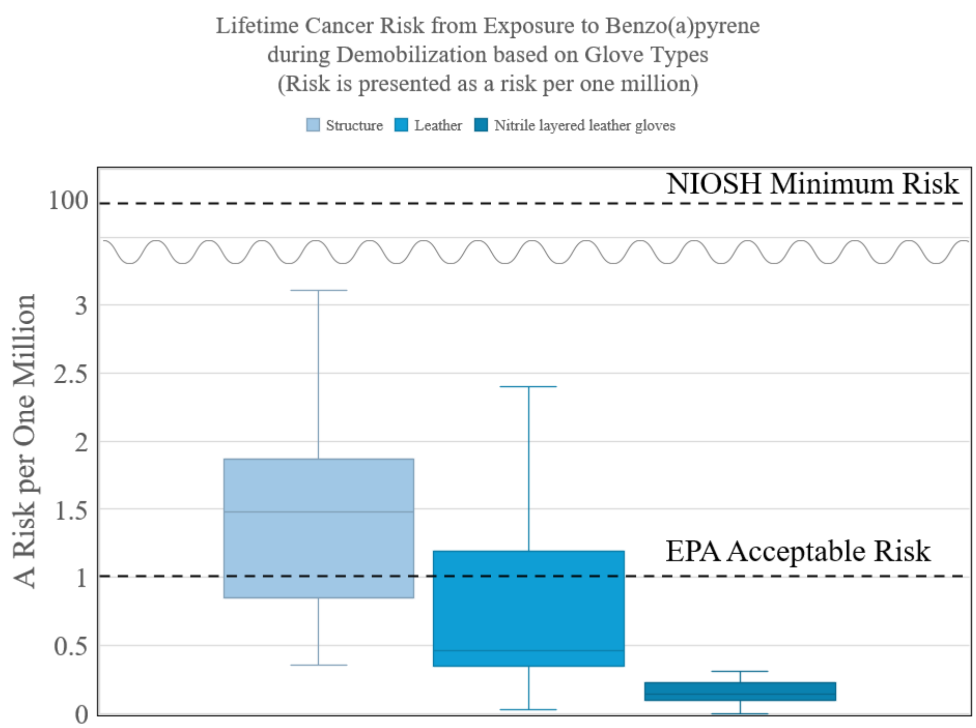



**Figure 4**: Lifetime cancer risks from exposure to benzo(a)pyrene during demobilization based on the types of gloves

nitrile layered leather gloves. All raw dermal PAH sample data used in the analysis are provided in Appendix D for reference.

### 3.5 QA/QC for Quantification Analysis of PAHs

Quality assurance (QA) and quality control (QC) methods were implemented to ensure the validity and reliability of the quantification analysis of dermal PAH samples collected during the study.

For the first round of dermal PAH sample analysis, the percentage recovery of spike QC samples for the 16 PAHs ranged from 79.1% to 110.2%. The coefficient of variance ranged from 1.6% to 4.2%. The linearity of the internal standards ranged from 0.9994 to 1.

Similarly, in the second round of dermal PAH sample analysis, the percentage recovery of spiked QC samples for the 16 PAHs ranged from 88.3% to 103%. The coefficient of variance ranged from 1.6% to 4.4%. The linearity of the internal standards ranged from 0.9997 to 1.

These QA/QC values fell within the acceptable range and confirmed that the PAH analysis for this study was valid and reliable [59]. Raw data for QA/QC metrics is provided in Appendix E.

## 4. Discussion

This study represents the first quantification of dermal PAH on firefighters' hands during demobilization. The detection of PAHs on firefighters' hands after demobilization tasks confirmed that dermal exposure occurs during this phase. Previous studies measured PAH concentrations on hands after fire suppression, with results ranging from 15.9 to 46.9 $\mu g/m^2$ [44,60]. In some cases, significantly higher concentrations, ranging from 135 to 226 $\mu g/m^2$, were observed [42]. This study concludes that firefighters face dermal PAH exposures during demobilization, although the overall exposure is lower than during fire suppression. Recognizing this dermal PAH exposure is essential for implementing effective measures to mitigate the associated health risks.

### 4.1 Cross Contamination and Gross Decontamination Efficiency

Dermal PAH samples were collected from firefighters' hand after wearing previously used structural gloves for ten minutes without engaging in fire suppression activities ("Post Wear") and after performing gross decontamination using premoistened wipes performed by firefighters ("Post Decon"). These samples were compared to assess the level of PAH contamination in structural gloves and the effectiveness of gross decontamination. Statistical analysis revealed no significant difference between the two samples ($p > 0.05$), indicating that structural gloves may serve as a source of PAH contamination. This finding suggests that firefighters can be exposed to PAHs even when not actively engaged in fire suppression activities due to cross contamination from structural gloves.

The Cross contamination from structural gloves was consistent with findings from previous studies, which detected PAHs on firefighters' hands after fire suppression [40,42,44,60].

*Bank et al.* further measured PAHs on the outer, middle, and inner layers of structural gloves [61]. This finding suggested that dermal PAH exposure on hands remains unavoidable despite the use of firefighting gear.

The mechanism of PAH exposure through structural gloves during fire suppression remains unclear. One hypothesis is that the seal around the wrists of structural gloves is insufficient, allowing PAH contaminated water to come into contact with the hands, resulting in dermal PAH exposure. Alternatively, the deterioration of the moisture barrier between the inner and outer layers of the structural gloves may increase permeability [42]. *Stull et al.* reported that laundering structural gloves negatively affected their ability to resist water penetration [62,63], potentially creating an exposure pathway for PAHs despite the use of protective gear.

Observations from this study indicated comparable PAH concentrations on firefighters' hands after wearing structural gloves and after performing gross decontamination. In Washington State, gross decontamination procedures is mandated prior to removing firefighting ensembles following the completion of fire suppression [15]. This process involves eliminating potentially hazardous chemicals from the gear by removing large debris through brushing, followed by the application of water [16]. The Washington State Council of Fire Fighters (WSCFF) also recommends the best practice of cleaning hands with water and soap or disposable wipes to reduce chemical exposure after removing structural gloves following gross decontamination [16]. The participants in the first live fire training followed these best practices and conducted gross decontamination of their hands utilizing premoistened wipes. Despite following these best practices, elevated PAH concentrations were observed on firefighters' hands, prompting researchers to evaluate the efficacy of gross decontamination performed by researchers as opposed to trainees in subsequent training sessions.

Samples collected gross decontamination performed by researchers (“Post Decon R”) revealed significantly lower PAH concentrations compared to those of “Post Wear” and “Post Decon” samples. The use of premoistened wipes by researchers improved decontamination efficacy, even in the absence of water at the sampling site. The findings support the best practices put forward by the WSCFF guidance but suggest the importance of administrative controls such as training to support this practice. These findings align with previous studies showing that water and soap are the most effective for PAH removal from skin, although hand wipes can also significantly reduce dermal PAH exposure [21,42,63]. *Keir et al.* reported that premoistened wipes reduced PAH concentrations by 23%, while water and soap achieved a 47% reduction [64]. Similarly, *Fent et al.* found that premoistened wipes reduced PAH contamination by 54% [42]. In this study, gross decontamination performed by researchers using disposable wipes achieved an approximately 75% reduction in PAH concentrations.

Our findings revealed that previously used structural gloves contributed to dermal PAH exposure through cross contamination. To mitigate this risk, structural gloves should be removed immediately after gross decontamination. Additionally, the results showed that gross decontamination performed by firefighters was not always effective in reducing dermal PAH exposure, while decontamination conducted by researchers showed much greater efficacy. This emphasizes the importance of implementing administrative controls, such as training and oversight, to ensure optimal outcomes.

To reduce PAH exposures following gross decontamination, firefighters should thoroughly and carefully cleanse their hands with water and hand soap or using premoistened wipes. This is consistent with the WSCFF best practices. Future work should consider the best administrative controls to ensure these steps are followed and effective.

### 4.2 PAH Exposure During Demobilization Based on Types of Gloves

Dermal PAH samples were collected from firefighters during live fire training to evaluate PAH exposure on their hands while wearing different types of gloves—structural, leather, and nitrile layered leather gloves—during demobilization. The results of this study revealed dermal PAH concentrations during demobilization were lower compared to those reported in other studies analyzing PAH concentrations on hands after fire suppression, which ranged from 15.9 to 226.0 $\mu g/m^2$ [27,40,42,44,60,64].

The higher PAH concentrations observed in previous studies are likely due to the substantial quantities of PAHs generated during fire suppression activities. In contrast, this study focused on dermal PAH exposure during demobilization, a phase characterized by lower overall exposure. Additionally, live fire training exercises utilized wood pallets as fuel, which are considered relatively clean burning compared to fires in real-world scenarios that may contain other combustible materials, such as plastics, solid waste, and assorted building materials. This difference further explain the low PAH concentrations observed on hands during demobilization. Despite the lower levels of exposure, firefighters were still exposed to carcinogenic PAHs during demobilization. Therefore, implementing changes to reduce exposure during this phase is critical for mitigating the associated health risks.

Dermal PAH exposure while wearing leather gloves ("Post Cleanup LT") was lower than the exposure from structural gloves ("Post Cleanup ST"), with the difference being statistically significant ($p < 0.001$). The mean difference in PAH concentrations between structural gloves and leather gloves was 1.25 $\mu g/m^2$, suggesting that contamination of structural gloves may have contributed to this variance. These findings suggest leather gloves may reduce PAH exposure, but it's unclear if this is due to their inherent protection or measured cross contamination from structural gloves. Consequently, a definitive conclusion regarding the comparative efficacy of leather gloves in mitigating dermal PAH exposure during demobilization could not be drawn.

In contrast, nitrile layered leather gloves exhibited substantially lower PAH concentrations on the hands of firefighters during demobilization compared to those wearing structural gloves ($p < 0.001$) and leather gloves ($p < 0.01$). The additional nitrile layer was effective in reducing dermal PAH exposure on the hands during demobilization tasks. Analysis of PAH concentrations across the three glove types revealed that firefighters were exposed to PAH regardless of the type of gloves worn. However, the magnitude and significance of the long-term exposure varied depending on the glove type.

Nitrile layered leather gloves exhibited the lowest PAH concentrations during demobilization compared to structural and leather gloves, making them the most effective option for mitigating dermal PAH exposure. Additionally, these gloves maintained comfort and usability for demobilization. Previous research by *Lykins* found that nitrile layered leather gloves provided better comfort, precision, and control in laboratory settings compared to structure gloves [31]. Based on our findings and those of *Lykins'* research, nitrile layered leather gloves represents the optimal choice for demobilization tasks, combining effective PAH protection with comfort and usability.

Of note, researchers did observe in field deployment that the nitrile gloves made the participants' hands clammy. While the additional nitrile layer effectively prevented dermal PAH exposure, it also restricted the evaporation of sweat, leading to clamminess of the hands during demobilization. Although the participants did not report significant discomfort related to clammy hands at the sampling sites, the potential long-term usability of this solution remains unclear. Further discussion with firefighters are needed to address these potential disadvantages and refine recommendations for the implementation of nitrile layered leather gloves in demobilization tasks.

### 4.3 Lifetime Cancer Risk from Exposure to Benzo(a)pyrene during Demobilization

The lifetime cancer risk was calculated to estimate the risk of exposure to benzo(a)pyrene during demobilization. The results aligned with the comparison of dermal PAH exposure across different glove types, as both analyses were based on the same datasets. Statistically significant differences in lifetime cancer risk were observed between structural gloves and leather gloves. However, due to cross contamination from structural gloves, it was not possible to conclusively determine whether leather gloves offered a reduction in lifetime cancer risk compared to structural gloves during demobilization.

On the other hand, the use of nitrile layered leather gloves could significantly reduce lifetime cancer risk compared to both structural and leather gloves. The risk associated with wearing nitrile layered leather gloves was significantly lower than that of wearing other types of gloves during demobilization. Based on these findings, nitrile layered leather gloves are recommended for demobilization tasks, as they reduce dermal PAH exposure, decrease lifetime cancer risk, enhance comfort compared to structural gloves, and improve usability in laboratory-based testing.

When comparing the calculated cancer risk with standards set by regulatory agencies, the risk of wearing structural gloves during demobilization exceeded the acceptable level established by the EPA. However, it remained below the threshold set by the NIOSH for occupational settings. It is important to note that the calculated lifetime cancer risk was derived solely from the exposure to benzo(a)pyrene during demobilization. Among the 16 PAHs analyzed in the dermal samples, some of the other reported analytes were classified as probably carcinogenic to humans (Group 2A) and possibly carcinogenic to humans (Group 2B) by the IARC. For example, Dibenz(a,h)anthracene is classified as a Group 2A carcinogen. Naphthalene, chrysene, benzo(a)anthracene, benzo(*)fluoranthene, and indeno(1,2,3-cd)pyrene are Group 2B carcinogens [11,65]. The inclusion of these additional carcinogens in the risk calculations could significantly elevate the estimated lifetime cancer risk for firefighters.

This study also assumed that firefighters respond to an average of four fire calls per month, spending approximately one hour on demobilization tasks for each call. The lifetime cancer risk would increase proportionally with more frequent fire responses or extended time spent on demobilization tasks. The calculations were intentionally conservative, and intentionally targeting a limited set of assumptions. Thus, demonstrating a significant reduction in overall cancer risk from this one change in best practices is more meaningful. Furthermore, demobilization constitutes only one component of the comprehensive fire suppression process. When considering the lifetime cancer risk associated with the entire process, the cumulative lifetime cancer risk of firefighters may exceed the minimum level of protection from carcinogens established by NIOSH. This consideration contributes to the IARC's classification of firefighter as a Group 1 occupation, carcinogenic to humans, due to various hazards encountered in both fire and non-fire events [1].

This study shows that firefighters face PAH exposure during demobilization, although there are at lower levels than during fire suppression. These exposures result in measurable increase in lifetime cancer risk, when PPE and decontamination procedures are not applied optimally. Simple modifications in glove usage during demobilization can mitigate this risk. The use of nitrile layered leather gloves during demobilization significantly reduces dermal PAH exposure, providing a straightforward yet effective intervention. The same principle applies to gross decontamination, where thorough use of premoistened wipes can reduce dermal PAH exposure when intentionally and carefully performed.

Administrative controls, such as training, education, and oversight can play a crucial role in promoting the adoption of effective practices during gross decontamination and demobilization. Implementing these changes through coordination with fire service partners could help protect firefighters from exposure to carcinogens and lower their lifetime cancer risk. Despite the relatively lower PAH exposure during demobilization compared to fire suppression, the exposure remains significant and actionable.

Consequently, the use of nitrile layered leather gloves is strongly recommended for demobilization tasks to mitigate lifetime cancer risk. Although no prior studies have specifically addressed dermal PAH exposure or lifetime cancer risks during demobilization, based on these results, such risks exist and can be meaningfully reduced. Nitrile layered leather gloves should therefore be considered a vital component of demobilization protocols to protect firefighters from harmful exposure.

### 4.4 Limitations and Strengths

Nitrile layered leather gloves were effective in reducing dermal PAH exposure during demobilization. However, during the sampling process, the research team observed that nitrile gloves made the hands of firefighters clammy. Although this did not significantly affect demobilization tasks, the possible disadvantages of an additional layer of nitrile gloves should be considered prior to the implementation of this practice. Further discussions with firefighters are necessary to refine the recommendations and ensure practicality and acceptability in real-world settings.

Another limitation of this study was the variability in the generation of PAHs during live fire training. The quantities of PAHs produced from the combustion of wood pallets for training purposes could not be standardized while maintaining the training objectives of the event, leading to possible variations in firefighters' exposure across different sessions. This inherent variability may have influenced the results. Additionally, while randomizing glove types for use during demobilization was initially planned, time constraints and training objectives of the academy made randomization infeasible. As a result, firefighters were assigned specific gloves for each session, which could introduce bias in the comparison. The comparison presented above of our results, as compared to previously published data, suggests that this limitation did not significantly bias our findings.

The study also relied on 70% isopropyl alcohol as a wetting agent for dermal PAH sampling, despite the limited solubility of PAHs in alcohol [45]. While alternatives such as corn oil offer better capture of PAHs, their complex background interferes with GC/MS analysis, making them unsuitable for analyzing all 16 priority pollutant PAHs [44]. Given this constraint, 70% isopropyl alcohol was selected as the most viable option, despite its limitations, to ensure consistent analysis of all 16 target PAHs.

Despite these limitations, this study had several notable strengths. The researchers collaborated with the fire services and fire departments to develop the research questions and to conduct dermal PAH sampling during live fire training exercises. This collaboration ensured the study's alignment with the real-world experience of firefighters, who were exposed to many hazards. Firefighters often lack guidance on the appropriate timing for removing structural gloves after gross decontamination and the selection of suitable gloves for demobilization tasks. Current best practices for demobilization provide limited recommendations regarding appropriate personal protective equipment (PPE). This study addresses these gaps by providing evidence-based recommendations on glove selection to reduce dermal PAH exposure during demobilization and lower the associated lifetime cancer risk.

Additionally, the study developed laboratory methodologies for analyzing PAHs in samples with high carbon content in collaboration with UW DEOHS Environmental Health Laboratory. Traditional Soxhlet extraction, approved by the EPA for PAH analysis, is recommended for samples containing excessive carbon [49]. However, this method requires a substantial volume of organic solvents, an extensive extraction period of 12 to 20 hours, and intensive staffing. This resulted in elevated costs and would have significantly reduced the ability to analyze samples cost effectively [49]. In contrast, the methodologies employed in this study, sonication for 30 minutes in a hexane/acetone solution (3:1 v/v), addressed this limitation without significantly impacting the comparability of our results with other published literature. Future studies, particularly within Washington State, can adopt this analytical approach to enhance the efficiency and sustainability of PAH analysis.

### 4.5 Possible Future Research

This research supported the use of the additional protective layer provided by nitrile gloves in reducing dermal PAH exposure during demobilization. While this study focused on dermal PAH exposure on hands during demobilization, further research should be considered to explore other routes of exposure to PAHs, including ingestion and inhalation. Investigating these additional pathways would provide a more comprehensive understanding of firefighters' PAH exposure during demobilization and contribute to enhanced protective measures for firefighters.

Future research could also investigate the use of nitrile layered structural gloves during fire suppression operations. Work by *Everaert et al.* has shown that nitrile gloves can provide effective protection against contaminants during fire suppression activities [66,67]. Although no scientific literature directly addresses the use of nitrile gloves underneath structural gloves, firefighters in Belgium have adopted this practice due to nitrile gloves' resistance characteristic to water and various hazards [67–69].

However, the practice of wearing nitrile gloves beneath structural gloves poses potential risks. *Everaert et al.* noted that nitrile gloves beneath structural gloves might increase the risk of severe burns during fire suppression. Despite this, in their estimation, the incidence of burn injuries caused by nitrile gloves was infrequent in Belgium, and the associated risk was deemed to be acceptable by the Belgium firefighters currently adopting this practice [67].

The use of nitrile gloves underneath structural gloves is not widely adopted by firefighters other than the Belgium case reported above. However, this practice could offer significant benefits in reducing dermal PAH exposures caused by cross contamination from structural gloves. Structural gloves may become contaminated with PAHs as they are used for an increasing number of fire calls [61] or when not adequately decontaminated after utilization. Adding a layer of nitrile gloves could mitigate this exposure, although in the context of other firefighting tasks not considered in this work such as fire suppression, there is an increased risk of severe burn injuries.

While only one scientific study has explored the added protection provided nitrile gloves under structural gloves during fire suppression, the findings highlight the potential of this practice to reduce dermal PAH exposure. Future research should include a comprehensive risk assessment of nitrile gloves used in this context to weigh their protective benefits against the risk of burn injuries. Such investigations could guide the adoption of this practice and reform safety standards. This could only occur if the National Fire Protection Association (NFPA) would consider the evaluation and safety of wearing nitrile gloves beneath structural gloves during fire suppression. Their input is crucial to determining whether this practice should be standardized to enhance firefighter protection while minimizing associated risks.

### 4.6 Practical Recommendations for Firefighters

Based on the findings of this study, the following recommendations are proposed to mitigate dermal PAH exposure and enhance firefighter safety during demobilization:

1) **Removal of structural gloves immediately after gross decontamination decreases exposure**: Changing to a clean set of gloves during demobilization will mitigate dermal PAH exposure.

2) **Improved gross decontamination significantly reduces risk:** Current best practices are effective in reducing dermal PAH exposures. These include the use of water and hand soap or premoistened wipes to effectively reduce dermal PAH exposure. However, improved administrative controls including training and education for firefighters are necessary to ensure effective decontamination in the field [42,64]. Fire departments should also evaluate the availability and accessibility of decontamination resources, such as portable washing stations and high-quality cleansing wipes, to support these practices.

3) **Nitrile layered leather gloves can significantly decrease dermal PAH exposure and reduce lifetime cancer risks during demobilization**: The efficacy of nitrile layered leather gloves in mitigating dermal PAH exposure is superior to that of structural and leather gloves. Both leather gloves and nitrile layered leather gloves provided enhanced

comfort and usability in laboratory settings compared to structural gloves [31]. Fire departments should consider adopting nitrile layered leather gloves as standard PPE for demobilization tasks to provide firefighters with better protection against dermal PAH exposure and carcinogens.

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**Appendix A – Initial Recruitment Email Template and Information Sheet**

Subject: UW Fire Fighter Sampling Study

Dear Trainees,

The Department of Environmental and Occupational Health Sciences (DEOHS) at UW is planning to conduct a fire fighter related research project at our upcoming live fire events. The researchers at DEOHS, are partnering with local fire departments to promote and expand existing glove use best practices to mitigate firefighter cancer risk. Funding and support for this project has been provided by the State of Washington, Department of Labor & Industries, Safety & Health Investment Projects.

We are inviting you to participate in this study. The decision to participate is yours alone and information on individual participants will not be shared with the department or any other party. You are eligible to volunteer if a) you intend to participate in live fire training at the North Bend Fire Training Academy on (Date of live fire training), b) you are 18 years of age or older and c) you have not engaged in recreational smoking of tobacco or other products over the past week. Participation will help us develop better guidance and recommendations on glove use and minimize health risks to firefighters. It is critical that you complete the steps below prior to the training

The team plans to collect skin wipe samples on-site before and after clean-up activities. This will be done by rubbing the palms and back of the hands with a 70% isopropyl wipe and bringing the wipe sample back to the lab for analysis. The team will also measure and record the size of your hand.

If you are interested in participating, please follow the steps below:

Complete the study eligibility form online (Survey link). When you submit this, if you are eligible, you will automatically be asked to read and sign the study consent form (~ 5 minutes). You must read and scroll to the bottom of the consent form to sign. You can complete this on a phone, tablet or computer.

Participate in live fire training on Wednesday, August 7th and 8th.

Be available for the research coordinator to collect skin wipe samples on site. Instructions will be provided on the day of sampling.

Please see the attached flyer for additional information about the project. If you have any questions or encounter technical issues, feel free to contact the study team.

(Information of UW research team who is sending the email)

Thank you.

# Glove Use Best Practices to Mitigate Firefighter Cancer Risk

A Safety & Health Investment Project (SHIP)

Washington State Department of Labor & Industries

SHIP Grant Program — Safety and Health Investment Projects — SafetyGrants.Lni.wa.gov

Funding and support provided by the Department of Labor & Industries

## What are some of the statistics related to cancer in the fire service?

**Cancer is a threat to firefighter health and safety.**

- A recent study by the International Agency for Research on Cancer (IARC) **classified the occupation of firefighting as carcinogenic to humans** (Group 1) (IARC 2022)
- Cancer caused **66 percent** of the career firefighter line-of-duty deaths from 2002 to 2019, according to data from the International Association of Fire Fighters (IAFF)
- Firefighters have a **9 percent** higher risk of being diagnosed with cancer and a **14 percent** higher risk of dying from cancer than the general U.S. population, according to research by the CDC/National Institute for Occupational Health and Safety (NIOSH)

## What are PAHs? Why is exposure reduction important?

Polycyclic aromatic hydrocarbons (PAHs) are components of incomplete combustion. **Firefighters are exposed to PAHs during fire suppression activities.**

- Of the **18 PAHs** that are commonly produced during fires, IARC classified **benzo[a]pyrene as carcinogenic** (Group 1) and **eight others as probably or possibly carcinogenic** (Group 2A or 2B) (IARC 2002, 2010)
- Firefighters wearing full protective ensembles may still absorb PAHs into their bodies
- PPE best practices like "decon" are a key strategy to reduce PAH exposures

## PAH Exposure Reduction Strategies

In 2014, the *Healthy In, Healthy Out* best practice manual to mitigate firefighter cancer risk was developed in partnership with the Washington State Council of Fire Fighters (WSCFF), the International Association of Fire Fighters (IAFF), and the Kent Fire Department.

**It identifies best practices that will, to the greatest extent possible, reduce the risk of exposures to carcinogens for firefighting activities.** For example, preventing the cross-contamination of possible carcinogens and other harmful agents using Hazard Control Zones (**Figure 1**).

In 2016, researchers at the University of Washington were tasked with validating the efficacy of the methods presented in *Healthy In, Healthy Out*. This research found that **decontamination strategies are effective at reducing PAH exposures.**

- **Wipe washing resulted in a mean dermal PAH reduction of ~66%**
- **Soap washing resulted in a mean dermal PAH reduction ~60%**

## Current Research

Glove use choice during clean-up activities may increase PAH exposures, however the extent and importance of this is not well understood (**Figure 1**). In this phase of fireground operations, firefighter skin may be exposed to PAHs via permeation, penetration through or around gloves, or from the cross-transfer of contaminants on PPE and equipment to the skin.

**This 2-year study, funded through a LNI SHIP grant award, aims to compare PAH exposures based on glove type used while performing clean-up activities.** Using a randomized field experiment (**Figure 3**), this research will contribute to developing exposure control strategies provided in *Healthy In, Healthy Out*.

Working in collaboration with Central Pierce Fire & Rescue, Puget Sound Regional Fire Authority, and other WA fire departments, this project will build upon previous efforts to provide specific glove use best practices to promote long-term firefighter health.

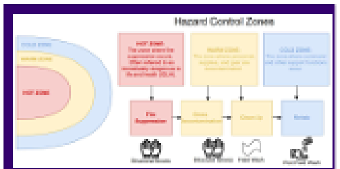

Figure 1. *Healthy In, Healthy Out* Best Practices

### Building on *Healthy In, Healthy Out*

**Current glove use best practices:**

> Use of structural gloves in IDLH (NFPA 1971)

> Post-fire "gross decon" of structural gloves using dry or wet mitigation techniques (NFPA 1851)

> Advanced cleaning of gear (NFPA 1851)

**Research Gap:**

Notably, these recommendations assume structural firefighting gloves are used **at all times** on a fire scene, including the duration of non-fire suppression "clean up" activities like rolling hoses, inspecting tools, and loading equipment back onto a fire engine. **The question is, what if firefighters don other glove types while performing these activities?**

Key informant interviews conducted with 20 career firefighters in 2021 identified a wide range of glove use during clean up (**Figure 2**).

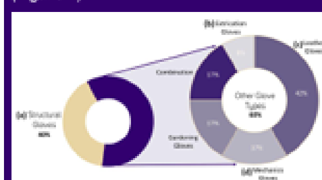

Figure 2. Reported Glove Use Post Fire Suppression

**Our Method to Address Research Needs:**

We will use skin wipe samples collected immediately following fire suppression activities to test if there is a statistical difference in dermal PAHs between firefighters who doff their structural gloves for leather gloves (the most used glove alternative) and firefighters who continue to don their structural gloves during clean up (as is standard practice) (**Figure 3**).

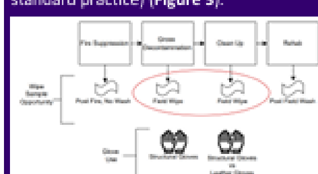

Figure 3. Wipe Sampling Protocol

This analysis will allow us to establish the degree of dermal protection afforded by structural gloves and inform current best practices to reduce firefighter cancer risk.

**Appendix B – REDCap Survey and Informed Consent Form**

ENVIRONMENTAL & OCCUPATIONAL HEALTH SCIENCES
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# Glove Study Eligibility Questions

**Welcome to the University of Washington's Glove Use Best Practices Study!**

Researchers at the University of Washington, in the Department of Environmental and Occupational Health Sciences are partnering with local fire departments to develop glove use best practices to mitigate firefighter cancer risk. Funding and support for this project has been provided by the State of Washington, Department of Labor & Industries, Safety & Health Investment Projects.

As part of this project, we will compare the degree of dermal protection afforded by standard issue gloves to carcinogenic chemicals (also known as polycyclic aromatic hydrocarbons or "PAHs"). To do this, we will collect skin wipe samples and hand surface area measurements immediately following gross decontamination ("decon") and clean up.

If you are interested in participating in our study, please answer the questions below:

**Are you 18 years of age or older?**

- ○ Yes
- ○ No

reset

**Gender Identity (select all that apply):**

- ☐ Woman
- ☐ Man
- ☐ Transgender
- ☐ Non-binary/non-conforming
- ☐ Prefer not to respond

**In the past 7 days, have you smoked or used a pipe containing tobacco or other products?**

- ○ Yes
- ○ No

reset

**Please select your fire department:**

**Please provide an email address.**

ONLY research-related communications will be sent to this email (e.g., copy of consent). This address WILL NOT be shared.

**Footer Page 1 of 4.**

ENVIRONMENTAL & OCCUPATIONAL HEALTH SCIENCES
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Survey Queue

AAA

# Glove Study Consent Form

**Please review and sign the form below.**

Thank you!

**UW RESEARCH TEAM**

Dr. Elena Austin, UW Professor, Environmental and Occupational Health, 206-221-6301, elaustin@uw.edu
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**INTRODUCTION**

**Please read carefully**. We are asking you to be in a research study. This form gives you information to help you decide whether to participate in the study. **Participation is voluntary**. You may ask any questions about the study at any time. After reviewing this information, you can accept or decline the invitation to participate.

**PURPOSE OF THE STUDY**

This study aims to develop glove use best practices during "demobilization" to reduce firefighter cancer risk. While previous research demonstrates the effectiveness of decontamination practices to significantly reduce post-fire skin contamination, little is known about the impact of specific glove use on exposure severity. We plan to collect skin wipe samples immediately following gross decontamination ("decon") and clean up to test if there is a statistical difference in dermal contamination between firefighters who doff their structural gloves for leather gloves and firefighters who continue to don their structural gloves for these activities. We may also collect air quality and surface wipe sample data to better understand firefighter occupational exposure risk during said activities.

**STUDY PROCEDURES**

As part of this study, we will be assessing dermal exposure to polycyclic aromatic hydrocarbons (PAHs). PAHs are components of incomplete combustion. Firefighters are exposed to these chemicals during fire suppression activities. Firefighter skin may become contaminated with PAHs via permeation, penetration through or around gloves, or from the cross-transfer of contaminants on PPE and equipment. Of the hundreds of known PAHs, 16 have been designated as High Priority Pollutants by the US Environmental Protection Agency (EPA 1993). We will perform a randomized field experiment to establish the degree of dermal protection afforded by structural firefighting gloves and leather gloves to High Priority PAHs.

To do this, a research coordinator will schedule a time to be present during structural fire suppression activities occurring (1) at the Washington Fire Training Academy OR (2) on-shift with a station crew. If you decide to participate, you will be given a Participant ID. Your participant ID will be used to randomly determine which glove type (structural firefighting glove or leather glove) you don during clean up.

**Skin Wipe Sampling**
Prior to conducting fire suppression activities, you will be asked to don a pair of standard issue, NFPA 1971 certified structural firefighting gloves. During fire suppression, you will continue to wear your structural firefighting gloves. Upon completion of fire suppression, you will perform gross decon as established by your fire department. After you complete gross decon, a research coordinator will be present to collect a skin wipe sample from you.

We will use isopropyl alcohol wipes to collect PAHs from the surface of your palms and the backs of your hands (Wipe Sample 1). After we have labeled and stored your sample, you will be randomly assigned to (1) place your structural gloves back on OR (2) given a pair of NFPA leather gloves to perform clean up. These gloves should be worn at all times during clean up. Please do not remove your gloves until instructed to do so.

During clean up, a researcher will take notes on the type and duration of activities that occur. At the end of clean up, you will be asked to check in with a researcher to collect a second set of skin wipe samples (Wipe Sample 2). At this time, you will remove your gloves and have the front and backs of your hands wiped with an isopropyl alcohol wipe. We will then measure your hand length (cm) and hand circumference (cm) to calculate hand surface area. Finally, you will be asked to recall/confirm the clean-up activities you specifically engaged in (e.g., rolling hoses, inspecting tools, handling equipment, etc.).

If feasible, this procedure may be repeated multiple times in a given setting for quality control purposes.

**Environmental Sampling**
To better understand occupational exposure at a fire scene, we may also assess chemicals in air and on surfaces. Air samples will be collected in real time, using area monitors and personal samplers attached to the belt of self-contained breathing apparatus (SCBA).

**RISKS, STRESS, OR DISCOMFORT**
There are minimal expected risks associated with participation in this study. However, there could be some level of discomfort associated with skin wipe sampling and personal air monitoring. Isopropyl alcohol wipes may cause skin irritation or a cold feeling where applied. Air sampling equipment may restrict full range of motion. If you experience discomfort, notify your research coordinator. Additionally, there is the risk of loss of privacy associated with your personal monitoring data.

**BENEFITS OF THE STUDY**
While there are no immediate direct benefits of participation in this study, collected data will be used to inform glove use best practices to mitigate firefighter cancer risk. We anticipate that findings from this research will be used to develop glove selection recommendations and updates to the Healthy In, Healthy Out manual. We will work closely with our Fire Service partners to ensure knowledge about and use of current best practices minimizes PAH exposures. In turn, we aim to promote long-term firefighter health.

**SOURCE OF FUNDING**
The research team, and the University of Washington are receiving funding from the Washington State Department of Labor and Industries (LNI) for the time spent collecting and analyzing samples.

**CONFIDENTIALITY OF RESEARCH INFORMATION**
All collected data will be stored on a secure server with confidential identifiers, but there is always the risk of a data breach and loss of privacy.

**USING YOUR DATA IN FUTURE RESEARCH**
The information and/or specimens that we obtain from you for this study might be used for future studies. We will remove anything that might identify you from the information and specimens. If we do so, the information and specimens may then be used for future research studies or given to another investigator without getting additional permission from you. It is also possible that in the future we may want to use or share study information that might identify you. If we do, a review board will decide whether or not we need to get additional permission from you.

**OTHER INFORMATION**
You may refuse to participate and you are free to withdraw from this study at any time without penalty or loss of benefits to which you are otherwise entitled. If you wish to withdraw, please contact the researcher listed at the beginning of this consent form.

A copy of the consent form will be emailed to you at an email address that you provide. It will be a "PDF" document. Most computers already have PDF viewer software installed, which will allow you to open, read, or print the consent form. The email we send you will include a link to PDF viewer software (such as Adobe Acrobat Reader) in case your computer doesn't already have it. If you would prefer to receive a paper copy of the consent form at no cost to you, please contact the researcher listed at the beginning of this consent form.

**RESEARCH-RELATED INJURY**
If you think you have been harmed from participating in this research, contact Dr. Austin at elaustin.uw.edu.

**1) Subject's Statement**

Add signature

This study has been explained to me. I volunteer to take part in this research. I have had a chance to ask questions. If I have questions later about the research, or if I have been harmed by participating in this study, I can contact one of the researchers listed on the first page of this consent form. If I have questions about my rights as a research subject, I can call the Human Subjects Division at (206) 543-0098 or call collect at (206) 221-5940. I will receive a copy of this consent form.

**2) First Name:** ______

* must provide value

**3) Middle Initial:** ______

Leave blank if not applicable

**4) Last Name:** ______

* must provide value

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**Appendix C – Descriptive Statistic of Population**

Descriptive Statistic of Participants from the 1st and 2nd Live Fire Training

| ID | Gender | Dominant Hand | Hand Length (cm) | Hand Circum. (cm) | Hand Surface Area (cm2) | Smoking | Age | Affiliation |
|---|---|---|---|---|---|---|---|---|
| 101 | M | R | 23 | 25 | 1401.85 | N | >18 | Y |
| 102 | M | R | 30 | 23.5 | 1718.79 | N | >18 | Y |
| 103 | M | R | 20 | 24 | 1170.24 | N | >18 | Y |
| 104 | M | R | 13.5 | 21.5 | 707.6295 | N | >18 | Y |
| 105 | M | R | 19.5 | 23 | 1093.443 | N | >18 | Y |
| 106 | F | R | 19 | 20 | 926.44 | N | >18 | Y |
| 107 | M | R | 20.5 | 23 | 1149.517 | N | >18 | Y |
| 108 | M | R | 21 | 24 | 1228.752 | N | >18 | Y |
| 109 | M | R | 20 | 23 | 1121.48 | N | >18 | Y |
| 110 | M | R | 22 | 24 | 1287.264 | N | >18 | Y |
| 111 | M | R | 21 | 23.5 | 1203.153 | N | >18 | Y |
| 112 | M | R | 20.5 | 23.5 | 1174.5065 | Y | >18 | Y |
| 113 | M | R | 20.5 | 22.5 | 1124.5275 | N | >18 | Y |
| 114 | M | R | 20.5 | 23 | 1149.517 | N | >18 | Y |
| 115 | F | R | 19 | 21.5 | 995.923 | N | >18 | Y |
| 116 | M | R | 21 | 24.5 | 1254.351 | N | >18 | Y |
| 117 | F | R | 19.5 | 21 | 998.361 | N | >18 | Y |
| 118 | M | L | 20 | 24.5 | 1194.62 | N | >18 | Y |
| 119 | M | R | 21 | 25 | 1279.95 | N | >18 | Y |
| 120 | M | R | 21 | 23 | 1177.554 | N | >18 | Y |
| 121 | M | R | 21 | 25.5 | 1305.549 | N | >18 | Y |
| 201 | M | R | 19.5 | 22 | 1045.902 | N | >18 | Y |
| 202 | F | R | 17 | 18.5 | 766.751 | N | >18 | Y |
| 203 | F | R | 19 | 20.5 | 949.601 | N | >18 | Y |
| 204 | M | R | 19.5 | 23.5 | 1117.2135 | N | >18 | Y |
| 205 | M | R | 17 | 20 | 828.92 | N | >18 | Y |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 206 | M | R | 20.5 | 22 | 1099.538 | N | >18 | Y |
| 207 | M | R | 19.5 | 22 | 1045.902 | N | >18 | Y |
| 208 | M | L | 18.5 | 21.5 | 969.7145 | N | >18 | Y |
| 209 | M | R | 20.5 | 24 | 1199.496 | N | >18 | Y |
| 210 | M | R | 20 | 22 | 1072.72 | N | >18 | Y |
| 211 | M | R | 21 | 21.5 | 1100.757 | N | >18 | Y |
| 212 | M | R | 17.5 | 20.5 | 874.6325 | N | >18 | Y |
| 213 | M | R | 20.5 | 23.5 | 1174.5065 | N | >18 | Y |
| 214 | M | R | 19 | 21.5 | 995.923 | N | >18 | Y |
| 215 | M | R | 17.5 | 22.5 | 959.9625 | N | >18 | Y |
| 216 | M | R | 17 | 20.5 | 849.643 | N | >18 | Y |
| 217 | M | L | 20 | 23.5 | 1145.86 | N | >18 | Y |
| 218 | M | R | 19 | 20.5 | 949.601 | N | >18 | Y |
| 219 | F | R | 17.5 | 19 | 810.635 | N | >18 | Y |
| 220 | F | R | 18.5 | 19.5 | 879.5085 | N | >18 | Y |
| 221 | M | R | 20.5 | 23 | 1149.517 | N | >18 | Y |
| 222 | M | R | 19 | 22 | 1019.084 | N | >18 | Y |
| 223 | M | R | 18.8 | 20.5 | 939.6052 | N | >18 | Y |
| 224 | M | R | 20 | 23 | 1121.48 | N | >18 | Y |

## Appendix D – Raw dermal PAH sample data

Raw data of dermal PAH concentrations from 1st live fire training

| **1st live fire training** | **PAH Conc. (μg/m²)** | **101** | **102** | **103** | **104** | **105** | **106** | **107** | **108** | **109** | **110** | **111** | **112** | **113** | **114** | **115** | **116** | **117** | **118** | **119** | **120** | **121** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1st Session on 2/4/23 | "Post Decon" | 2.12 | 0.84 | 0.68 | 3.75 | 2.24 | 0.58 | 3.29 | 5.57 | 0.45 | 0.43 | | | | | | | | | | | |
| | "Post Wear" | 7.85 | 1.75 | 4.96 | 2.43 | 5.61 | 1.49 | 3.04 | 1.98 | 1.24 | 2.00 | | | | | | | | | | | |
| 2nd Session on 2/4/23 | "Post Decon" | | | 2.13 | 3.58 | | 0.72 | | 1.53 | 2.57 | 1.16 | | | | | | | | | | | |
| | "Post Cleanup ST" | | | 4.41 | 2.83 | | 3.31 | | 3.49 | 3.13 | 2.47 | | | | | | | | | | | |
| 3rd Session on 2/5/23 | "Post Decon" | 0.77 | 0.52 | 3.48 | 13.31 | 2.77 | 0.37 | 2.26 | 5.11 | 0.16 | 0.75 | 7.90 | N/A | 4.48 | 1.10 | 4.04 | 5.32 | 0.75 | 9.33 | 1.86 | 1.50 | 2.06 |
| | "Post Cleanup ST" | 3.47 | 0.70 | 1.50 | 2.43 | 2.06 | 4.41 | 2.03 | 2.50 | 3.04 | 2.12 | 0.97 | N/A | 2.73 | 0.72 | 3.97 | 1.28 | N/A | 4.27 | 3.27 | 0.62 | 2.31 |
| 4th Session on 2/5/23 | "Post Decon" | 1.98 | 0.89 | 2.34 | 5.13 | 1.15 | 1.98 | 1.57 | 0.79 | 1.34 | 0.80 | 5.07 | N/A | 1.69 | 0.87 | 3.02 | 1.23 | 3.10 | 4.56 | 1.06 | 0.73 | 1.56 |
| | "Post Cleanup LT" | 0.18 | 0.47 | 0.81 | 3.73 | 0.42 | 0.31 | 1.91 | 0.94 | 0.63 | 1.84 | 2.87 | N/A | 2.57 | 0.77 | 1.59 | 0.49 | 2.01 | 0.27 | 3.82 | 0.03 | 0.61 |

Raw data of dermal PAH concentrations from 2nd live fire training

| 2nd live fire training | PAH Conc. (µg/m²) | 201 | 202 | 203 | 204 | 205 | 206 | 207 | 208 | 209 | 210 | 211 | 212 | 213 | 214 | 215 | 216 | 217 | 218 | 219 | 220 | 221 | 222 | 223 | 224 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1st Session on 8/7/24 | "Post Decon R" | | | | 1.32 | | | 0.60 | | | 0.46 | | | | | | | | | | 0.91 | | 0.37 | | |
| | "Post Cleanup LM" | | 0.48 | 0.43 | | | 0.28 | | | 0.09 | 0.66 | | 0.64 | | | | | 0.44 | | 0.42 | 0.27 | 0.25 | | | |
| 2nd Session on 8/8/24 | "Post Decon R" | | | | | 0.53 | | | | | | | | 0.56 | | | | | | | | | | | |
| | "Post Cleanup LM" | 0.47 | 0.20 | 0.22 | | 0.23 | | | | 0.13 | | | | 0.35 | | | | | | | | 0.25 | | | |
| | | | | | | 0.15 | | | | | | | | | | | | | | | | | | | |

Raw data of lifetime cancer risk from 1st live fire training

| 1st live fire training | Lifetime Cancer Risk | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 | 116 | 117 | 118 | 119 | 120 | 121 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2nd Session on 2/4/23 | "Post Cleanup ST" | | | 1.69 | 0.92 | | 1.69 | | 2.12 | 1.84 | 1.62 | | | | | | | | | | | |
| 3rd Session on 2/5/23 | "Post Cleanup ST" | 2.40 | 0.78 | 0.92 | 0.78 | 1.13 | 2.18 | 1.27 | 1.48 | 1.91 | 1.41 | 0.64 | N/A | 1.62 | 0.42 | 2.18 | 0.71 | N/A | 3.11 | 1.69 | 0.35 | 1.48 |
| 4th Session on 2/5/23 | "Post Cleanup LT" | 0.13 | 0.42 | 0.49 | 1.34 | 0.35 | 0.15 | 0.99 | 0.64 | 0.42 | 1.13 | 1.69 | N/A | 1.27 | 0.42 | 0.73 | 0.35 | 1.21 | 0.25 | 2.40 | 0.03 | 0.42 |

Raw data of lifetime cancer risk from 2nd live fire training

| 2nd live fire training | Lifetime Cancer Risk | 201 | 202 | 203 | 204 | 205 | 206 | 207 | 208 | 209 | 210 | 211 | 212 | 213 | 214 | 215 | 216 | 217 | 218 | 219 | 220 | 221 | 222 | 223 | 224 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1st Session on 8/7/24 | "Post Cleanup LM" | | 0.30 | 0.22 | | | 0.16 | | | 0.04 | 0.31 | | 0.24 | | | | | 0.30 | | 0.18 | 0.10 | 0.16 | | | |
| 2nd Session on 8/8/24 | "Post Cleanup LM" | 0.14 | 0.11 | 0.08 | | 0.08 | | | | 0.10 | | | | 0.14 | | | | | | | | 0.10 | | | |
| | | | | | | 0.00 | | | | | | | | | | | | | | | | | | | |

## Appendix E – QA/QC Raw Data

QA/QC values of PAHs quantification from 1st live fire training

| 1st live fire training | Analytes | R2, Calibration | Percent Recovery (%) | Coefficient of Variance (%) |
|---|---|---|---|---|
| | Naphthalene | 1.0000 | 0.9791 | 0.0193 |
| | 2-Methylnaphthalene | 0.9999 | 1.0275 | 0.0261 |
| | 1-Methylnaphthalene | 0.9999 | 0.9584 | 0.0261 |
| | Acenaphthylene | 1.0000 | 0.9647 | 0.0331 |
| | Acenaphthene | 1.0000 | 0.9306 | 0.0199 |
| | Fluorene | 1.0000 | 0.9746 | 0.0318 |
| | Phenanthrene | 1.0000 | 0.9384 | 0.0183 |
| | Anthracene | 0.9998 | 0.9798 | 0.0385 |
| | Fluoranthene | 1.0000 | 0.9502 | 0.0286 |
| | Pyrene | 0.9999 | 0.9454 | 0.0243 |
| | Benz(a)anthracene | 0.9999 | 0.8831 | 0.0378 |
| | Chrysene | 0.9999 | 1.0298 | 0.0159 |
| | Benzo(*)fluoranthene | 1.0000 | 0.9324 | 0.0271 |
| | Benzo(a)pyrene | 0.9997 | 0.9369 | 0.0218 |
| | Indeno(1,2,3-cd)pyrene | 0.9999 | 0.9978 | 0.0164 |
| | Dibenz(a,h)anthracene | 1.0000 | 0.9938 | 0.0445 |
| | Benzo(g,h,i)perylene | 1.0000 | 0.9683 | 0.0302 |

QA/QC values of PAHs quantification from 2nd live fire training

| 2nd live fire training | Analytes | R2, Calibration | Percent Recovery (%) | Coefficient of Variance (%) |
|---|---|---|---|---|
| | Naphthalene | 1.0000 | 0.9690 | 0.0347 |
| | 2-Methylnaphthalene | 0.9999 | 1.0671 | 0.0206 |
| | 1-Methylnaphthalene | 0.9998 | 1.0320 | 0.0346 |
| | Acenaphthylene | 0.9999 | 0.9475 | 0.0173 |
| | Acenaphthene | 0.9999 | 0.9187 | 0.0165 |
| | Fluorene | 0.9998 | 0.9804 | 0.0190 |
| | Phenanthrene | 0.9998 | 0.9198 | 0.0191 |
| | Anthracene | 1.0000 | 0.9863 | 0.0198 |
| | Fluoranthene | 0.9994 | 0.9281 | 0.0170 |
| | Pyrene | 0.9997 | 0.7909 | 0.0337 |
| | Benz(a)anthracene | 0.9999 | 0.9340 | 0.0223 |
| | Chrysene | 0.9997 | 0.9925 | 0.0240 |
| | Benzo(*)fluoranthene | 0.9994 | 0.9015 | 0.0182 |
| | Benzo(a)pyrene | 0.9997 | 0.9694 | 0.0163 |
| | Indeno(1,2,3-cd)pyrene | 0.9997 | 1.1021 | 0.0418 |
| | Dibenz(a,h)anthracene | 0.9999 | 1.0398 | 0.0384 |
| | Benzo(g,h,i)perylene | 0.9999 | 1.0061 | 0.0266 |