Evaluation of Erionite and Silica Exposure During Forestry Activities

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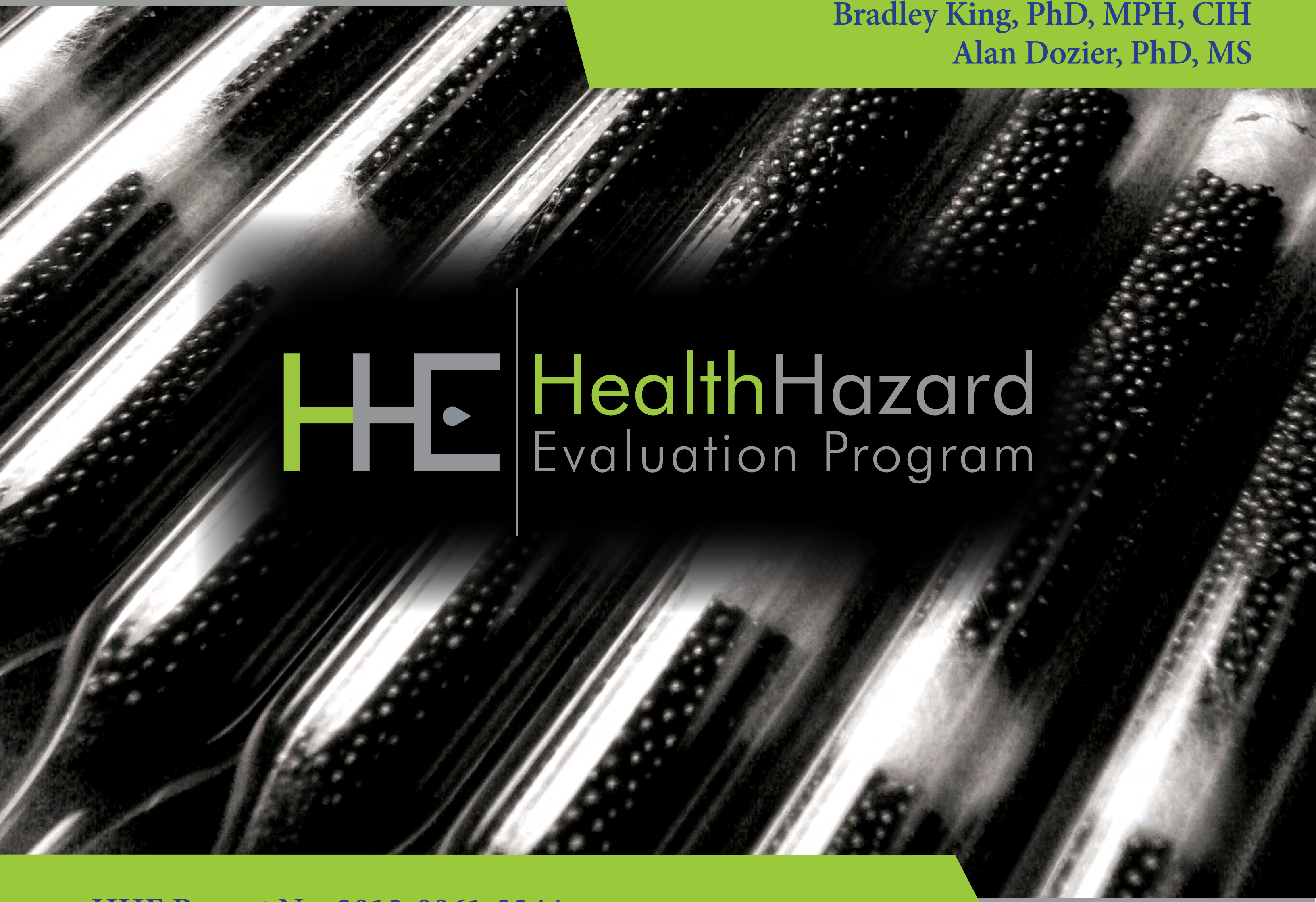

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Contents

The employer is required to post a copy of this report for 30 days at or near the workplace(s) of affected employees. The employer must take steps to ensure that the posted report is not altered, defaced, or covered by other material.

The cover photo is a close-up image of sorbent tubes, which are used by the HHE Program to measure airborne exposures. This photo is an artistic representation that may not be related to this Health Hazard Evaluation. Photo by NIOSH.

Highlights of this Evaluation

The Health Hazard Evaluation Program received a request from a federal government agency. This employer was concerned about potential employee exposures to erionite mineral fibers during forestry activities in areas where erionite had been confirmed or was suspected to be present.

What We Did

- We observed employees thinning, felling, and bucking trees; digging fireline; spraying invasive weeds; mowing campgrounds; using a Bobcat® to masticate timber and grade roads; and reclaiming a push pit.
- We took personal air samples for mineral fibers and respirable crystalline silica.
- We took rock and soil samples to analyze for erionite.

What We Found

- We developed a revised approach to confirm erionite in air samples.
- Most of the personal air samples contained erionite.
- The rock and soil samples contained erionite.
- Some task-based personal air samples contained respirable crystalline silica.

We took air samples for erionite mineral fibers and respirable crystalline silica during forestry activities and collected bulk rock and soil samples in the vicinity of the employees. All employees were exposed to erionite mineral fiber. We recommended against repairing roads with aggregate that contained erionite. We also recommended controlling dust exposures with ventilated vehicle cabs, wet methods, and other work practices.

What the Employer Can Do

- Do not repair roads with aggregate that contains erionite.
- Keep the windows and doors to the equipment operators' cabs closed when operating equipment or driving down dirt roads.
- Maintain air filters in the equipment regularly and improve air filtration in the vehicle cabs.
- If soil is dry, wet it before doing dust-generating activities.
- Provide clean hearing protection on work trucks.
- Wash personal protective equipment, such as turnout gear, regularly to remove dust and dirt.

What Employees Can Do

- Change hearing protection more frequently and do not reuse when dirty.
- When personal protective equipment, such as turnout gear, is contaminated, ask the employer to have it cleaned. Do not take personal protective equipment home for cleaning.

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Abbreviations

µm	Micrometer
Al	Aluminum
Ca	Calcium
EDS	Energy-dispersive spectroscopy
FBAS	Fluidized bed asbestos segregator
f/cc	Fibers per cubic centimeter
g	Grams
K	Potassium
MERV	Minimum efficiency reporting value
Na	Sodium
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PEL	Permissible exposure limit
PCM	Phase contrast microscopy
PLM	Polarized light microscopy
PPE	Personal protective equipment
REL	Recommended exposure limit
Si	Silicon
TEM	Transmission electron microscopy
TLV®	Threshold limit value
TWA	Time-weighted average
WEEL™	Workplace environmental exposure level
XRD	X-ray diffraction

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Introduction

The Health Hazard Evaluation Program received a request from a management representative at a federal government agency whose employees work in the Sioux Ranger District of the Custer National Forest. The requestor was concerned about potential employee exposures to erionite mineral fibers when employees worked in areas where erionite was known or suspected to be present. We visited these areas in July 2013 and September 2014. We sent summary letters with preliminary recommendations in July 2013, April 2014, September 2014, and March 2015.

Erionite and Respirable Crystalline Silica

Erionite is a member of the zeolite mineral family. It is a naturally occurring mineral found in some geologic environments, including extensive fine-grained volcanic ash deposits of a certain age that have been altered by weathering and ground water. Erionite deposits have been identified in all of the western states except Washington [USGS 1996, 2010]. In the Sioux Ranger District of the Custer National Forest, the geologic formations that may contain erionite are the Arikaree Formation and White River Group, specifically the Chadron and Brule formations [Van Gosen et al. 2012]. Exposure to erionite fibers is associated with health effects similar to those typically seen with exposure to asbestos, including malignant mesothelioma [Carbone et al. 2001; Kliment et al. 2009]. Health effects associated with exposure to erionite are described in Appendix B.

Crystalline silica is another mineral commonly found in many geologic formations, usually as quartz. Occupational exposure to respirable crystalline silica has been associated with silicosis, lung cancer, and other airway diseases [NIOSH 2002]. Erionite fibers and crystalline silica only pose a health hazard when they are airborne.

Thinning, Felling, and Bucking Trees

Thinning tree growth is done to prevent forest fires. Removing slower growing or defective trees creates more space between trees. By creating more space, it becomes more difficult for a fire to spread from tree to tree. Felling is the process of downing individual trees, while bucking is the process of cutting a felled and delimbed tree into logs. Personal protective equipment (PPE) worn by the sawyers included hearing protection (canal caps, ear plugs, or ear muffs), hard hat, chainsaw chaps, and safety glasses (Figure 1).

Figure 1. Thinning tree growth around the Reva Gap campground in the Slim Buttes. Photo by the National Institute for Occupational Safety and Health (NIOSH).

Digging Fireline

Fire fighters perform many tasks besides direct fire suppression during a wildland firefight. A fireline is a break in fuel (e.g., grasses, trees, shrubs) made by cutting, scraping, or digging to remove all plant debris; firelines usually range from 6 inches to 3 feet wide, with the width depending on the type of fuel and slope of the land. The fireline needs to be wide enough to prevent smoldering or burning embers from blowing or rolling across the line to ignite additional fuel and perpetuate the fire. While digging fireline can be done by mechanized equipment such as bulldozers, it is more commonly done using hand tools. Fire fighters may spend 12 hours or more digging fireline per shift once a fire has started. Their PPE includes hard hats, leather gloves, and safety glasses. In addition, all fire fighters wear fire resistant clothing and carry an approximately 50-pound wildland fire pack that contains a self-rescue tent and water (Figure 2).

Figure 2. Employees using hand tools to dig fireline in the Ekalaka Hills. Photo by NIOSH.

Spraying Invasive Species

The agency employees used universal terrain vehicles to access pastures off the main roads to search for invasive plant species. When an invasive plant was discovered, the employee sprayed it with a pesticide mixture to kill it. The employee then sprayed the plant with a blue dye to indicate it had been treated. PPE for the pesticide applicator included rubber gloves, a Tyvek® suit, and safety glasses (Figure 3).

Figure 3. Using a universal terrain vehicle to access off-road locations to spray invasive weed species with pesticides. Photo by NIOSH.

Mowing Campground

The agency was responsible for maintaining the national forest campgrounds in their district. Maintaining the campgrounds included using push and riding lawnmowers and operating weed whackers. PPE for these employees included leather gloves, safety glasses, and hearing protection (ear muffs or ear plugs). Employees on the riding lawn mowers also wore hard hats.

Figure 4. Campground maintenance. Castle rock, an erionite containing rock formation, can be seen in the background. Photo by NIOSH.

Vegetation Mastication

A masticator attached to a Bobcat® grinds woody vegetation into wood chips that are deposited onto the forest floor. The masticator cuts down and grinds up whole standing trees in a single, continuous process. The operator remained inside of the closed vehicle cab of the Bobcat. PPE worn by the employee included disposable foam ear plugs and a hard hat.

Figure 5. Masticator. Photo by NIOSH.

Push Pit Reclamation

Push pits were dug to explore for uranium in the late 1950s and early 1960s. An agency employee uses a Bobcat to refill the pit by pushing the dirt that was removed from the pit into the trench, and then another employee spreads grass seed on the newly filled-in trench. The activity involves a Bobcat operator, a safety manager to evaluate radiation levels, and grass seed applicators. PPE for the Bobcat operator included ear plugs and a hard hat. No PPE was required for other team members.

Methods

Our objectives were to:

1. Assess employee exposure to erionite and respirable crystalline silica during forestry activities.
2. Determine if erionite was present in certain rock formations within the national forest.
3. Develop a revised approach to more accurately detect and measure erionite in air samples from this location.

Air Sampling

We took air samples to evaluate employee exposure to erionite and respirable crystalline silica. We did this during forestry activities including thinning, felling, and bucking trees; digging fireline; spraying invasive weed species; mowing campgrounds; using a Bobcat to masticate timber and grade roads; and reclaiming push pits. These activities took place within the Arikaree and White River rock formations in July 2013 and September 2014.

During the July 2013 visit we took 36 task-based personal air samples for erionite and 37 task-based personal air samples for respirable quartz. During the September 2014 visit, we took 14 full-shift personal air samples for erionite and 14 full-shift personal air samples for respirable quartz.

We collected and analyzed the erionite samples according to NIOSH Method 7400 [NIOSH 2015]. We then used transmission electron microscopy (TEM) with energy dispersive spectroscopy to analyze the erionite samples according to a modified NIOSH Method 7402 for asbestos [NIOSH 2015]. Initially, we attempted to confirm the presence of erionite by TEM using the method described by Dogan and Dogan [2008]. In doing so, we discovered limitations of the Dogan and Dogan method, which are described in Appendix A. As a result of those limitations, we developed and used the following methodology. The fibers that we found in the air samples were easily visualized using TEM (Figure 6). Fibers meeting certain size parameters (length greater than 5 micrometers [µm], and length to width aspect ratio greater than 3:1) underwent energy-dispersive spectroscopy (EDS) to identify the chemical composition of the fiber. A fiber was considered erionite if it contained major peaks of silicon (Si) and aluminum (Al) and minor peaks of at least one of the elements calcium (Ca), sodium (Na), or potassium (K).

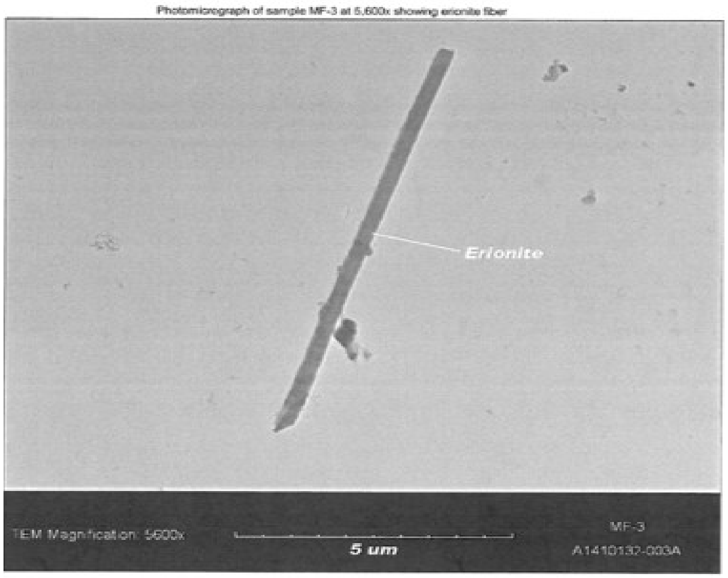


Figure 6. Erionite fiber under TEM. Photo by Bureau Veritas North America.

We collected the respirable crystalline silica samples on preweighed, 5-µm pore size polyvinyl chloride filters with a Dorr-Oliver nylon cyclone at a nominal flow rate of 1.7 liters per minute in July 2013, and with a BGI cyclone at a nominal flow rate of 4.2 liters per minute in September 2014. The July 2013 samples were task-based and the September 2014 samples were full-shift. We analyzed the samples according to NIOSH Method 7500 [NIOSH 2015] with modification. The modification included wiping the interior walls of the filter cassette with the back side of the sample filter to collect particles on the inside of the cassette walls as recommended by NIOSH [2014a].

Bulk Rock and Soil Samples

We collected bulk rock samples and soil samples to determine if erionite was present in the rock formations surrounding the areas where employees worked. We analyzed all the bulk rock samples collected in 2013 by phase-contrast microscopy (PCM) to look for fibers. In the laboratory, we gently crushed small amounts of material into a fine powder between two glass slides and mounted the material in a drop of mounting medium. A few of these samples were also analyzed in different laboratories for confirmation of erionite by polarized light microscopy (PLM), x-ray diffraction (XRD), and TEM-EDS.

During the September 2014 visit, we collected 10 bulk soil samples according to a bulk sampling method for asbestos developed by the U.S. Environmental Protection Agency [EPA 2013]. Each of these 10 samples was collected as a composite consisting of a total of 50 grams (g) of soil from 30 individual sampling points equidistant from each other and representative of the 1,500-square-foot cell around each worker. We identified the location of each cell using GPS coordinates.

In the laboratory, the sample was shaken to homogenize it. From each sample we split two 10-g portions into different containers; the remaining 30 g of soil was not analyzed. One 10-g portion was analyzed according to a modified NIOSH Method 9002 for bulk asbestos by PLM [NIOSH 2015]. The modification includes identifying erionite in lieu of asbestos. The second 10-g portion was analyzed by XRD. Approximately 1 g of the sample was added to a mortar and ground to a fine powder with a pestle. The ground powder was wet sieved through a 45-µm sieve using 2-propanol, which was then evaporated. Approximately 0.5 g of sample powder was placed into an aluminum sample plate, which was then placed in the automated sample changer. A fast, full range XRD scan of the powder was performed to determine the primary sample constituents. Slow scans for selected regions were then done to confirm erionite presence. The sample peak identifications were assigned referencing known mineral data found in the American Mineralogist crystal structure database and Jade 8.0 software [Bish and Chipera 1991].

We also analyzed the bulk samples by a fluidized bed asbestos segregator (FBAS). We blended 1-g aliquots of the soil sample with 19 g of clean sand and mixed them together. We then placed the soil-sand combination in the glass vessel of the FBAS according to a procedure developed by U.S. Environmental Protection Agency researchers [Januch et al. 2013]. Filtered air was passed through the vibrated sample, and a portion of the outlet air was collected on a 25-mm diameter mixed-cellulose ester filter in a conductive plastic cassette. We then examined the filter under PCM. We identified fibers as erionite using their morphology and refractive index and then counted and measured them. We calculated an estimate of fiber mass per unit area of filter from the dimensions and the density of erionite, and converted the result to a mass per gram of soil concentration using the known area of filter and the air flows through the sample and filter.

Results and Discussion

Erionite Air Sampling

The July 2013 visit took place in the following areas: (1) Slim Buttes, (2) Long Pines, (3) East Short Pines, and (4) the Ekalaka Hills. All of these locations were located within outcrops of the Arikaree and White River rock formations and included soils developed from those locations. We took air samples for the entire duration of dust-generating tasks, though not for the entire work shift, which included long commute times into and out of forest service lands. Erionite concentrations ranged from not detected to 0.36 fibers per cubic centimeter (f/cc). The tasks (Table 1) that resulted in the highest airborne mineral fiber concentrations included operating the masticator in the East Short Pines (0.36 f/cc), mowing in the Slim Buttes/Reva Gap campground (0.26 f/cc), digging fireline in Ekalaka Hills with the polaski tool (0.11 f/cc), and chainsaw operations in the East Short Pines (0.11 f/cc). These exposures cannot be directly compared to the NIOSH recommended exposure limit (REL) of 0.1 f/cc for asbestos because the definition of airborne asbestos fibers does not explicitly encompass elongate mineral particles from other micro-fibrous minerals such as erionite.

Table 1. Task-based personal air sample results by location and activity, July 2013

Location: activity (Number of employees sampled)	Erionite (f/cc)	Sample duration (minutes)
Slim Buttes/Reva Gap: campground maintenance		
Felling and bucking (11 employees)	Not detected*–0.056	155–233
Mowing (5 employees)	0.012–0.26	54–290
Long Pines: universal terrain vehicle operation		
Operator and assistant (4 employees)	0.0077–0.015	302–336
East Short Pines: thinning, bucking, felling, mastication		
Chainsaw operation (6 employees)	0.024–0.11	141–225
Masticator (1 employee)	0.36	213
Log stacker (1 employee)	0.061	214
Skid loading (1 employee)	0.078	164
Ekalaka Hills: digging fire line		
Polaski† (2 employees)	0.025 and 0.11	204 and 206
Combi† (2 employees)	0.081 and 0.026	203 and 321
Rogue hoe† (2 employees)	0.016 and 0.057	218 and 324
McCloud† (1 employee)	0.0081	320

*Not detected means no fibers were seen after counting 100 TEM grids.

†These are the names of the tools that the employees used while digging fire line.

We returned to the East Short Pines and the Slim Buttes areas in September 2014 to re-evaluate the full-shift exposure for the tasks that previously contributed to the highest airborne mineral fiber concentrations. Table 2 lists the results of these full-shift samples. The concentrations ranged from 0.009–0.096 erionite f/cc. We collected these samples while it was raining and snowing. Airborne concentrations would likely be higher in dry weather.

Table 2. Full-shift personal air sample results by location and activity, September 2014

Location: activity (Number of employees sampled)	Erionite (f/cc)	Sample duration (minutes)
East Short Pines: thinning, bucking, felling, mastication		
Chainsaw operation (4 employees)	0.012–0.096	516–522
Masticator (1 employee)	0.015	501
Driving (1 employee)	0.013	496
Slim Buttes/Reva Gap: campground maintenance and push pit reclamation		
Mowing (3 employees)	0.0010–0.0020	296–298
Seeding push pit (2 employees)	0.0050 and 0.0060	595 and 597
Safety at push pit (2 employees)	0.0030 and 0.0040	564 and 569
Bobcat operator (1 employee)	0.009	585

Respirable Crystalline Silica

Respirable crystalline silica was present, but below the minimum quantifiable concentration in some task-based personal air samples collected in July 2013 (Table 3). Quartz was the only form of crystalline silica detected. The concentration estimates were based on short duration samples and cannot be directly compared to full-shift occupational exposure limits (OELs). Respirable crystalline silica was not detected in any of the full-shift air samples collected in September 2014. The minimum detectable concentration ranged from 0.002–0.004 milligrams per cubic meter, which is below the ACGIH threshold limit value (TLV) of 0.025 milligrams per cubic meter. Health effects associated with exposure to respirable crystalline silica are described in Appendix B. Although we did not find detectable silica concentrations in full-shift samples taken on the follow-up evaluation, crystalline silica was detected in some short-term air samples on the initial evaluation, a finding that was consistent with our results during another health hazard evaluation involving outdoor work in federal land known or suspected to contain erionite [NIOSH 2014b]. In addition, samples from September 2014 were taken while it was raining and snowing; airborne concentrations could be higher in dry weather.

Table 3. Task-based personal air sample results for silica by location and activity, July 2013

Location: activity (Number of employees sampled)	Quartz (milligrams per cubic meter)	Sample duration (minutes)
Slim Buttes/Reva Gap: campground maintenance		
Felling and bucking (11 employees)	Not detected	155–233
Mowing (4 employees)	Not detected	54–290
Long Pines: universal terrain vehicle operation		
Operator and assistant (4 employees)	Not detected	302–336
East Short Pines: thinning, bucking, felling, and mastication		
Chainsaw operation (6 employees)	Not detected–(0.02)*	141–225
Piler/stacker (2 employees)	Not detected	139 and 219
Masticator (1 employee)	(0.02)	213
Log stacker (1 employee)	(0.02)	214
Skid loading (1 employee)	Not detected	164
Ekalaka Hills: digging fire line		
Polaski† (2 employees)	(0.03 and 0.05)	204 and 206
Combi† (2 employees)	(0.03 and 0.03)	203 and 321
Rogue hoe† (2 employees)	(0.01 and 0.03)	218 and 324
McCloud† (1 employee)	(0.01)	320
Minimum detectable concentration	0.01–0.02	—
Minimum quantifiable concentration	0.030–0.070	—

*Parentheses are used when results were between the minimum detectable concentration and the minimum quantifiable concentration, making these estimated results due to greater uncertainty associated with these values.

†These are the names of the tools that the employees used while digging fire line.

Bulk Rock and Soil Samples

In July 2013, we collected bulk rock samples from various locations in the Arikaree and White River Formations in the Sioux Ranger District of the Custer National Forest. These locations included the cliffs above the campground at Reva Gap, in the Castles area of Slim Buttes, and in the Capitol Rock area of Long Pines. All samples contained fibrous minerals. Some of these samples were sent for further identification in other laboratories. All laboratories confirmed that the fibrous minerals in each sample included erionite. Some of these laboratories also compared reference erionite samples from Rome, Oregon, and Karain, Cappadocia, Turkey. We observed some differences in composition and mineralogy between the reference erionites and the Custer National Forest erionite samples, which may have a bearing on toxicity (Appendix C).

We observed the highest concentration of fibrous minerals in the samples collected in the Arikaree Formation, about 30 meters above the White River Formation. The area of fibers by point-counting is high (Figure 7), but because of the much larger volume of the accessory mineral grains (mainly quartz) the weight percentage of erionite is low (about 1%).

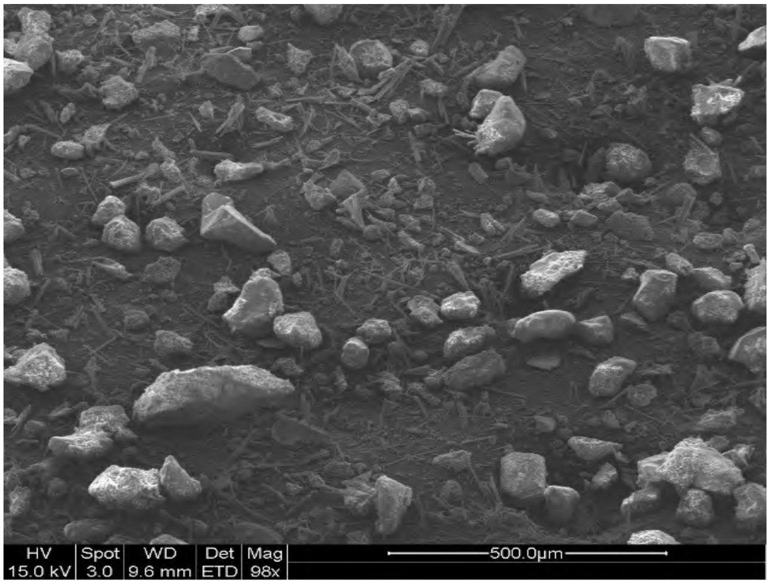


Figure 7. Scanning electron microscopy image at 100x of erionite. Photo by NIOSH.

We split each of the bulk soil samples into three separate groups and analyzed each split by PLM, FBAS/PCM, and XRD. The variability in the analytical results is believed to be due to method variability. The bulk soil samples that we collected in September 2014 and analyzed by PLM consisted mostly of particles of calcite, gypsum, quartz, opaque minerals, and cellulose fibers. Most of the fibers seen (8%–10%) were cellulose fibers. The percentage of erionite fibers in the soil samples analyzed by PLM ranged from not detectable to approximately 5% (Table 4). The soil samples collected in the East Short Pines had the highest percentage of erionite.

Table 4. Soil sample results collected in September 2014

Task description	Latitude	Longitude	Elevation (feet)	PLM erionite (%)	FBAS erionite (%)	XRD erionite (%)
East Short Pines						
Masticating	45°22.629N	103°43.366W	3915	5	5.1	10
Masticating	45°22.710N	103°42.906W	3986	3	3.9	10
Sawing	45°22.612N	103°43.168W	3946	< 1	1.0	5
Masticating	45°22.683N	103°42.630W	3940	< 1	1.3	1
Sawing	45°22.618N	103°43.195W	4051	< 1	1.4	2
Slim Buttes						
Mowing	45°31.559N	103°10.714W	3301	2	2.5	6
Mowing	45°31.684N	103°10.613W	3342	3	4.2–4.6	7
Mowing	45°31.887N	103°10.711W	3299	ND	0.1	4
Mowing	45°31.852N	103°10.719W	3347	ND	0.1	7
Push pit	45°34.965N	103°11.918W	3632	ND	ND	4

ND = not detectable

The soil samples analyzed by a fast qualitative XRD scan (5 to 80 two-theta degrees) identified quartz, clinoptilolite (another zeolite that can crystallize in a needle-like or fibrous form, but which is not considered carcinogenic), alkali feldspar, and calcite. We found zeolites in all samples. In addition, some samples had low levels of erionite (Table 4), which required further confirmation with a slow scan below 20 two-theta degrees so that erionite could be confirmed in the presence of interfering minerals. A high purity (80%–85%) erionite reference sample was obtained from Rome, Oregon. Two lower concentration erionite reference samples were prepared from the Rome, Oregon, reference erionite material. Reference A contained 0.7% erionite, while reference B contained 5.1% erionite. The reference A sample was created to investigate the limit of detection, while reference B was prepared to investigate the erionite fingerprint and compare it to the bulk soil samples. The values in Table 4 for XRD should be considered rough estimates.

We took photographs of representative erionite fibers seen with PLM and PCM after FBAS concentration (Figures 8 and 9). We anticipated the FBAS results would be similar to concentrations seen in the PLM analysis, but with more precision, because of the similarities of the two methods (Table 4). Erionite mineral fibers can clearly be seen in both microscopic photographs and can be visually differentiated from other types of fibers. Interestingly, the erionite fibers found in this region differed from erionite fibers found in Cappadocia, Turkey, and Rome, Oregon. Appendix C contains a description of these differences.

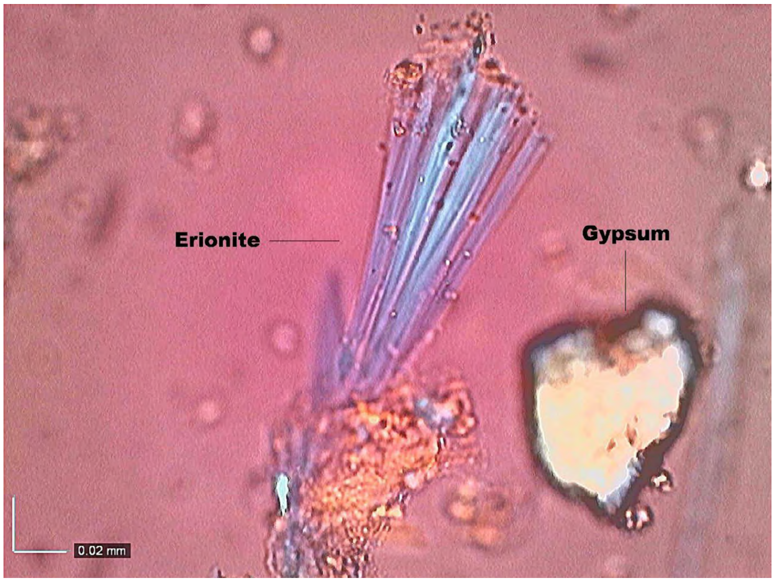


Figure 8. Photograph collected using PLM. Photo by Bureau Veritas North America.

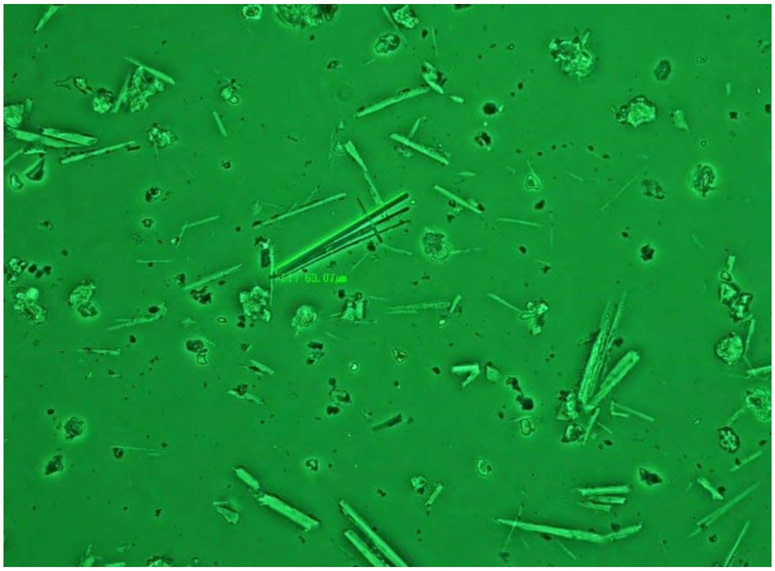


Figure 9. Photograph collected using PCM after FBAS concentration. Photo by NIOSH

Observations

Hearing protection was required for certain tasks. In those cases the employees used it diligently. However, their disposable foam ear plugs were often covered in dirt and oil. Using dirt- and oil-coated ear plugs can introduce these contaminants into the ear canal and can also alter the fit of the ear plug and therefore potentially limit its effectiveness. Employees told us that new ear plugs were not available on the work trucks. In addition, the agency-issued turnout gear was dirty and had oil on it. Some employees indicated to us that they only washed their turnout gear a few times a year. The National Fire Protection Association recommends that fire fighter protective clothing be kept clean to ensure its proper performance. Soiled or contaminated turnout gear is a hazard to fire fighters because oils and contaminants can be flammable, toxic, or carcinogenic. In addition, dirty ensembles can have reduced protective performance [NFPA 2011, 2014].

One seasonal employee who was applying pesticides and dye to invasive weed species did not know about the hazards of the pesticides and reported he had neither seen the safety data sheets nor received chemical-specific health and safety training.

The Bobcat Skid Steer was used for multiple tasks, including vegetation mastication, grading roads, removing plants from the center of the roadway, and filling in the push pit with dirt. The Bobcat had two cabin air filters, one on the fresh air intake and one on the recirculating air intake. We observed accumulated dust inside the cab. Recent NIOSH studies have shown that an effective vehicle cab filtration system includes both a powered and pressurized air intake as well as filtered circulation air to reduce respirable dust [Cecala et al. 2012; Organiscak et al. 2013; Cecala et al. 2014]. The ventilation system on the Bobcat Skid Steer was not powered, and there was no change-out schedule for its air filters. Also, we were unable to determine the minimum efficiency reporting value (MERV) for the filters for comparison with recommendations.

Conclusions

Erionite mineral fibers were found in the personal air samples and in the bulk rock and soil samples collected in rock formations within the national forest. We defined erionite as fibers that had a length greater than 5 µm, and a length to width aspect ratio greater than 3:1 with major peaks of silicon and aluminum and minor peaks of at least one of the elements Ca, Na, or K. Although OELs specific to erionite have yet to be developed, and toxicological studies of the health effects of the various forms of erionite are ongoing, health hazards of erionite exposure have been identified elsewhere. Characterizing and minimizing potentially hazardous exposures until an evidence-based OEL for erionite is developed is necessary. Although we did not measure overexposures to respirable crystalline silica during this evaluation, detectable silica concentrations were found in several task-based personal air samples and we have previously identified overexposures among employees performing similar outdoor tasks on other federal land. Therefore, minimizing dust exposure during dust-generating activities is prudent.

Recommendations

On the basis of our findings, we recommend the actions listed below. We encourage the agency to use a labor-management health and safety committee or working group to discuss our recommendations and develop an action plan. Involve those who do the work in the national forest.

Our recommendations are based on an approach known as the hierarchy of controls. This approach 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 feasible, administrative measures and personal protective equipment may be needed.

Elimination and Substitution

Eliminating or substituting hazardous processes or materials reduces hazards and protects employees more effectively than other approaches. Prevention through design, considering elimination or substitution when designing or developing a project, reduces the need for additional controls in the future.

1. Do not use aggregate known or suspected to contain erionite to build or repair roads.

Engineering Controls

Engineering controls reduce employees' exposures by removing the hazard from the process or by placing a barrier between the hazard and the employee. Engineering controls protect employees effectively without placing primary responsibility of implementation on the employee.

1. Keep the windows and doors to the equipment operators' cabs closed when operating equipment or driving down dirt roads.
2. Maintain equipment air filters regularly as recommended by the equipment

manufacturers. Change the gaskets and seals when signs of age (cracking or wear) or damage occur. Air intake filters should have a MERV of 16 and should be part of a powered, pressurized system. Ensure the enclosed cab has the structural integrity to achieve pressurization. The recommended flow rate should be 40–140 cubic feet per minute. The filtration efficiency of the recirculation filter should be between a MERV-14 and MERV-16 filter at a flow rate of 200–300 cubic feet per minute [Cecala et al. 2014].

3. Wet wash equipment and vehicle exteriors, and vacuum the inside of work trucks with a high-efficiency particulate air filtered vacuum to minimize the buildup of dust in the cab of the vehicles.

Administrative Controls

The term administrative controls refers to employer-dictated work practices and policies to reduce or prevent hazardous exposures. Their effectiveness depends on employer commitment and employee acceptance. Regular monitoring and reinforcement are necessary to ensure that policies and procedures are followed consistently.

1. Educate employees on the health effects and hazards of crystalline silica and the potential health effects of erionite, where they are likely to encounter these hazards, which tasks are likely to expose them, and how they can protect themselves. Inform employees of the need to use dust control methods during any dust-generating work, and train them on dust control techniques. Links for information on silica exposure and dust control techniques that will help you develop a comprehensive training program are available at http://www.cdc.gov/niosh/topics/silica/.
2. Wet the soil or aggregate before disturbing it to reduce dust generation. It is common practice at construction and other outdoor work sites to use water trucks for dust suppression.
3. Restrict, whenever possible, dust-generating activities to times when environmental conditions are conducive to minimizing dust generation (e.g., snow, rain, calm weather). Avoid dust-generating tasks on windy days. Whenever possible, schedule dust-generating tasks on days when the soil is already moist.
4. Establish standard operating procedures for reducing dust exposure for vehicles used on dirt/gravel roads (i.e., drive slowly, vents closed, windows up).
5. Characterize fire fighter exposure to erionite during fire suppression activities (wildland fires and prescribed burns).
6. Ensure an effective hazard communication program so that employees understand the hazards associated with workplace chemicals and know how to protect themselves. Follow the guidelines available at https://www.osha.gov/dsg/hazcom/.

Personal Protective Equipment

Personal protective equipment is the least effective means for controlling hazardous exposures. Proper use of personal protective equipment requires a comprehensive program and a high level of employee involvement and commitment. The right personal protective equipment must be chosen for each hazard. Supporting programs such as training, change-out schedules, and medical assessment may be needed. Personal protective equipment should not be the sole method for controlling hazardous exposures. Rather, personal protective equipment should be used until effective engineering and administrative controls are in place.

1. Provide employees with clothes (i.e., turnout gear) and boots that are solely designated for work activities, and prevent employees from washing these work clothes at home. Require employees who have been working in dusty areas to change into clean clothing before leaving the worksite.
2. Wash protective clothing and other equipment (chaps, hard hats, and tools) regularly to remove dust, dirt, and other contaminants.
3. Inspect hearing protection devices prior to each use. When contaminated, clean them if they are reusable or throw them away if they are disposable. Ensure that replacement hearing protection devices are available to employees working in the field.

Appendix A: Sampling and Analytical Methods

Air samples for erionite were first analyzed by PCM according to NIOSH Method 7400 to identify fibers [NIOSH 2015]. Fibers are defined as those particles having a length-to-width aspect ratio equal to or greater than 3:1. Fibers longer than 5 µm are counted until either a minimum of 100 fibers is counted in 20 or more fields, or a maximum of 100 fields is examined. Samples with a high fiber count were then selected for a second analysis using TEM.

We analyzed samples from our first visit with TEM per NIOSH Method 7402 and then applied a method developed by Dogan and Dogan [2008] to determine if the fibers were erionite. Portions of the mixed cellulose ester filters were transferred to a glass slide and then placed on a 200-mesh copper TEM grid. Structures that had a width to length aspect ratio of greater than 3:1 and a minimum length of 5 µm were selected for further evaluation. We first identified a fiber by morphology then evaluated its elemental makeup using EDS. The Dogan and Dogan paper recommended that to confirm erionite, the fibers have a magnesium content of < 0.8 atoms per unit cell, and a balance error (E%) of $\leq 10\%$. Atomic percentages of the elements, not weight percentages, should be used when computing the balance error formula.

The E% was determined using the following formula:

$$E\% = [(Al+Fe)-(Na+K)-2(Ca+Mg)]/[(Na+K)+2(Ca+Mg)]*100$$

Note the minus sign in front of the 2, which was accidentally left out in the published Dogan and Dogan paper [2008]. The balance error formula is applicable to erionite crystals from vesicles in mafic volcanic lavas but works less well when applied to erionites that have formed in a sedimentary environment [Dogan 2012]. The erionites from the Custer National Forest were formed in a sedimentary environment; therefore, the Dogan and Dogan method might not work well for these fibers.

When using a TEM for the EDS analysis of erionite, two problems are encountered that can have a large impact on accuracy: the beam sensitivity of erionite and the accuracy of the analysis software package. The beam sensitivity problem is most notable by the observation of Na reduction under electron beam exposure during the EDS analysis. To address this problem, we used a JEOL 2100F high resolution TEM with scanning capability and detectors for EDS and electron energy-loss spectroscopy for sample analysis. We analyzed three bulk samples of highly concentrated erionite from (1) Rome, Oregon; (2) Custer National Forest, South Dakota; and (3) Cappadocia, Turkey. To prepare the samples for analysis, the three samples were crushed to a fine powder in a negative pressure hood. We then transferred a small portion of each fine powder to a lacey carbon TEM grid for analysis. We performed EDS analysis of a reference zeolite material from the National Institute of Standards and Technology (8851A) to find acceptable beam conditions for EDS analysis. The Na content in 8851A is very beam sensitive, meaning if the beam is left in one spot for even a short period of time, the Na content may degrade. Beam conditions tested were standard TEM imaging mode with a small condenser aperture and small spot size to minimize beam dose, and scanning TEM imaging mode with different spot sizes. While 8851A does not have certified values for major and minor trace element contents, as do standard reference materials, 8851A does provide information values and a common source of zeolite material for measurement comparisons. We found only the smallest scanning TEM spot size of 0.2 nanometers with a 25-µm condenser aperture would not produce alteration in composition of the 8851A standard or the erionite. In addition, the scanning TEM probe could not be stopped but always had to be scanning a small region to prevent the reduction in Na content.

As mentioned earlier, another factor affecting EDS results is the quantification software used to obtain atomic and weight percentages for the elements present. The currently available commercial EDS quantification software functions as a "black box," without the user's knowledge of the analytical parameters or the accuracy of the quantification algorithms used. We obtained our analytical results with two commercial EDS software packages, Gatan and Oxford, and compared them to the 8851A elemental values. After the EDS data acquisition conditions and analysis method were determined, the ten samples from each of the three types of "known" erionite from Rome, Oregon, Custer National Forest, and Cappadocia Turkey were analyzed. Percent errors (by the percent error formula or balance equation) were computed for each sample using each type of commercial software packages. The average percent error for Rome, Oregon using the Oxford software was 54.2 (range 17–95) and 178.8 (range 36 – infinity) using the Gatan Software. For the Custer National Forest samples, the average percent error was 311.8 (range 28 – 975) using Oxford and 386.6 (range 85 – infinity) using Gatan. The Cappadocia, Turkey samples had a percent error of 311.8 (range 28–975) with Oxford and 386.6 (range 84.8 – infinity) with Gatan. These results show that the percent error formula could not be used to identify erionite with either type of analytical software because not one fiber analyzed passed the less than 10% rule.

Because of the problems associated with using the balance equation for erionite identification, we developed a new way to confirm erionite. We again used the "known" erionite samples to compare the Gatan and Oxford software, but this time only for Na, Al, and Si. The Gatan software produced results differing from the reference weight percentages of Na, Al, and Si by 23.8, 7.2, and 12.9 percent, whereas the Oxford analysis differed from the reference by 6.4, 3.2, and 2.0 percent respectively. This comparison shows that the Gatan analysis software had a maximum deviation from the reference of 23.8 percent whereas the Oxford software had a maximum deviation of 6.4 percent. These comparisons were done with the 0.2 nm probe that was used for the analysis of all samples. This indicates that accurate and reproducible EDS analyses of erionite can be obtained from a TEM/scanning TEM microscope as long as a careful assessment is made of the EDS quantitative software and beam exposure using a beam sensitive EDS standard.

Our revised method to identify erionite included the following: we first identified a fiber then evaluated its elemental makeup using electron dispersive spectroscopy. We defined erionite mineral fiber as any particle longer than 5 µm, with an aspect ratio of equal to or greater than 3:1 length to width, with strong peaks for Si and Al and minor peaks for at least one of the elements Na, Ca, or K.

Appendix B: Occupational Exposure Limits and Health Effects

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 pre-existing 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 time-weighted average (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 limit or ceiling values. Unless otherwise noted, the short-term exposure limit 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.

- The U.S. Department of Labor Occupational Safety and Health Administration (OSHA) permissible exposure limits (PELs) (29 CFR 1910 [general industry]; 29 CFR 1926 [construction industry]; and 29 CFR 1917 [maritime industry]) are legal limits. These 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 2010]. NIOSH also recommends risk management practices (e.g., engineering controls, safe work practices, employee education/training, personal protective equipment, and exposure and medical monitoring) to minimize the risk of exposure and adverse health effects.
- Other OELs commonly used and cited in the United States include the threshold limit values (TLVs), which are recommended by the American Conference of Governmental Industrial Hygienists, a professional organization, and the workplace environmental exposure levels (WEEL), which are recommended by the American Industrial Hygiene Association, another professional organization. The TLVs and WEELs are developed by committee members of these associations from a review of the published, peer-reviewed literature. These OELs are not consensus standards. TLVs 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 2015]. WEELs have been established for some chemicals "when no other legal or authoritative limits exist" [AIHA 2015].

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 http://www.dguv.de/ifa/GESTIS/GESTIS-Internationale-Grenzwerte-für-chemische-Substanzen-limit-values-for-chemical-agents/index-2.jsp contains international limits for more than 1,500 hazardous substances and is updated periodically.

OSHA 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 [Occupational Safety and Health Act of 1970 (Public Law 91–596, sec. 5(a)(1))]. 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. NIOSH investigators also encourage use of the hierarchy of controls approach to eliminate or minimize workplace hazards. This includes, in order of preference, the use of (1) substitution or elimination of the hazardous agent, (2) engineering controls (e.g., local exhaust ventilation, process enclosure, dilution ventilation), (3) administrative controls (e.g., limiting time of exposure, employee training, work practice changes, medical surveillance), and (4) personal protective equipment (e.g., respiratory protection, gloves, eye protection, hearing protection). Control banding, a qualitative risk assessment and risk management tool, is a complementary approach to protecting employee health. Control banding focuses on how broad categories of risk should be managed. Information on control banding is available at http://www.cdc.gov/niosh/topics/ctrlbanding/. This approach can be applied in situations where OELs have not been established or can be used to supplement existing OELs.

Erionite

Erionite is a naturally occurring mineral that belongs in a group of hydrated aluminosilicate minerals called zeolites [NTP 2011]. Erionite has three forms: erionite-Ca, erionite-Na, and erionite-K, each determined by the predominant element [Coombs et al. 1998; Dogan et al. 2008]. The International Agency for Research on Cancer has determined that there is sufficient evidence in humans to classify erionite as carcinogenic to humans, and that it causes mesothelioma [IARC 2004]. This determination was made primarily because of exposure studies of villagers in the Cappadocia region of Turkey, and did not examine the variability of the different forms of erionite. Extensive toxicological and epidemiological research has been done on exposure to erionite in the Cappadocia region of Turkey [Baris et al. 1978; Baris and Grandjene 2006; Carbone et al. 2007]. Pulmonary fibrosis and mesothelioma have been associated with people who live and work in areas of the western United States known to have erionite [Rom et al. 1983; Ilgren et al. 2008]. Dogan [2012] determined that erionite-K was positively identified in Oregon, Nevada, Germany, and the Cappadocia region of Turkey. Research on health effects of erionite-Na and erionite-Ca is sparse.

Airborne erionite fibers have no specific OELs. NIOSH has established an REL for asbestos of 0.1 fibers greater than 5 µm in length per cubic centimeter of air as determined in a sample collected over any 100-minute period at a flow rate of 4 liters per minute. In 1990, NIOSH revised the REL to include elongated mineral particles that also met the same length (> 5 µm) and aspect ratio (3:1 length:width) definition of asbestos and expanded the method to use NIOSH Method 7400 or equivalent (e.g., NIOSH Method 7402). The revised definition of airborne asbestos fibers did not explicitly encompass elongated mineral particles from other micro-fibrous minerals (e.g., erionite) that are known to be associated with health effects similar to those caused by asbestos [NIOSH 2011]. Therefore, for the purpose of this report, we use 0.1 f/cc OEL only as a point of reference. Characterizing and minimizing potentially hazardous exposures until an evidence-based OEL for erionite is developed remains a necessity.

Respirable Crystalline Silica

Silica, or silicon dioxide, occurs in a crystalline or noncrystalline (amorphous) form. In crystalline silica, the silicon dioxide molecules are oriented in a fixed pattern versus the random arrangement of the amorphous form. The more common crystalline forms in workplace environments are quartz and cristobalite, and to a lesser extent, tridymite. Occupational exposures to respirable crystalline silica (quartz and cristobalite) have been associated with silicosis, lung cancer, pulmonary tuberculosis, and airway diseases.

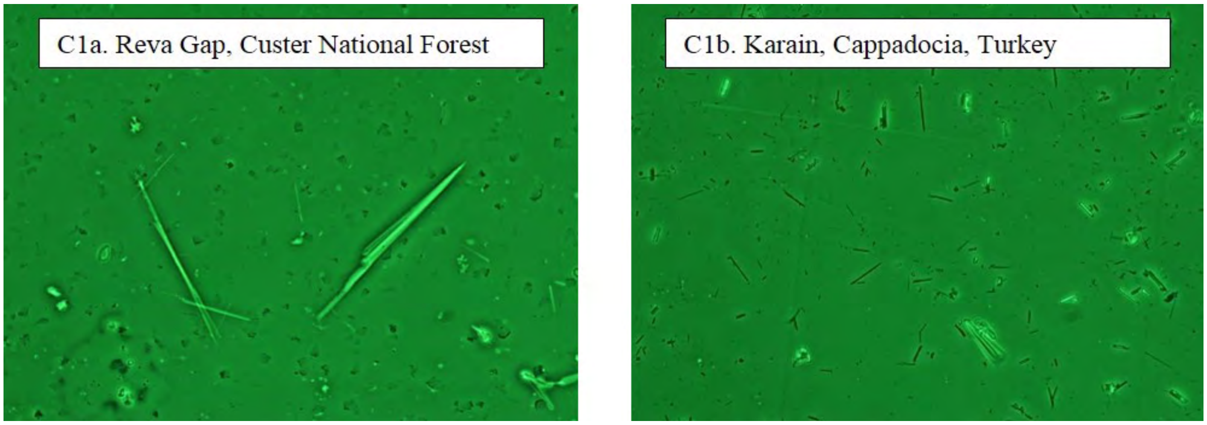
Silicosis is a fibrotic disease of the lung caused by the deposition of fine crystalline silica particles in the lungs. It is the disease most often associated with exposure to respirable crystalline silica. This lung disease is caused by the inhalation and deposition of crystalline silica particles that are 10 µm or less in diameter. Particles 10 µm and below are considered respirable particles and classified as having the potential to reach the lower portions of the human lung (alveolar region). Although particle sizes 10 µm and below are considered respirable, some of these particles can be deposited before they reach the alveolar region [Hinds 1999]. Symptoms of silicosis usually develop insidiously, with cough, shortness of breath, chest pain, weakness, wheezing, and nonspecific chest illnesses. Silicosis usually occurs after years of exposure (chronic), but may appear in a shorter period of time (acute) if exposure concentrations are very high. Acute silicosis is typically associated with a history of high exposures from tasks that produce small particles of airborne dust with a high silica content [NIOSH 1986]. Even though the carcinogenicity of crystalline silica in humans has been strongly debated in the scientific community, the International Agency for Research on Cancer in 1996 concluded that there was "sufficient evidence in humans for the carcinogenicity of inhaled crystalline silica in the form of quartz or cristobalite from occupational sources" [IARC 1997]. A NIOSH publication also lists several other serious diseases from occupational exposure to crystalline silica. These include lung cancer and noncarcinogenic disorders including immunologic disorders and autoimmune diseases, rheumatoid arthritis, renal diseases, and an increased risk of developing tuberculosis after exposure to the infectious agent [NIOSH 2002].

When proper practices are not followed or controls are not maintained, respirable crystalline silica exposures can exceed the OSHA PEL, NIOSH REL, or the ACGIH TLV. For general industry, the OSHA PEL for respirable dust containing 1% or more of quartz is calculated by dividing 10 milligrams per cubic meter (mg/m^3) by the percent quartz in the sample, plus two [OSHA 2014]. NIOSH recommends an exposure limit of 0.05 mg/m^3 as a TWA for up to a 10-hour work day to reduce the risk of developing silicosis, lung cancer, and other adverse health effects [NIOSH 2010]. The ACGIH TLV for quartz is 0.025 mg/m^3, as an 8-hour TWA [ACGIH 2015].

Appendix C: Comparison of Erionite from the Custer National Forest with Erionites from Cappadocia, Turkey, and Rome, Oregon

Morphological Differences

Figure C1a shows Euparal-mounted slide preparations of bulk rock material from Reva Gap, Custer National Forest (Arikaree Formation) and C1b shows similarly mounted slides from Karain, Cappadocia, Turkey, under phase-contrast microscopy at 400x magnification. In each case, a small quantity of the volcanic tuff was pressed between two glass slides to liberate individual mineral particles, but there was no aggressive attempt to pulverize the material. The particles liberated with the Custer National Forest fibers are long and thick, with a distinct appearance of being bundles. The Turkish particles, in contrast, are commonly shorter, thinner fibers, with an appearance of being single fibers, although under higher magnification they are comprised of bundles of finer fibers. Rome, Oregon, erionite particles (NIOSH research material) are similar in appearance to the Arikaree Formation particles at this level of magnification (not shown), but differences appear at higher magnification.



C1a. Reva Gap, Custer National Forest

C1b. Karain, Cappadocia, Turkey

Figure C1. Using PCM to compare Custer National Forest (C1a) and Cappadocia, Turkey, (C1b) erionites. Photo by NIOSH.

Figure C2a shows high-resolution TEM images of the same Arikaree Formation material compared to erionite from Rome, Oregon, in Figure C2b. Many of the Arikaree Formation particles appear to consist of ribbon-like fibers approximately 0.1–0.15 µm in diameter, while the particles from Rome, Oregon, although they are of similar size, appear to be bundles of finer "fibrils" around 30–40 nanometers in diameter.

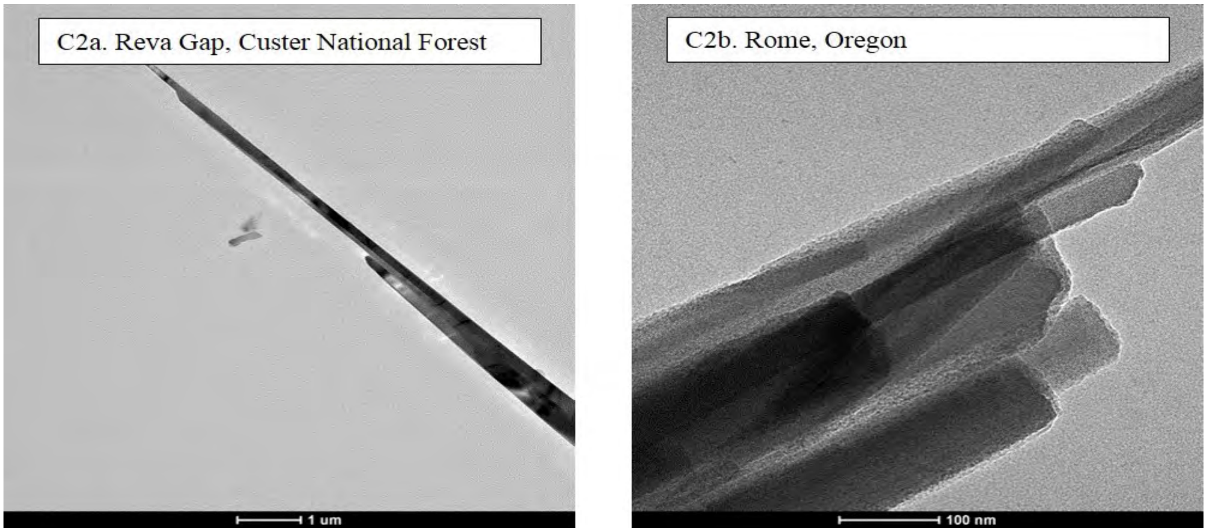


Figure C2. High resolution TEM image of C2a. Custer National Forest and C2b. Rome, Oregon, erionite fibers. Photo by NIOSH.

However, individual nanometer-scale fibers were found in all samples, including the Arikaree Formation material, as in the image in Figure C3, obtained with a field-emission scanning electron microscope.

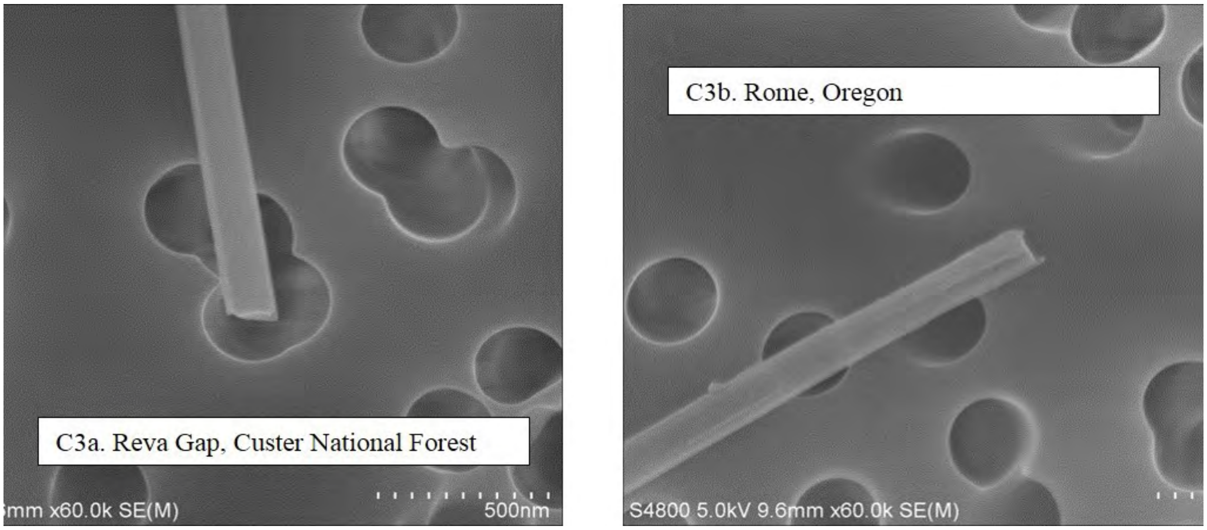


Figure C3. Field-emission scanning electron microscope image of C3a. Custer National Forest and C3b. Rome, Oregon erionite samples. Photo by NIOSH.

Chemical Differences

Zeolites are a silicate structure where Al atoms can substitute for Si. Because the valency of Si is 4 and Al only 3, cations such as Na, K, and Ca are incorporated in the aluminosilicate structure to level out the charge imbalance. All of the erionites we have examined from volcaniclastic sedimentary environments have ratios of Si to Al that are much higher than anticipated from published analyses of erionite crystals removed from vesicles in mafic volcanic rocks. A publication comparing 26 samples of erionite from mafic volcanic rocks from various regions across the globe shows that they have a tight range of ratios around an average of 2.6, which is compatible with the typical erionite formula of $Si_{26}Al_{10}$ [Passaglia et al. 1998]. However, all the sedimentary erionites we have analyzed (Cappadocia, Turkey; Rome, Oregon; Custer National Forest Arikaree; South Killdeer Mountain Arikaree; Reese River, Nevada) have a tight range of average ratios around 4.0, which is closer to a formula $Si_{29}A_{l7}$. Fewer cations are required for balance, but when these particles are analyzed very carefully by scanning TEM with EDS or electron microprobe with wavelength-dispersive spectroscopy, the cation content is found to be insufficient even to meet this lower requirement. Thus the minerals do not meet the cation-balance formula requirement for cations, and are likely balanced instead by acidic H+ ions.

Large variations in cation contents are found between different particles even in the same sample, so that large numbers of analyses are required to provide average cation contents for comparison between different samples. Differences exist in the average cation contents between sedimentary erionites from different sources, with erionite from Cappadocia, Turkey, having the largest total cation content [USGS 2010]. Differences also exist in the relative abundance of cations, with the erionite from Cappadocia, Turkey, having more Na and Ca than others. However, as noted, there is considerable variation (order of magnitude) between individual particle analyses, so that the range of cation contents in erionites from different sources has considerable overlap. A possible indicator of toxicity is iron. Iron is typically present at low levels (less than 1 percent by weight) in these particles, although individual particles can show high levels. Erionite from Rome, Oregon, has the highest average iron content, with a large proportion of particles having iron content in the percent range [Harper and Shvedova 2015]. Ballirano has suggested that nanometer-sized clusters of iron atoms on the exterior of Rome, Oregon, erionite particles may be a factor in the toxicity of that material [Ballirano et al. 2009].

Toxicity Differences

In preliminary NIOSH laboratory studies, toxicity differences between erionites from different sources have been seen. However, these experiments have involved whole rock. The erionite content of different rock samples varies dramatically, so that it is not possible to conclude at this time whether the observed differences in toxicity are due to differences in erionite dosage or even associated with the other minerals in the samples. For example, while the Custer National Forest Arikaree samples appear to have lower toxicity than samples from Rome, Oregon, on an equal rock weight basis, the weight percent erionite in Rome, Oregon, has been calculated to be around 15% while that in the Custer National Forest Arikaree is around 1% [Harper and Shvedova 2015]. Thus additional work with purified extracts will be required to fully interpret the results.

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Availability of Report

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