Evaluation of Wildland Fire Fighters' Exposures to Asbestos During a Prescribed Burn

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Disclaimer

The Health Hazard Evaluation Program investigates possible health hazards in the workplace under the authority of the Occupational Safety and Health Act of 1970 [29 USC 669a(6)]. The Health Hazard Evaluation Program also provides, upon request, technical assistance to federal, state, and local agencies to investigate occupational health hazards and to prevent occupational disease or injury. Regulations guiding the Program can be found in Title 42, Code of Federal Regulations, Part 85; Requests for Health Hazard Evaluations [42 CFR Part 85].

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Introduction

Request

Management at a federal forest management agency was concerned about wildland fire fighters' exposures to asbestos during prescribed burns near a former vermiculite mine.

Workplace

This federal forest management agency is responsible for approximately 28,000 acres of Kootenai National Forest. Within this zone, approximately 10,000 acres of land are centered on a former vermiculite mine. The geological deposit where the vermiculite was mined contains amphibole asbestos. The prescribed burn in this evaluation was just outside of this area.

To learn more about the workplace, go to Section A in the Supporting Technical Information

Our Approach

During our two visits to the worksite, we completed the following activities:

- Reviewed the respiratory protection program.
- Observed work processes and practices.
- Collected air samples for asbestos and total fibers.

To learn more about our methods, go to Section B in the Supporting Technical Information

Our Key Findings

Exposures to total fibers in air were less than the lowest occupational exposure limit

- We saw the highest concentrations during tasks with greater plant and soil disturbance and where water was not used (e.g., fire line construction and dry mop-up).
- We detected small numbers of asbestos fibers in the air samples we collected. The tasks associated with the most asbestos fibers were fire line construction and dry mop-up.

Decontamination line procedures could be improved

- Some confusion and inconsistencies existed around the decontamination line procedures because this was one of the first times these procedures were used during a live event. Some decontamination steps did not focus on particulate or fiber decontamination, and not all employees went through the same level of decontamination as others did.

- Some employees were not aware of the overall purpose and intended effectiveness of the decontamination process.

The respiratory protection program could be strengthened

- We observed that the fit testing equipment used was not calibrated according to the manufacturer's specifications.
- We saw fire fighters with facial hair. This would affect the ability of the respirator to get a good seal against an employee's face.

To learn more about our results, go to Section B in the Supporting Technical Information

Our Recommendations

The Occupational Safety and Health Act requires employers to provide a safe workplace.

Benefits of Improving Workplace Health and Safety:

↑ Improved worker health and well-being	↑ Enhanced image and reputation
↑ Better workplace morale	↑ Superior products, processes, and services
↑ Easier employee recruiting and retention	↑ May increase overall cost savings

The recommendations below are based on the findings of our evaluation. For each recommendation, we list a series of actions you can take to address the issue at your workplace. The actions at the beginning of each list are preferable to the ones listed later. The list order is based on a well-accepted approach called the "hierarchy of controls." The hierarchy of controls groups actions by their likely effectiveness in reducing or removing hazards. In most cases, the preferred approach is to eliminate hazardous materials or processes and install engineering controls to reduce exposure or shield employees. Until such controls are in place, or if they are not effective or practical, administrative measures and personal protective equipment might be needed. Read more about the hierarchy of controls at https://www.cdc.gov/niosh/topics/hierarchy/.

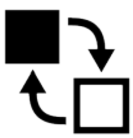
We encourage the company to use a health and safety committee to discuss our recommendations and develop an action plan. Both employee representatives and management representatives should be included on the committee. Helpful guidance can be found in "*Recommended Practices for Safety and Health Programs*" at https://www.osha.gov/shpguidelines/index.html.

Recommendation 1: Use wet mop-up methods whenever possible

Why? Wet methods are better for preventing exposures to hazardous dusts, particles, or fibers. Water helps keep the dust, particles, or fibers from getting into the air. Water can also suppress dust, particles, and fibers that have already become airborne and can minimize the distance that they travel.

We saw that dry mop-up produced more visual dust than wet mop-up. Most of the asbestos fibers we measured occurred during dry mop-up tasks. Wherever possible, wet methods should be used.

How? At your workplace, we recommend these specific actions:



Use wet mop-up methods instead of dry mop-up methods.

- Using wet methods or a combination of wet and dry methods will further reduce the amount of dust and potential asbestos exposures.

Recommendation 2: Review the decontamination line setup

Why? Decontamination lines protect employees from exposures to hazardous substances that may have contaminated the personal protective equipment, tools, and vehicles used in the burn. A well-constructed decontamination line protects employees by minimizing or eliminating the migration of hazardous substances from dirty areas into clean areas (https://www.osha.gov/SLTC/hazardouswaste/training/decon.html).

We observed some confusion, inconsistencies, and deviation from written protocol around the decontamination line procedures. The decontamination line could be improved with better communication and training.

How? At your workplace, we recommend these specific actions:

Talk with employees about the effectiveness of decontamination.

- Explain to employees that the decontamination process is designed to remove contaminant from the gear before leaving the fire zone. So fire packs that have been decontaminated thoroughly with high efficiency particulate air-filtered vacuums and/or water are clean and present minimal risk of exposure once dry.

The decontamination line should be open and ready to receive fire fighters before they enter the fire zone.

- Be prepared to decontaminate and remove fire fighters from the fire zone immediately if an emergency arises. Do not allow fire fighters to enter the fire zone without the decontamination line being set up first.

Follow a decontamination plan focused on particulate or fiber contamination.

- Do not include a chlorine bath step if asbestos is the only contaminant of concern—chemical rinses do not eliminate asbestos.
- Do not use biohazard bags unless disposing of a biological hazard. Use asbestos disposal bags instead.
- Consider adding a high efficiency particulate air vacuum to the gross decontamination step. It is an effective method to remove dust and particulates from fabric and other surfaces, such as radios or other equipment that should not get wet during decontamination. If you decide to use these vacuums, establish appropriate protocols for emptying the vacuum and cleaning the filters.

Avoid deviating from decontamination line standard operating procedures.

- Fire zone employees should go through the decontamination line first. The decontamination line employees should go through the line once all fire zone employees have been decontaminated.
- Employees furthest away from the clean side should start going through the decontamination line first.

Provide training on decontamination line setup, use, and breakdown.

- Practice dry runs of setting up and breaking down the decontamination line to improve efficiency during live events. This training should focus on the following:
    - Never backtrack while in the decontamination line. Individuals moving through the line should always be moving from the dirty side to the clean side. If current practices involve moving people from the clean side to the dirty side, adjust those practices.
    - Do not allow employees to skip parts of the decontamination line. Every employee should go through the decontamination process as it is written in your standard operating procedures.
    - Develop a standard operating procedure to keep pools that catch contaminated water clean. We observed buildup of debris in the boot wash station. Empty the pools more frequently to prevent excessive buildup.
    - Do not allow employees working on the decontamination line to break down equipment like a chainsaw. Instead, instruct the individual going through the decontamination line to break down the tool. The decontamination line employee can then clean the parts of the tool.
- Avoid dry sweeping, and incorporate high efficiency particulate air vacuums if feasible.

Clean all equipment after each fire event.

- There were totes were left over from previous fire events. Handling the gear left inside could cause a resuspension of dust. Cleaning all gear after each event will eliminate the risk of resuspension when handling the gear in the future.

Recommendation 3: Strengthen your respiratory protection program

Why? Because respiratory protection is required for certain tasks, a respiratory protection program is also required. Mandatory respiratory protection programs must be in compliance with the Occupational Safety and Health Administration (OSHA) respiratory protection standard, 29 CFR 1910.134. This program must be a written program that documents worksite-specific procedures requiring respirator use as well as identifying a competent program administrator. Requirements include annual fit testing, documented training, and medical clearance, among other things.

We identified some technical issues that affected the validity of fit testing results during one of our visits. We also saw employees with facial hair and noted that your fit testing equipment calibration was not up to date according to manufacturer's recommendations.

How? At your workplace, we recommend these specific actions:

Perform fit tests and calibrate fit testing equipment annually.

- Make sure all employees required to wear a respirator are fit tested prior to the start of each fire season.
- Follow the manufacturer's recommendations related to calibration and maintenance of the fit testing equipment. This will ensure that equipment is operating as intended.

Inspect your equipment thoroughly before each use.

Provide annual respiratory protection training.

- Provide more frequent training to employees on the appropriate donning and doffing procedures. Some employees had difficulty donning and doffing their respiratory protection. Employees were observed helping each other navigate this process.

Develop a plan for addressing employees who arrive to a burn with facial hair.

- Provide training to increase awareness around the importance of having a tight seal.
- Offer a mechanism for employees to correct the issue (e.g., keep disposable razors on site in case they are needed).

Supporting Technical Information

Evaluation of Wildland Fire Fighters' Exposures to Asbestos During a Prescribed Burn

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Section A: Workplace Information

Workplace

Various forest management activities, including fire response and prescribed burns, are performed within an area of national forest (approximately 28,000 acres) overseen by a federal forest management agency. Within the forest management area is a zone known as Operable Unit 3 (OU3) by the United States Environmental Protection Agency (EPA). OU3 surrounds a former vermiculite mine and areas impacted by the releases from the mine. OU3 is approximately 10,000 acres centered on the mine and is an EPA National Priorities List Superfund site. The National Priorities List contains sites with known releases of hazardous substances throughout the United States. The boundary of OU3 changes from year to year. The prescribed burn in this evaluation was just outside of OU3.

Employee Information

- Among 19 employees, 6 worked on the decontamination line, and 13 worked in various capacities as fire fighters.
- All employees worked a single shift lasting approximately 12 hours on the day of a prescribed burn.
- Most employees belonged to a union.

Process Description

The prescribed burn day had five parts: briefing and preparation, fire line construction, burn, mop-up, and decontamination.

Briefing and Preparation

On the morning of the prescribed burn, employees gathered at the ranger station to prepare for the day. The agency follows Incident Command Structure (ICS), so the entire group reviewed the Incident Action Plan. The plan lays out all pertinent information for the prescribed burn including safety, communications, logistics, and weather. After the briefing, employees prepared their fire packs, dressed in their wildland fire gear, and ensured that their powered air purifying respirators (PAPRs) were working. Employees then put their packs onto various vehicles and departed for the site of the burn. Different types of vehicles were used including fire trucks, a decontamination equipment truck, utility task vehicles (UTVs), and personal vehicles.

Fire Line Construction

Fire fighters put on their PAPRs prior to leaving the cold zone (the "clean" side of the decontamination line) and entering the fire zone (the "dirty" side of the decontamination line). The fire trucks departed for the burn site, and UTVs shuttled fire fighters into the site. Fire fighters worked to construct a fire line around the perimeter of the proposed burn site (Figure 1). They were able to utilize existing forest roads along two sides of the burn site, reducing the amount of fire line construction necessary

(Figure 2). Fire hose was laid along those lines to ensure access to water across the burn area. One fire fighter used a leaf blower to clear debris from the fire line. Another fire fighter used a chainsaw to manage the fuel (e.g., grass, brush, or timber) within the burn zone, preparing it for the burn.

Figure 1. Fire fighters using tools to construct a fire line by digging into the forest floor to create a break in the fuel. Photo provided by employer.

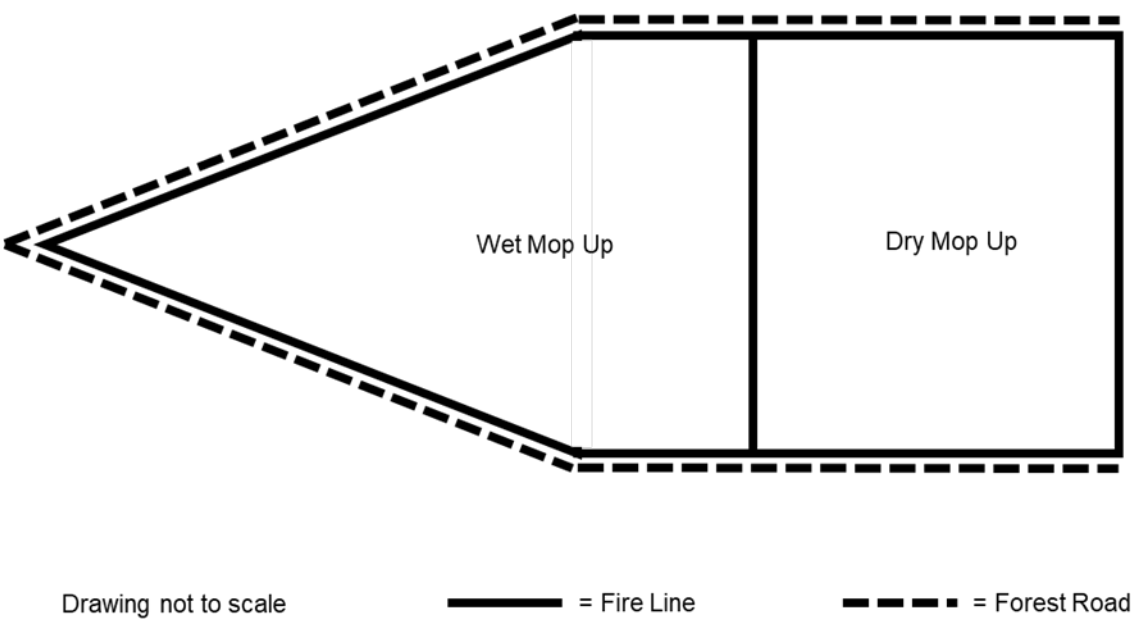

Figure 2. Diagram of the burn site showing fire lines and forest road boundaries. A fire line cuts through the middle of the burn area in order to make it easier to move from one side to the other. The division of wet and dry mop-up is also indicated. Figure by NIOSH.

Prescribed Burn

Two fire fighters were tasked with ignition duties once the fire line was constructed. They walked the perimeter of the burn lighting the fire with drip torches (Figure 3). Fire fighters spread out across the perimeter of the fire once it was lit and let it burn for approximately 100 minutes. During this time, fire fighters worked to keep the fire from crossing the fire line and, where appropriate, from climbing too high up tree trunks (Figure 4).

Figure 3. Fire fighter using a drip torch to start the burn. Photo provided by employer.

Figure 4. Fire moving along the planned burn area along the fire line. Photo provided by employer.

Mop Up

Fire fighters were assigned to either wet or dry mop-up duties to put out the fire completely (Figure 5). Wet mop-up methods were used on the east side of the burn and dry mop-up methods were used on the west side (Figure 2). Wet mop-up uses water to put out the fire. Dry mop-up uses physical disruption of the soil and roots to put out the fire. Three fire fighters were assigned to wet mop-up, and seven were assigned to dry mop-up. The remaining three fire fighters served in supervisory roles and helped with mop up as necessary.

Figure 5. Fire fighters performing wet and dry mop-up activities. The fire fighter on the wet mop-up side of the line is using the hose to apply water. The dry mop-up side of the line is using the hand tool to dig and turn soil to extinguish the fire. Photo provided by employer.

Decontamination

Fire fighters were sent through the decontamination line at staggered times once the fire was under control. Employees working on the decontamination line were responsible for breaking down and cleaning the equipment and tools at each step. First, UTVs dropped the fire fighters at the beginning of the decontamination line where they left any tools (e.g., chainsaw) that they had used. We then observed the fire fighters go through these steps:

1. Remove fire pack, detach PAPR from fire pack, and keep PAPR and facemask on.
2. Place radio and helmet on table.
3. Proceed to gross decontamination of boots. Wet down boots, remove boots, and discard laces.
4. Perform gross decontamination rinse with clothing and PAPR on.
5. Move to decontamination trailer.
6. Remove wildland fire clothing, and keep PAPR on.
7. Enter “dirty” side of the trailer. Keep PAPR on. Cut or remove undershirt and undress.

8. Move into shower stalls and rinse head to toe in shower with PAPR on.
9. Remove PAPR. Move backward in decontamination line ("upstream") to hang PAPR on hook.
10. Move into shower stalls and shower with soap and shampoo.
11. Proceed to clean side of trailer, put on personal clothing, and exit trailer.

Fire fighters gathered at a resting area after decontamination was complete to wait for the remainder of the fire fighters to complete decontamination. UTVs were decontaminated at the station where tools were dropped before being driven out of the fire zone.

Section B: Methods, Results, and Discussion

Methods: Observations of Work Processes and Practices

On one visit, we observed the fit testing procedures and storage areas for equipment. On a second visit, we evaluated the use of personal protective equipment (PPE) and the decontamination line during a prescribed burn.

Results: Observations of Work Processes and Practices

Fit Testing

- We observed fit testing procedures as part of this evaluation. Fire fighters are required to be fit tested annually. Many of the employees who respond in or around OU3 are stationed in other parts of the forest full time or are seasonal fire fighters.
- This agency used quantitative fit testing methods (PortaCount, TSI Inc.). The PortaCount used had not been calibrated according to the manufacturer's recommendations. The manufacturer recommends that the instrument be calibrated annually.
- We observed that the tube connecting the PortaCount to the PAPR mask through the air hose was twisted and pinched just enough to allow some air through but not enough to register an error on the machine. The pinched tube was causing automatic passes for all fit tests.
- We advised the agency to adjust their practices to avoid getting the PortaCount tube twisted up in the hose of the PAPR. We also advised them to re-test any employees who had been fit tested recently. After identifying these issues, the worksite made efforts to re-fit test employees prior to the prescribed burn and fire season. All employees participating in the prescribed burn were re-fit tested before the burn.
- Some employees had facial hair, which can affect the ability to get a good seal of the respirator to the face.

Storage

All fire fighters had their own tote where they stored their equipment. The agency used different colored tops for the totes to indicate whether the equipment inside was clean (black) or dirty (red). If an event were to last multiple days, the fire fighters might not clean certain items and simply store them in the red topped tote. Fire fighters discarded or cleaned all gear and washed out the totes at the end of an event. At the time of our first visit, we recommended that they store their black and red totes in separate areas to minimize the chances of someone mistaking the dirty totes for clean ones. When we arrived for our second visit, the totes were stored in separate areas.

Prescribed Burn

- Fire fighters were required to wear a wildland fire shirt and pants, tall leather boots, a fire pack with a fire shelter, a full-face elastomeric PAPR, leather gloves, and a fire helmet.

- Employees working on the decontamination line were required to wear a Tyvek® suit with hood, shoe covers, half-face elastomeric air purifying respirator with P100 cartridges, nitrile gloves, safety glasses, and a fire helmet.
- Fire fighters removed their PAPRs and fire packs for the drive over to the burn site after the morning briefing and equipment preparation.
- Fire fighters drove two fire trucks, two UTVs, and the decontamination equipment truck to the burn site. A water truck and the decontamination trailer were already on site.
- Fire fighters were sent into the fire zone to begin fire line construction before the decontamination line was operational.
- Many fire fighters had drinking tubes in their respirator masks.
- We observed employees dry sweeping to clean out the bottom of the decontamination equipment truck after the event. The employees cleaning the truck were not wearing respiratory protection.

Decontamination

- The decontamination line was not set up prior to the fire fighters entering the fire zone to begin working.
- One of the steps in the decontamination process was to clean PAPR hoses in a chlorine bath.
- Pools used to catch water from boot rinsing were not changed between each person. These pools filled with contaminated water quickly.
- Biohazard (red) bags were used to collect discarded items.
- Two high efficiency particle air (HEPA) filter vacuums were available, but they were not used during the decontamination process.
- We were told that decontamination employees cleaned out some totes during the burn that contained contaminated gear from a previous event. We did not directly observe this process.
- Decontamination employees were helping, rather than instructing, fire fighters during some of the steps in the process.
- Steps for entering the decontamination trailer "dirty" side and removing the PAPR involved moving upstream (backward) through the decontamination line.
- Some employees voiced concerns that dried fire packs that had gone through the decontamination line could expose or harm them.
- Fire fighters gathered at a resting area after decontamination was complete to wait for the remainder of the fire fighters to complete decontamination. A table and some chairs were set up, but some fire fighters chose to sit on the ground.

- Employees working on the decontamination line broke down the line and then went through a shorter, dry decontamination procedure after all fire fighters passed through the decontamination line. These employees removed their protective Tyvek suits and shoe covers, wiped their faces and exposed skin, removed their respirators, and wiped their faces again. These employees then moved directly into the cold zone without passing through the trailer or using the gross wet decontamination methods used for the fire fighters.

Methods: Exposure Assessment

- We collected a series of task-based personal air samples that covered the entire shift for 19 employees.
- We analyzed each sample for total fibers using the National Institute for Occupational Safety and Health (NIOSH) Method 7400. This method uses Phase Contrast Microscopy (PCM).
- We analyzed a subset of samples for asbestos fibers using NIOSH Method 7402. This method uses Transmission Electron Microscopy (TEM). For samples that became overloaded, we first used International Organization for Standardization (ISO) Method 13794 via indirect preparation, and then we analyzed them using NIOSH Method 7402.
- We changed the sampling media between every step in the burn process (e.g., between fire line construction and the burn) as well as when we suspected that samples were in danger of being overloaded.
- We visually inspected the filters as often as possible to determine when to change them. If we saw any sign of color on the filter, we changed it, because no conventional method existed in this setting to determine when a sample became overloaded.

Results: Exposure Assessment

Fibers by Phase Contrast Microscopy

Although we tried to minimize the possibility, some samples taken on fire fighters during the prescribed burn were overloaded with debris. None of the samples collected on the decontamination employees were overloaded. The overloaded samples could not be analyzed for total fiber counts, and we could not calculate a time-weighted average (TWA) that could be compared directly to an occupational exposure limit (OEL). However, we were able to analyze the overloaded samples for the presence of asbestos fibers.

- For the 55 task samples that were not overloaded, all exposures to fibers in air were below the lowest OEL. For asbestos, the OSHA permissible exposure limit (PEL), the NIOSH recommended exposure limit (REL), and the American Conference of Governmental Industrial Hygienists® (ACGIH) threshold limit value® (TLV) are 0.1 fibers per cubic centimeter of air (f/cc).
- For samples that were not overloaded with debris, task-based fiber concentrations ranged from 0.0013 through 0.13 f/cc for fire fighters (Table C1). The highest concentrations came during mop-up (average = 0.065 f/cc) and fire line construction (average = 0.031 f/cc) activities. The

lowest concentrations were found in the samples taken while traveling to the burn site (average = 0.0061 f/cc) and after going through the decontamination line (average = 0.018 f/cc). All samples collected during the burn and many of the samples collected during the mop-up were overloaded.

- For employees on the decontamination line, full-shift TWA fiber concentrations ranged from 0.0016 through 0.050 f/cc (average = 0.013 f/cc) (Table C2).

Asbestos Fibers by Transmission Electron Microscopy

We detected 13 asbestos fibers (12 Tremolite and 1 Richterite) in the samples that were analyzed using TEM (Table C3). The greatest number of asbestos fibers were detected during the mop-up (six fibers) and fire line construction (four fibers) tasks. Five of the six fire fighters who had asbestos fibers detected during mop-up activities were assigned to the dry mop-up task. The sixth fire fighter's time was split between wet and dry mop-up. There was one fiber detected on a sample taken during the burn, one fiber detected on a sample taken after decontamination (these samples covered the time period between when an employee finished going through the decontamination line through leaving the burn site), and one fiber detected on a sample taken on a decontamination employee during the burn.

Discussion

We found low concentrations of total fibers in the air during prescribed burn activities. The highest concentrations were detected during tasks with greater plant and soil disturbance (e.g., fire line construction and mop-up). Most exposures to total fibers in air were below all applicable OELs, although, one fire fighter had a task concentration of 0.13 f/cc during dry mop-up. Because this sample was approximately one hour long, the employee was not overexposed. However, if this employee was to perform mop-up activities for the entire day, the OSHA PEL of 0.1 f/cc may be exceeded.

We were not able to determine fiber concentrations in air during the burn work tasks due to overloading of the filters. It is likely that the filters were overloaded due to an excess of organic material resulting from the burning vegetation. It is also very likely that the greatest potential for exposure to asbestos fibers would be during the fire line construction and mop-up tasks, as these activities have the greatest direct disruption of soil. This latter assumption is supported by our TEM analyses, which found that tasks associated with detection of the most asbestos fibers were the fire line construction and mop-up tasks.

We detected multiple asbestos fibers on a subset of the air samples. The tasks associated with the most asbestos fibers were fire line construction and dry mop-up. This is likely due to the amount of soil and plant disturbance and the lack of water used in these tasks. Water is an excellent method for controlling dust exposures in many occupational settings, so wet mop-up methods should be used when possible.

We are unsure about the origin of the one asbestos fiber found after the decontamination process was finished. The concentration of total fibers for the sample was 0.032 f/cc, which was below the OEL for total fibers of 0.1 f/cc (Table C1). The concentration was also the highest concentration detected among fire fighters during that task (range: not detected–0.032 f/cc). The exposure occurred while an employee was sitting on the ground after going through the decontamination line. A lot of debris was not disturbed, however, asbestos is endemic to the region, especially near the mine.

It is also unclear where the asbestos fiber found on the decontamination employee's sample may have come from. The sample that this fiber was found on was collected during the burn and decontamination process. It had the second highest concentration of fibers (0.009 f/cc) out of the employees working on the decontamination line (average = 0.013 f/cc). This exposure may have come from working closely with contaminated fire fighters and gear that moved through the decontamination line or from cleaning out totes with contaminated gear during the burn. These totes were left over from previous fire events, and there could have been a re-suspension of dust during the handling of this gear.

During our visit was one of the first times that this decontamination process was implemented in a live situation. Some confusion and inconsistencies around the decontamination line procedures occurred, for example, the line was not fully set up before the fire fighters entered the fire zone; decontamination line employees did not undergo the same decontamination procedures as fire fighters (a deviation from the written protocol); and some steps did not apply to particulate or fiber decontamination (i.e., an unnecessary chlorine bath step for PAPR hoses). Additionally, decontamination line employees gave help instead of just instruction to fire fighters, thereby, increasing line employees' risk of contamination.

We also learned that some employees were concerned that they could be exposed to asbestos when handling fire packs that had been through the decontamination line and had dried. Fire packs that have been decontaminated thoroughly with HEPA vacuums and/or water are clean and present minimal risk of exposure when they dry. The decontamination process is designed to remove contaminant from the gear before leaving the fire zone.

Some areas of the respiratory protection program could be improved. This includes providing annual fit testing for all employees required to wear respirators and calibrating the fit testing equipment according to the manufacturer's recommendations. Another area for improvement would be confirming that employees shave before wearing respirators to ensure a tight seal between the face and the respirator.

Limitations

This evaluation is subject to several limitations. First industrial hygiene sampling can only document exposures on the days of sampling in the locations sampled. These results may not be representative of conditions during other days. Although steps were taken to select the samples with the greatest likelihood for having asbestos fibers, there could have been additional asbestos fibers on the samples that were not analyzed by TEM. In addition, the small size and homogenous nature of the population sampled limit the generalizability of our evaluation results.

Conclusions

All exposures to total fibers in air were below the lowest OEL—these concentrations were able to be determined for samples that were not overloaded with debris. Fibers, including asbestos fibers, were detected during multiple tasks performed throughout the prescribed burn. The majority of fibers were found during dry activities and during tasks associated with greater plant and soil disturbance, such as fire line construction and dry mop-up. Using wet mop-up procedures whenever possible could decrease fiber exposures. Reworking decontamination line procedures and setup and improving the respiratory protection program will further protect employees from fiber exposures.

Section C: Tables

Table C1. Personal breathing zone samples for fibers analyzed by phase contrast microscopy for fire fighters during a prescribed burn

Task:	Travel to burn site		Fire line construction		Burn		Mop-up		After decontamination	
Fire fighter #	Time (min)	Concentration (f/cc)*†	Time (min)	Concentration (f/cc)*†	Time (min)	Concentration (f/cc)*†	Time (min)	Concentration (f/cc)*†	Time (min)	Concentration (f/cc)*†
1	283	0.0096	104	0.012	88	Overloaded	93	0.043	100	Not detected
2	324	Not detected	46	0.018	98	Overloaded	73	0.026	116	Not detected
3	300	0.0059	76	0.029	103	Overloaded	152	Overloaded	41	0.022
4	80	0.0036	12	0.018	155	Overloaded	41	Overloaded	83	0.023
5	310	0.0085	48	Overloaded	100	Overloaded	142	Overloaded	70	0.0013
6	285	Not detected	96	Not detected	81	Overloaded	118	0.061	80	Not detected
7	312	0.0051	50	0.052	108	Overloaded	148	Overloaded	21	Not detected
8	278	0.0040	93	0.022	80	Overloaded	127	Overloaded	82	Not detected
9	315	0.0035	50	0.027	97	Overloaded	118	Overloaded	86	0.011
10	294	0.011	86	0.032	81	Overloaded	146	Overloaded	68	0.022
11	283	0.0045	88	0.049	93	Overloaded	140	Overloaded	56	0.032
12	326	0.0064	50	0.039	106	Overloaded	62	0.13	110	0.016
13	279	0.0046	95	0.046	75	Overloaded	148	Not detected	60	Not detected

*The minimum detectable concentrations ranged 0.002–0.03 f/cc.

†OSHA, NIOSH, and ACGIH have OELs of 0.1 f/cc for asbestos. OSHA has a short-term excursion limit of 1 f/cc.

Table C2. Personal breathing zone samples for fibers analyzed by phase contrast microscopy for decontamination employees during a prescribed burn

Employee	Travel to burn site*		Prescribed burn†		Time-weighted average (f/cc)‡
	Time (min)	Concentration (f/cc)	Time (min)	Concentration (f/cc)	
1	295	Not detected§	414	0.0079	0.0016
2	339	0.010	373	0.086	0.050
3	341	0.0027	374	0.0090	0.0060
4	332	0.0034	365	0.0079	0.0058
5	339	0.0071	379	0.0065	0.0068
6	338	0.0050	374	0.0064	0.0057

*These samples included prepping gear, safety briefing, gathering gear, loading trucks, driving to the site, further briefing, and then lunch.

†These samples spanned the entire prescribed burn, including fire line construction, burn, and mop-up activities.

‡OSHA, NIOSH, and ACGIH have occupational exposure limits of 0.1 f/cc for asbestos. OSHA has a short-term excursion limit of 1 f/cc.

§The minimum detectable concentration was 0.002 f/cc.

Table C3. Personal breathing zone samples for asbestos analyzed by transmission electron microscopy (TEM) for fire fighters and decontamination employees during a prescribed burn

Employee	Task	Number and type of fiber detected by TEM
Fire fighter #1	Burn	0
	Mop-up (dry)	0
Fire fighter #2	Burn	0
	Mop-up (dry)	0
Fire fighter #3	Fire line construction	0
	Burn	0
	Mop-up (wet/dry)	0
	After decontamination	0
Fire fighter #4	Burn	0
	Mop-up (wet/dry)	1 (Richterite)
	After decontamination	0
Fire fighter #5	Fire line construction	0
	Burn	1 (Tremolite)
	Mop-up (dry)	1 (Tremolite)
Fire fighter #6	Burn	0
	Mop-up (dry)	4 (Tremolite)
Fire fighter #7	Fire line construction	2 (Tremolite)
	Burn	0
	Mop-up (dry)	0

Table C3 (continued). Personal breathing zone samples for asbestos analyzed by transmission electron microscopy (TEM) for fire fighters and decontamination employees during a prescribed burn

Job Title	Task	Number and type of fiber detected by TEM
Fire fighter #8	Fire line construction	0
	Burn	0
	Mop-up (dry)	0
Fire fighter #9	Fire line construction	1 (Tremolite)
	Burn	0
	Mop-up (dry)	0
Fire fighter #10	Travel to burn site	0
	Fire line construction	0
	Burn	0
	Mop-up (wet)	0
	After decontamination	0
Fire fighter #11	Fire line construction	1 (Tremolite)
	Burn	0
	Mop-up (dry)	0
	After decontamination	1 (Tremolite)
Fire fighter #12	Fire line construction	0
	Burn	0
	Mop-up (dry)	0
Fire fighter #13	Fire line construction	0
	Burn	0
Decontamination employee #2	Travel to burn site	0
	Prescribed burn*	0
Decontamination employee #3	Prescribed burn*	1 (Tremolite)

*These samples spanned the entire prescribed burn, including fire line construction, burn, and mop-up activities.

Section D: Occupational Exposure Limits

NIOSH investigators refer to mandatory (legally enforceable) and recommended OELs for chemical, physical, and biological agents when evaluating workplace hazards. OELs have been developed by federal agencies and safety and health organizations to prevent adverse health effects from workplace exposures. Generally, OELs suggest levels of exposure that most employees may be exposed to for up to 10 hours per day, 40 hours per week, for a working lifetime, without experiencing adverse health effects.

However, not all employees will be protected if their exposures are maintained below these levels. Some may have adverse health effects because of individual susceptibility, a preexisting medical condition, or a hypersensitivity (allergy). In addition, some hazardous substances act in combination with other exposures, with the general environment, or with medications or personal habits of the employee to produce adverse health effects. Most OELs address airborne exposures, but some substances can be absorbed directly through the skin and mucous membranes.

Most OELs are expressed as a TWA exposure. A TWA refers to the average exposure during a normal 8- to 10-hour workday. Some chemical substances and physical agents have recommended short-term exposure limits (STEL) or ceiling values. Unless otherwise noted, the STEL is a 15-minute TWA exposure. It should not be exceeded at any time during a workday. The ceiling limit should not be exceeded at any time.

In the United States, OELs have been established by federal agencies, professional organizations, state and local governments, and other entities. Some OELs are legally enforceable limits; others are recommendations.

- OSHA, an agency of the U.S. Department of Labor, publishes permissible exposure limits [29 CFR 1910 for general industry; 29 CFR 1926 for construction industry; and 29 CFR 1917 for maritime industry] called PELs. These legal limits are enforceable in workplaces covered under the Occupational Safety and Health Act of 1970.
- NIOSH RELs are recommendations based on a critical review of the scientific and technical information and the adequacy of methods to identify and control the hazard. NIOSH RELs are published in the *NIOSH Pocket Guide to Chemical Hazards* [NIOSH 2007]. NIOSH also recommends risk management practices (e.g., engineering controls, safe work practices, employee education/training, PPE, and exposure and medical monitoring) to minimize the risk of exposure and adverse health effects.
- Another set of OELs commonly used and cited in the United States include the threshold limit values or TLVs, which are recommended by ACGIH. The ACGIH TLVs are developed by committee members of this professional organization from a review of the published, peer-reviewed literature. TLVs are not consensus standards. They are considered voluntary exposure guidelines for use by industrial hygienists and others trained in this discipline "to assist in the control of health hazards" [ACGIH 2019].

Outside the United States, OELs have been established by various agencies and organizations and include legal and recommended limits. The Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (Institute for Occupational Safety and Health of the German Social Accident Insurance) maintains a database of international OELs from European Union member states, Canada (Québec), Japan, Switzerland, and the United States. The database, available at https://www.dguv.de/ifa/gestis/gestis-stoffdatenbank/index-2.jsp, contains international limits for more than 2,000 hazardous substances and is updated periodically.

OSHA (Public Law 91-596) requires an employer to furnish employees a place of employment free from recognized hazards that cause or are likely to cause death or serious physical harm. This is true in the absence of a specific OEL. It also is important to keep in mind that OELs may not reflect current health-based information.

When multiple OELs exist for a substance or agent, NIOSH investigators generally encourage employers to use the lowest OEL when making risk assessment and risk management decisions.

Asbestos

Asbestos is a commercial name that includes a group of six different fibrous minerals (amosite, chrysotile, crocidolite, and the fibrous varieties of tremolite, actinolite, and anthophyllite) that occur naturally in the environment. One of these, chrysotile, belongs to the serpentine family of minerals, while all of the others belong to the amphibole family. These minerals possess high tensile strength, flexibility, resistance to chemical, biological, and thermal degradation, and electrical resistance. Because of these properties, asbestos has been mined for use in a wide range of manufactured products, mostly in building materials, friction products, and heat-resistant fabrics.

Chrysotile, also known as white asbestos, is the predominant commercial form of asbestos; amphiboles are considered of minor commercial importance. Chrysotile accounts for more than 99% of the world's mined asbestos [USGS 2019]. Chrysotile asbestos has been used in a number of applications in the United States, including thermal piping and industrial oven insulation, floor tile, vehicle brake pads, and in building material such as soffits. More information about asbestos is available at the NIOSH asbestos topic page http://www.cdc.gov/niosh/topics/asbestos/.

The current OSHA occupational 8-hour TWA exposure limit for airborne asbestos as determined by PCM is 0.1 f/cc for fibers greater than 5 micrometers in length and an aspect ratio (length to width) greater than or equal to 3:1 [29 CFR 1910.1001]. OSHA has also established an excursion limit that requires the employer to ensure that no employee is exposed to an airborne concentration of asbestos in excess of 1.0 f/cc as averaged over a sampling period of 30 minutes. Exposure limits or risk criteria for bulk or surface samples for asbestos have not been established. The OSHA definition of asbestos applies to chrysotile, amosite, crocidolite, tremolite asbestos, anthophyllite asbestos, actinolite asbestos, and any of these minerals that have been chemically treated and/or altered [29 CFR 1910.1001]. The OSHA definition of asbestos-containing material is any material containing more than 1% asbestos.

In 1990, NIOSH reviewed the available information on elongate mineral particles and concerns about potential health risks associated with employee exposures to the analogs of the asbestos minerals [NIOSH 1990a,b]. These analogs occur in a different mineral "habit" and are often referred to as cleavage fragments. PCM, the analytical method routinely used for characterizing airborne exposures, is incapable of differentiating these non-asbestiform analogs from asbestos fibers on the basis of physical appearance. To address these concerns and ensure that employees are protected, NIOSH defined "airborne asbestos fibers" to encompass not only fibers from the six asbestos minerals (chrysotile, crocidolite, amosite, anthophyllite asbestos, tremolite asbestos, and actinolite asbestos) but also elongate mineral particles from their non-asbestiform analogs as a precautionary measure. NIOSH retained the use of PCM for measuring airborne fiber concentrations and counting those elongate mineral particles having an aspect ratio of 3:1 or greater and a length greater than 5 micrometers. The REL (0.1 f/cc) was set at the limit of quantification for the PCM analytical method for a 400-liter sample, but risk estimates indicate that exposure at 0.1 f/cc throughout a working lifetime would be associated with a residual risk for lung cancer. No risk-free level of exposure to airborne asbestos fibers has been established [NIOSH 1976, 1984, 2011]. More information on asbestos from NIOSH can be found at http://www.cdc.gov/niosh/docs/2011-159/.

Libby amphibole is a complex mixture of amphibole fibers found in the rocks and ore of Zonolite Mountain, 6 miles northeast of Libby, Montana. The mixture primarily includes tremolite, winchite, and richterite fibers with trace amounts of other minerals. These fibers exhibit a complete range of morphologies from prismatic crystals to asbestiform fibers [Meeker et al. 2003]. Zonolite Mountain contains a large vermiculite deposit that has been mined since the early 1920s for various commercial uses. Vermiculite miners, mill employees, and those working in the processing plants were exposed to these amphibole fibers, which remain within vermiculite ore and product. As amphibole asbestos is present in the geological deposit from which the vermiculite ore was being mined, employees were exposed to asbestos fibers during various activities such as extracting ore from the mine, transporting ore and waste rock, milling operations, and shipping the final product [Meeker et al. 2003].

Health Effects

Inhalation exposure to asbestos can result in a scarring disease of the lung known as asbestosis, inflammation of the chest cavity (pleuritis) with or without fluid build-up, lung cancer, and another type of cancer known as malignant mesothelioma. The risk of these diseases, which can be disabling or fatal, generally increases with intensity and duration of exposure. The risk of lung cancer from inhaling asbestos fibers is also increased in smokers. Most people who get asbestos-related diseases have been exposed to high levels of asbestos for a long time. Most asbestos-related diseases rarely occur until at least 15 years after first exposure to asbestos. All forms of asbestos are hazardous, and all can cause cancer, but amphibole forms of asbestos are considered to be somewhat more hazardous to health than chrysotile [ATSDR 2001]. Asbestos fibers have no detectable odor or taste, and fibers associated with these health risks are too small to be seen with the naked eye. A summary of asbestos-related diseases are listed below:

- Asbestosis – a serious, progressive, long-term disease of the lungs. It is caused by inhaling asbestos fibers that irritate lung tissues and cause the tissues to scar. The scarring makes it hard for oxygen to get into the blood.
- Lung cancer – people who mine, mill, or manufacture asbestos, and those who use asbestos, and products containing asbestos, are more likely than the general population to develop lung

cancer, as well as other cancers of the respiratory tract, including tracheal, laryngeal, and bronchial cancers.

- Mesothelioma – a rare form of cancer that is found in the thin membrane lining (pleura) of the lung, chest, abdomen, and heart. The vast majority of cases are linked to asbestos exposure.

Exposure may also occur through ingesting (swallowing) asbestos, especially where airborne asbestos may deposit in the nose and mouth. Although some gastrointestinal cancers have been reported in asbestos-exposed employees, the evidence is considered suggestive, but not sufficient, to link asbestos exposure to those cancers [IOM 2006].

Exposure to Libby amphibole results in the same types of adverse health effects as are seen with exposure to other asbestos fibers. Mortality and morbidity studies on the mine and mill employees from Libby have reported adverse health effects in these employees, including lung cancer, mesothelioma, nonmalignant respiratory disease, asbestosis, pleural anomalies, interstitial fibrosis, and altered lung function. Epidemiologic studies of employees exposed to Libby amphibole asbestos fibers indicate increased lung cancer and mesothelioma, as well as asbestosis and other nonmalignant respiratory diseases [Amandus and Wheeler 1987; Amandus et al. 1987; Larson et al. 2010; Peipins et al. 2003; Sullivan 2007].

Asbestos minerals are widespread in the environment. They may occur in large natural deposits or as contaminants in other minerals. Low levels of asbestos can be detected in almost any air sample. The results of numerous measurements indicate that average concentrations of asbestos in ambient outdoor air are within the range of 10^{-8} to 10^{-4} f/cc; levels in urban areas may be an order of magnitude higher than those in rural areas [ATSDR 2001]. In indoor air, the concentration of asbestos depends on whether asbestos was used for insulation, ceiling, or floor tiles, or for other purposes, and whether these asbestos-containing materials are in good condition or are deteriorated and easily crumbled. Concentrations measured in homes, schools and other buildings that contain asbestos range from about 0.00003–0.006 f/cc. Indoor air concentrations of asbestos ranged from approximately 10^{-5} to 10^{-4} f/cc in a study of air concentrations measured in 315 U.S. public and commercial facilities [ATSDR 2001].

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