Evaluation of Erionite and Silica Exposure During Dirt Road Maintenance

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Contents

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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 management representative at a federal government agency who was concerned about potential employee exposures to erionite mineral fibers when employees maintained dirt roads in areas where erionite has been confirmed or is suspected to be present. We visited the work areas in October 2012 and August 2013.

What We Did

- We observed employees blading and grading dirt roads, replacing culverts and cattle guards, and replacing aggregate on parking lots.
- We observed employees pulverizing and analyzing rock samples.
- We took air samples for mineral fibers and crystalline silica.
- We took bulk rock and soil samples to analyze for erionite.

What We Found

- Dirt road maintenance activities disturbed dust.
- The dust contained crystalline silica.
- Employees who maintain dirt roads could be exposed to quartz above the recommended limits.
- No air or bulk samples contained erionite.

What the Employer Can Do

- Monitor employees' exposure to respirable crystalline silica in air over their work shift.
- Do not use aggregate that contains erionite to repair roads.
- Maintain air filters in the equipment regularly.
- If it is dry, wet the soil before doing road maintenance.
- Educate employees on the health effects of crystalline silica and erionite.
- Train employees in proper work practices for working in areas that contain crystalline silica or erionite.
- Develop a procedure for cleaning work clothing.

We took air samples for mineral fibers and respirable crystalline silica on employees who repaired dirt roads and analyzed rock samples. Some employees had silica exposures above occupational exposure limits. We did not find erionite in the air or bulk rock/soil samples. We recommended that the employer not use aggregate that contains erionite to repair roads and that they control dust exposures with ventilated vehicle cabs, wet methods, and other work practices.

What Employees Can Do

- Keep the windows and doors to the operator's cab on equipment closed.
- Do not bring work clothing home.

Abbreviations

µm	Micrometer
ACGIH®	American Conference of Governmental Industrial Hygienists
Ca	Calcium
K	Potassium
MCE	Mixed cellulose ester
MERV	Minimum efficiency reporting value
Mg	Magnesium
mg/m³	Milligrams per cubic meter
Na	Sodium
ND	Not detected
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PCM	Phase contrast microscopy
PEL	Permissible exposure limit
REL	Recommended exposure limit
TEM	Transmission electron microscopy
TLV®	Threshold limit value
TWA	Time-weighted average
WEEL™	Workplace environmental exposure level

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Introduction

The Health Hazard Evaluation Program received a request from a management representative at a government agency. The requestor was concerned about potential employee exposures to erionite mineral fibers when employees maintained dirt roads in areas where erionite has been confirmed or is suspected to be present [USGS 1996]. We visited two field offices to assess potential employee exposures to erionite and respirable crystalline silica during road maintenance activities in October 2012 and August 2013. We sent summary letters with preliminary recommendations in October 2012, January 2013, and March 2014.

Erionite and Respirable Crystalline Silica

Erionite, a member of the zeolite mineral family, is a naturally occurring mineral found in fine-grained sediments such as volcanic ash deposits that have been altered by weathering and ground water. Erionite deposits have been identified in all of the western states except Washington [USGS 1996]. According to the agency, the geologic formations that may contain erionite in the part of the state where our evaluation occurred are in the (1) Arikaree formation above the Fort Union formation, (2) the Absaroka volcanics formation, (3) the Willwood formation, and (4) the Wagon Bed formation. 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].

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 disturbed and become airborne, which may occur during road maintenance and construction.

Road Maintenance

Because of use and weather conditions, dirt roads are susceptible to potholes, ruts, erosion, and poor drainage and require regular maintenance. Agency employees operate a variety of specialized heavy equipment depending on road maintenance needs. In road blading/grading, loose material and aggregate are pulled across the surface of the road to smooth it. As an operator in its enclosed cab drives a road blader/grader down the road, the blade makes the road smoother by filling in surface irregularities. The same blade tilted at a different angle grades the road to improve water drainage (Figure 1). Where necessary, metal or plastic culverts are installed along the road with a backhoe to allow water to flow without damaging the road (Figure 2). These culverts fill with sediment and other debris and require periodic cleaning or replacement. Roadside drainage ditches may also need to be cleared of obstructions to permit proper water flow. In addition, some of the agency's land is leased to ranchers for cattle grazing, requiring cattle guards to be placed where roads cross fence lines. A cattle guard is a metal grid of beams placed in a shallow ditch that prevents cattle from crossing. Cattle guards can become clogged with weeds and brush and must be cleaned periodically. Employees use a backhoe to dig the ditches where the guards will be placed

(Figure 3). The agency is also responsible for maintaining campgrounds and river access boat launches, which can require applying aggregate. This aggregate can be aerosolized as it leaves the dump truck (Figure 4). Because of the remote locations of these work sites, the equipment operators traveled in personal vehicles to and from the site each day. Most of the trip (approximately 1 hour) was spent on paved roads with a limited amount of road dust exposure. The remaining 15–30 minutes of the drive was on a dirt road.

Figure 1. Road blading/grading. Photo by NIOSH.

Figure 2. Culvert replacement. Photo by NIOSH.

Figure 3. Cattle guard replacement. Photo by NIOSH.

Figure 4. Parking lot maintenance. Photo by NIOSH.

Minerals Laboratory

The agency has a minerals laboratory where two geologists collect rock samples, grind and pulverize the samples, and analyze the mineral content of the samples (Figure 5). Laboratory employees expressed concerns about potential aerosolization of mineral dust during such activities. Employees use local exhaust ventilation during these operations to minimize their exposure to aerosolized dust.

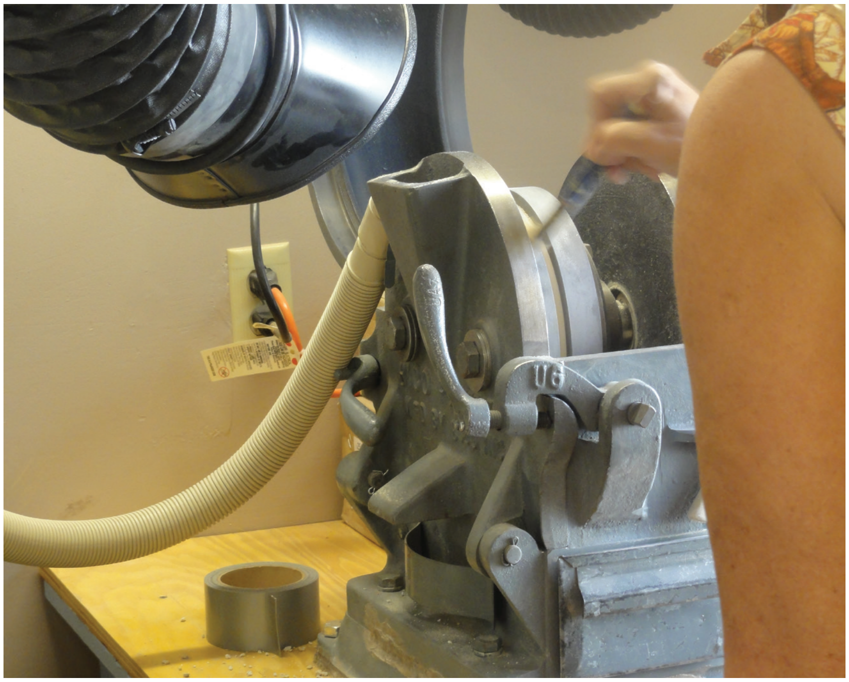

Figure 5. Pulverizing rock samples. Photo by NIOSH.

Methods

Air Sampling

We took air samples to evaluate employee exposure to erionite and respirable crystalline silica. We did this during dirt road maintenance tasks in the Fort Union formation in October 2012. The agency was concerned that erionite present in the Arikaree formation could wash down the mountain into the road bed where they were working. During the 3-day visit, we took eight personal air samples (4 for erionite and 4 for silica) and 12 area air samples (6 for erionite and 6 for silica). We took the personal air samples on the backhoe operator and the helper during culvert replacement, on the road grader operator, and on the backhoe operator during ditch digging. We took area air samples upwind and downwind during culvert replacement and ditch digging tasks.

During the August 2013 visit we took 10 personal air samples for erionite and 10 for respirable crystalline silica during road blading/grading, replacing a cattle guard with a backhoe, and using a backhoe and a dump truck to replace aggregate on a boat launch parking lot. We also took air samples in the breathing zone of three geologists while they collected and crushed bulk rock samples.

We collected and analyzed the erionite samples according to the National Institute for Occupational Safety and Health (NIOSH) Method 7400 [NIOSH 2014]. We then used transmission electron microscopy with energy dispersive spectroscopy to analyze the erionite samples according to a modified NIOSH Method 7402 for asbestos [NIOSH 2014]. Initially, we attempted to confirm the presence of erionite using the method described by Dogan and Dogan [2008]. In doing so, we discovered several limitations of the Dogan and Dogan method, which are described in Appendix A. For the samples collected on the second site visit, we revised the analysis solely to determine the presence of zeolite mineral fiber. Erionite is one of many minerals in the zeolite family. Confirmation of erionite specifically in air samples was not possible with electron microscopy.

We collected the crystalline silica samples on preweighed, 5-micrometer (µm) pore size polyvinyl chloride filters with a nylon (October 2012) and aluminum (August 2013) cyclone at a nominal flow rate of 1.7 liters per minute. During the August 2013 visit we mistakenly sampled the thoracic fraction of airborne dust instead of the respirable fraction. The thoracic fraction includes particles of a wider size range, including some that do not penetrate deep into the lung which is of concern for silica exposures. No occupational exposure limits exist for silica in the thoracic size range; therefore we cannot compare these sample results to an occupational exposure limit. We analyzed samples according to NIOSH Method 7500 [NIOSH 2014].

We measured real-time total and respirable dust levels by placing a direct reading DustTrak™ particle monitor in the cab of the road grader during blading and in the cab of the backhoe during ditch digging. However, the instrument was damaged during sampling and therefore we do not present these data.

Bulk Rock Samples

We collected 4 bulk rock and 4 soil samples to determine if erionite was present in the rock formations surrounding the areas where the employees worked. We analyzed all samples by polarized light microscopy to look for fibers. We gently crushed small amounts of material into a fine powder then placed it between two glass slides and mounted the material in a drop of 1.500 refractive index oil. All of the bulk rock samples were analyzed by x-ray diffraction [Bish and Chipera 1991]. One fibrous mineral was analyzed with scanning electron microscopy.

Results and Discussion

Erionite

The October 2012 visit took place in the Fort Union formation. We did not find any zeolites in either the personal or area air samples. Only two air samples contained fibers that met the definition of an asbestos-like fiber; 3:1 length to width aspect ratio and longer than 5 µm. They were composed of silicon and aluminum, but without alkalis or magnesium (Mg) and therefore were not considered zeolites.

During the August 2013 visit, the road grading/blading, cattle guard replacement, and dumping of aggregate on the boat launch parking lot took place in the Wagon Bed formation. Only a geologist's personal air sample contained a zeolite fiber and this was collected while the geologist was grinding rock samples in the minerals lab. We were not able to determine if that zeolite fiber was erionite (see Appendix A).

Respirable Dust and Crystalline Silica

The general industry Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for respirable dust containing crystalline silica varies because it is calculated using the percentage of quartz, tridymite, and crystobalite in each respirable dust sample. The NIOSH recommended exposure limit (REL) of 0.05 milligrams per cubic meter (mg/m^3) and American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) of 0.025 mg/m^3 are based on the concentration of respirable crystalline silica in each sample [NIOSH 2010; ACGIH 2014].

The respirable dust concentrations in personal air samples from the October 2012 visit ranged from not detected (ND) to 0.22 mg/m^3 (Table 1). Sample duration ranged from 269 to 322 minutes. The sampling period included the time that operators spent working at the work sites, but not the time they spent driving to and from the work site. We measured the highest respirable dust concentration (0.22 mg/m^3) on the backhoe operator during ditch digging when the backhoe cab window was open.

Table 1. Respirable quartz concentrations in personal air samples, October 9–10, 2012

Task/job title	Sample duration* (minutes)	Respirable quartz (mg/m^3)	Respirable particulate (mg/m^3)	Percent quartz in the air sample	OSHA respirable quartz PEL (mg/m^3)
Culvert replacement					
Backhoe operator	286	0.04	(0.10)	37	0.3
Assistant outside backhoe	295	(0.02)	ND	NA	5.0
Road grading/blading					
Road grader operator	322	(0.03)	ND	NA	5.0
Ditch clearing					
Backhoe operator	269	0.11	0.22	50	0.2
NIOSH REL ACGIH TLV		0.05 0.025	NA	NA	NA

NA = Not applicable

( ) = Concentrations between the minimum detectable and minimum quantifiable concentrations are in parentheses because there is more uncertainty in these values. The minimum quantifiable concentration for respirable quartz ranged from 0.01 to 0.04 mg/m^3 and from 0.04 to 0.17 mg/m^3 for respirable particulate based on the sample volumes.

*Sample times do not include the approximately 1.5 hour drive to and from the site.

During the October 2012 visit, one employee engaged in one task was found to have a quantifiable exposure to respirable dust containing crystalline silica (quartz), and one employee engaged in another task was found to have quantifiable exposure to crystalline silica but the respirable dust value for this sample was less certain as it was below the laboratory limit of quantitation. The quartz content in the respirable dust samples for the backhoe operator was 37% during culvert replacement and 50% during ditch clearing. No cristobalite or tridymite (other less common forms of crystalline silica) were present in the air samples. One of the four personal samples, taken on the backhoe operator during ditch clearing, may have exceeded its OSHA calculated PEL of 0.2 mg/m^3.

Our sampling should not be considered OSHA compliance sampling because we did not collect samples for a full 8-hours (length of the work shift). The un-sampled time was spent in commute to the job site, however we cannot assume zero exposure during that time period because the employees were driving on dirt roads which may contain a high silica concentration. Our sampling results suggest that employees may be overexposed to respirable crystalline silica at times and that resampling for the full shift is warranted. One sample also exceeded the NIOSH REL for silica; this sample was collected on the backhoe operator during ditch clearing. Two of the four samples exceeded the ACGIH TLV and one other may have exceeded the 8-hour time-weighted average (TWA) TLV.

Table 2 contains the results of the area air samples. These area samples show that the percent quartz in the respirable dust ranged from not detectable to 100% (average concentration 39%).

Table 2. Respirable quartz concentrations in area air samples, October 9–10, 2012

Task	Sample duration (minutes)	Respirable quartz (mg/m^3)	Percent quartz in the respirable dust sample
Culvert replacement			
Outside backhoe	278	0.10	100
On truck from culvert	233	ND	ND
Downwind	116	(0.05)	18
Upwind	104	0.16	39
Road grading/blading			
Outside road grader	317	0.34	43
Outside road grader	333	0.18	40
Ditch clearing			
Outside backhoe	257	0.15	36
Downwind	197	0.51	41
Upwind	63	1.3	31

( ) = Concentrations between the minimum detectable and minimum quantifiable concentrations are in parentheses because there is more uncertainty in these values. The minimum quantifiable concentration for respirable quartz ranged from 0.02 to 0.05 based on the sample volume.

During the August 2013 visit, exposure to quartz in the thoracic fraction ranged from 0.01 to 0.21 mg/m^3. Because we mistakenly collected the thoracic fraction we cannot compare the sample results to occupational exposure limits for silica which are only for the respirable size fraction. However, the results did indicate the presence of airborne crystalline silica during all of the work activities we evaluated. Silica concentrations were highest during backhoe operations (47%), cattle guard maintenance (50%), and road blading (37%).

Bulk Rock Samples

Of the four geological formations that the agency identified as possibly containing erionite, its presence has been documented only in the Wagon Bed formation [USGS 1996]. Discussion with United States Geological Survey personnel about the geology of the two field offices we visited revealed that no volcanic ash was present in the Willwood formation. In their opinion, the environment of the Willwood formation probably was not conducive to the preservation of volcanic ashes, meaning that the presence of erionite was highly unlikely in this formation. Although the Fort Union formation is not known to have erionite fibers, it is layered underneath the Arikaree formation, which may contain erionite. Figure 6 shows an example of this type of formation in the Custer National Forest. Because the formations are exposed to weathering, the agency was concerned that erionite could wash down from the Arikaree formation into the formation where the employees were blading the road and installing culverts. We could not confirm if this was occurring. Although ash may have been present in the Absaroka Volcanics formation, according to geologists, the formation and any erionite in it has been eroded away from the area in which work was taking place.

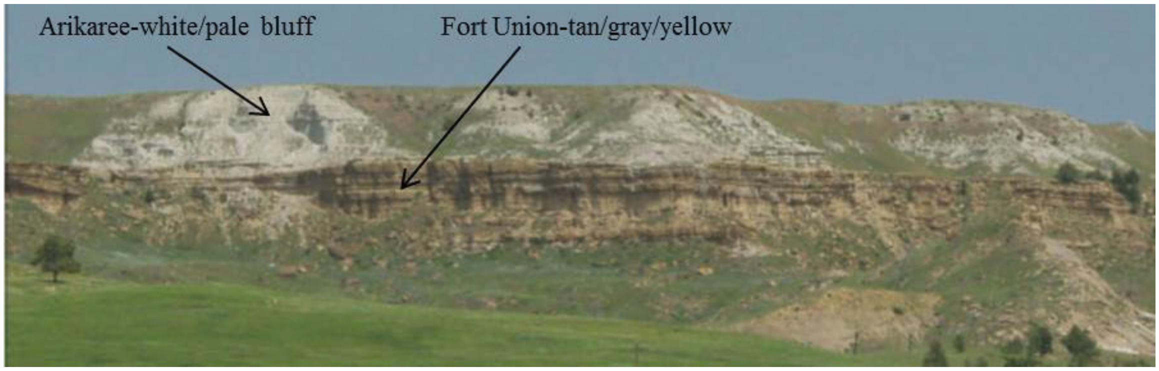

Figure 6. Arikaree formation layered over Fort Union formation in Custer National Forest. Photo by the Bureau of Land Management.

One formation has a record of erionite where the employees were working [USGS 1996]. The sample was collected in 1979 near the summit of Hawkes Butte (Figure 7), which is part of the Wagon Bed formation; this occurrence has not been confirmed with replicate samples. Most of this formation is inaccessible by road, except for one part of a road that crosses it. On the basis of this information, we collected bulk rock samples from borrow pits along this road and bulk rock and soil samples around a burn area from a recent small fire on Hawkes Butte.

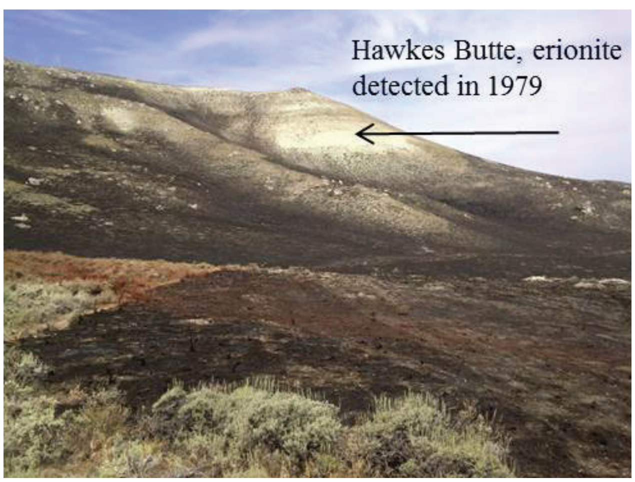

Figure 7. Hawkes Butte, Wagon Bed formation. Photo by NIOSH.

We did not detect erionite by x-ray diffraction in any sample. We found a fibrous mineral in one sample from an isolated outcrop of what was believed to be the Wagon Bed formation near Four Bears campground in the Shoshone National Forest. There was insufficient material to examine it with x-ray diffraction. The fibrous structure was not maintained under vacuum in the electron microscope, suggesting the mineral was not erionite.

Observations

Road grading/blading took place during our October 2012 and August 2013 visits. During this task, the operator remained in a closed, ventilated cab and drove back and forth along the roadway, often for several miles. The only time the employee was visibly exposed to dust was when he/she opened the cab door. We did not observe accumulations of dust on any surface inside the cab. Although the cabin air filter was in good condition at the time of our August 2013 visit (Figure 8), the agency did not have a schedule for replacing the filters. Recent NIOSH studies have shown that an effective vehicle cab filtration system includes both a powered and pressurized air intake as well as filtered recirculation air to reduce the respirable quartz particulates to an acceptable level [Cecala et al. 2012; Organiscak et al. 2013; Cecala et al. 2014]. The truck created a large dust cloud behind it as it traveled down the road. If employees were downwind of the area (Figure 9) they were exposed to the dust that the road grader created. However, if the truck bladed/graded the road after a light rainfall as can be seen in Figure 10, the dust cloud lessened.

Figure 8. Air filter for the road grader. Photo by NIOSH.

Figure 9. Road blader/grader traveling along a dry dirt road. Photo by NIOSH.

Figure 10. Road blader/grader travels along a moist dirt road. Photo by NIOSH.

Culvert and cattle guard replacement involved a backhoe operator and an assistant. The assistant remained outside of the cab and often stood directly in the dust cloud that the backhoe created. While the backhoes do have fully enclosed operator cabs, the operators often work without closing the cab's windows and door. We observed dust accumulation on the surfaces inside the backhoe and piles of dust on the floor that were disturbed each time the operator entered the cab.

The minerals lab was equipped with a Micro Air® local exhaust ventilation system (Figure 11) and Micro Air downdraft table (Figure 12). Both branches of the ventilation system were connected to a dust handling unit located just outside of the minerals lab. The two filters had a minimum efficiency reporting value (MERV) of 11. The agency had no written procedures or maintenance schedule for changing the filters in the ventilation system. To pulverize rock samples, the geologist loaded rocks into the pulverizer, turned on the ventilation system, and placed the moveable duct inlet as close as possible to the rock pulverizer. The pulverizer separated the sample into two bins on the downdraft table. The geologist then used a central vacuum cleaner system to clean up the area. The dust from this vacuum cleaner system was exhausted directly outside the window. The geologists typically spend most of their shifts on the computer, doing paperwork, and answering phone calls and only grind rock samples for an hour or two per shift at most.

Figure 11. Moveable local exhaust ventilation duct, placed close to the rock pulverizer. Photo by NIOSH.

Figure 12. Downdraft hood and a moveable duct placed close to a metal box used to separate pulverized rock samples. Photo by NIOSH.

Conclusions

Some employees had overexposures to respirable crystalline silica (quartz). Area air samples indicated a high percentage of quartz, up to 100%. Zeolite mineral fibers, a class of fibers that includes erionite, were not found in the personal air samples. None of the bulk rock samples collected in the areas surrounding where employees worked contained erionite. Because of the variable environmental and geological conditions encountered by the employees and the variability in job tasks, including tasks that aerosolize dust particles, the potential for exposure to erionite and silica dust exists. 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. Those involved in the work can best set priorities and assess the feasibility of our recommendations for the specific situation at the work site.

Our recommendations are based on an approach known as the hierarchy of controls (Appendix B). 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. Avoid using aggregate that is known or suspected to contain erionite to 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 operator's 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 a powered,

pressurized system. The recommended flow rate should be between 40 and 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 to 300 cubic feet per minute [Cecala et al. 2014].

3. Develop a maintenance schedule and standard operating procedure to maintain the local exhaust ventilation system in the minerals lab.

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. Conduct full-shift personal air sampling for respirable crystalline silica. If immediate efforts to reduce dust levels (e.g., wetting soil and aggregate, closing cab windows and door) are not successful in reducing silica levels below the most protective occupational exposure limit (OEL), implement a respiratory protection program that, at a minimum, meets the requirements of the OSHA respiratory protection standard, 29 CFR 1910.134. Ensure that employees are medically cleared, fit-tested, clean-shaven, and adequately trained on respirator use and care before they use respirators. Re-sample after additional controls have been put in place to confirm that exposures are consistently below applicable occupational exposure limits before eliminating respirator use.

2. Inform employees of the need to use dust control methods during any work and train them on dust control techniques. Links for information on engineering controls are available at http://www.cdc.gov/niosh/topics/silica/.

3. 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.

4. Restrict, whenever possible, dust-generating activities to conditions conducive to reducing dust generation (e.g., snow, rain, calm weather). Avoid dust-generating tasks on windy days. When possible, schedule dust-generating tasks on days when the soil is moist.

5. Establish standard operating procedures for vehicle use on dirt/gravel roads (drive slowly, vents closed, windows up).

6. Educate employees on the health effects and hazards of crystalline silica and erionite, how they may be exposed, and control measures.

7. Train employees in proper work practices for working with soil or aggregate that may contain crystalline silica or erionite.

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. If follow-up monitoring shows overexposures to silica, provide employees with respiratory protection until the dust control measures keep employee exposures below the most protective occupational exposure limits. Additional silica information is available at https://www.osha.gov/dsg/topics/silicacrystalline/index.html.

2. Provide employees with clothes (i.e., chaps) and boots that are solely designated for work activities and refrain from washing these work clothes at home. Require employees who have been working in dusty areas to change into clean clothing before leaving the work site or going home.

Appendix A: Sampling and Analytical Methods

Erionite

Air samples for erionite were first analyzed by phase contrast microscopy (PCM) according to NIOSH Method 7400 to identify fibers [NIOSH 2014]. 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 (1) a minimum of 100 fibers is counted in 20 or more fields, or (2) a maximum of 100 fields is examined. Samples with a high fiber count were then selected for a second analysis using transmission electron microscopy (TEM).

Samples from our first visit were analyzed with TEM per NIOSH Method 7402 and then determined to be erionite by applying a method developed by Dogan and Dogan [2008]. Portions of the mixed cellulose ester (MCE) 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 used electron diffraction and energy-dispersive x-ray spectroscopy to determine the elemental composition of the fiber. The Dogan and Dogan method recommended that to confirm erionite, the fibers have a magnesium content of < 0.8, and a balance error (E%) of $\leq 10\%$. The E% was determined using the following formula:

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

Between our first and second visits, we further researched the Dogan and Dogan [2008] method. We determined that this method could not be used to identify erionite partly because of the potential degradation of sodium (Na) [Dogan 2012] under the TEM electron beam, but mainly because the general variability of Na, potassium (K), and calcium (Ca) content in erionite does not allow it. We determined that we were unable to specify if the mineral fiber was erionite; we could only confirm or reject it as a zeolite.

For samples collected on our second visit, we first identified a fiber then evaluated its elemental makeup. The elemental chemistry of a zeolite typically has an approximate 10:3 ratio of silicon to aluminum, with variable concentrations of Na, Ca, and K. If the particle met both of those definitions, we determined it to be a zeolite mineral fiber.

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 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 OSHA 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 TLVs, which are recommended by ACGIH, a professional organization, and the workplace environmental exposure levels (WEELs), 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 2014].

> WEELs have been established for some chemicals "when no other legal or authoritative limits exist" [AIHA 2014].

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/Gefahrstoffdatenbanken/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]. 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]. 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 exposure to erionite in the western United States [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 occupational exposure limits. NIOSH has an REL for asbestos of 0.1 fibers per cubic centimeter as an 8-hour TWA. In 1990, NIOSH revised the REL to include similar elongated mineral fibers that met the same length (> 5 µm) and aspect ratio (3:1 length:width) definition of asbestos. The revised definition of airborne asbestos fibers did not explicitly encompass elongated mineral particles from other asbestiform minerals (e.g., erionite) that are known to be associated with health effects similar to those caused by asbestos [NIOSH 2011].

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, 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 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 2014].

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