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Hydraulic Fracturing and the Risk of Silicosis

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Abstract: "Fracking," the common name for hydraulic fracturing is widely used to extract oil and gas, particularly from deep shale formations. A single well requires the use of millions of gallons of water and tons of sand. Air sampling results show that the majority of silica levels at hydraulic fracturing sites were above the Occupational Safety and Health Administration allowable standard and 84% were above Occupational Safety and Health Administration's new proposed standard. These exposure levels put workers, particularly sand mover operators and T-belt operators who had the highest levels, at risk of silicosis and the other silica-related conditions of lung cancer, end-stage renal disease, chronic obstructive pulmonary disease, tuberculosis, and connective tissue disease. Because of the fracking industry's demand for silica, sand mining has markedly increased, which has also increased the number of workers at risk of developing silicosis and other silica-related conditions in the mining industry. This paper reviews the parts of the country where health care providers should be most concerned about possible patients in their practice who are at risk from this newly recognized source of silica exposure and the appropriate medical testing to perform. However, given the long latency, 20 or more years, of most silica-related health conditions and the fact that fracking did not become widely used until the 2000s, it may be years before health care providers see clinical-related disease in their practices.

Key Words: hydraulic facturing, silicosis, COPD, oil and natural gas drilling, lung cancer, chronic renal failure, tuberculosis, connective tissue disease

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Fracking is the popular term for the process of hydraulic fracturing. Hydraulic fracturing began to be used in the 1940s. As initially developed, the process involved the injection of hydrocarbons into gas and oil wells to increase production. The process was shown to increase the production of oil and gas wells by 50%. Water was initially used in 1953, a few thousand gallons per well. By 2010, 60% of new wells had hydraulic fracturing. The more recent concern about fracking has occurred because of major changes in the process, although the process name of hydraulic fracturing has remained unchanged. The current fracking process involves the high-pressure injection of 7 to 20 million gallons of water, tons of sand at a concentration of 5% to 20%, and chemical additives at 0.5% concentration into a single well. High-pressure fracking is typically used with horizontal and directional rather than traditional vertical well drilling to access previously unattainable oil and gas particularly from deep shale formations. The map in Figure 1 shows that there are major geologic areas throughout the country where the use of high-pressure hydraulic fracturing is the preferred technology for extraction. In 2012, fracking operations were underway in 17 states and >22,000 wells were drilled or permits were obtained using hydraulic fracturing.

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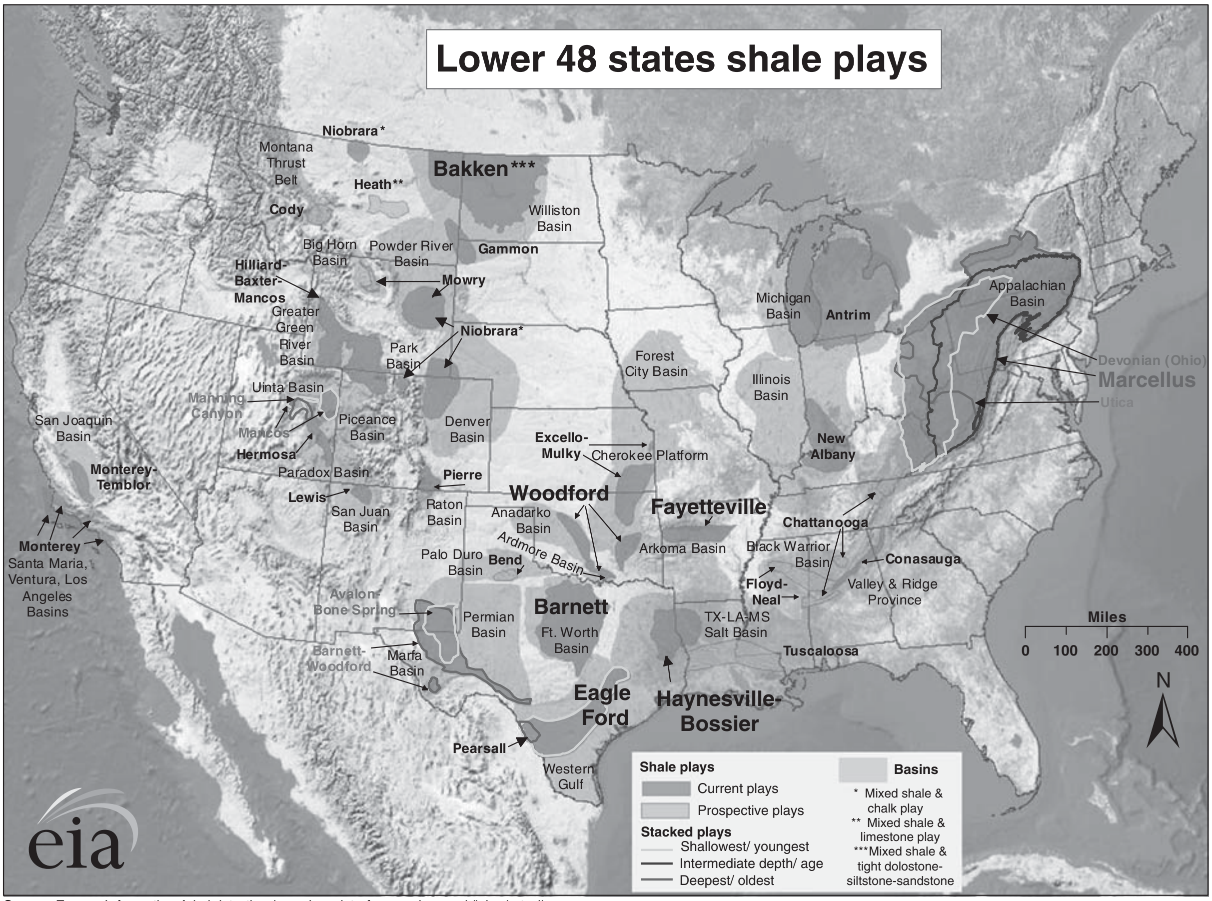
FRACKING PROCESS

Injection of millions of gallons of water under high pressure fractures the rock containing the petroleum product. Figure 2 shows a graphic of the fracking process. Hundreds of thousands of pounds of sand, which is typically 99% silica, are mixed with the water before injection. The silica is used as a "proppant" to hold open the fractures created by the high-pressure injection so as to allow the natural gas/oil to flow. Although other proppants such as aluminum pellets, sintered bauxite, refractory ceramics, and resin-coated sand maybe used depending on the geology, sand is the most common proppant. In some sandstone formations in Colorado, companies have been able to perform hydraulic fracturing without any proppant. It is thought that these sandstone formations maybe naturally brittle with natural fractures that make proppant use unnecessary. The geologic formation where a proppant is not required is limited to a small percentage of the area in Figure 1 where hydraulic fracturing is the preferred approach to drilling.

Chemicals are also added to the mixture of sand and water before injection. These chemicals include scale inhibiters, friction reducers, gelling agents, biocides, solvents, and acids to protect equipment, reduce pumping requirements, and maintain integrity of the gas formation. The typical mixture pumped underground is 90% water, 9.5% sand, and 0.5% chemicals. Concern in the press and on the internet has focused on community air pollution, noise, and dust from these around the clock, large scale industrial operations that generate frequent truck deliveries in rural settings. For example, it is estimated it takes 500 trips by large trailer trucks to deliver the sand required for a typical well. Concern has also been directed at the requirement for millions of gallons of water and the potential for environmental contamination of ground or surface water by natural gas/oil and the chemicals used in the fracking process either during underground well injection or from the holding ponds dug at the sites to hold water that returns to the surface. During the fracking process, 30% to 60% of the water mixture injected in the wells returns to the surface. The water that returns to the surface has petroleum and chemical contaminants. The chemical additives used have been classified as trade secrets by the manufacturers/formulators of the additives, which has heightened fear among nearby residents. Figures 3 and 4 illustrate that a fracking operation is a major industrial site that will at least during the drilling process change the character of the rural setting where these operations are located.



Source: Energy Information Administration based on data from various published studies.
Updated: May 9, 2011

FIGURE 1. Map of United States showing major geologic formations with oil and gas where hydraulic fracturing is the preferred technology for extraction. *Source*: Energy Information Administration based on data from various published studies, http://www.eia.gov/energy_in_brief/article/about_shale_gas.cfm. Reproduced with permission.

REGULATORY STANDARD FOR SILICA

Occupational exposures at fracking sites are enforced by the Occupational Safety and Health Administration (OSHA). The OSHA Silica Standard was adopted in 1971 and allows an air level for silica at drilling sites of 100 μg/m^3 as an 8-hour time-weighted average in general industry and 250 to 500 μg/m^3 in construction and shipyards. On September 12, 2013, OSHA proposed lowering the allowable silica level to 50 μg/m^3 as an 8-hour time-weighted average in general industry, construction, and shipyards as a gravimetric measurement of respirable silica.[1] This level would replace a formula that includes the crystalline silica content of the dust sampled and for construction and shipyards a conversion from particle counts. The current enforceable 1971 OSHA standard only addresses the allowable air level of silica, whereas the new proposed standard proposes regulations for exposure assessment, methods for controlling exposure, medical surveillance, hazard communication, and record keeping. This level not only lowers the allowable level but also simplifies the level by replacing a formula that includes the crystalline silica content of the dust sampled and for construction and shipyards a conversion from particle counts. The National Institute for Occupational Safety and Health (NIOSH) proposed in 1974 that OSHA lower the allowable silica level to 50 μg/m^3 in 1974. OSHA followed up on NIOSH's recommendation shortly after it was released and published an Advanced Notice of Proposed Rulemaking in December 1974 but OSHA did not pursue further action at that time.

In the background section for the proposed new silica standard, OSHA estimated that there were 25,000 workers with exposure to silica in 444 establishments operated by 200 businesses at hydraulic fracking sites.[2] OSHA estimated that the annual benefits to workers in the fracking industry of lowering the silica standard to 50 μg/m^3 would be 12 fewer fatalities (2.9 from lung cancers, 6.3 from silicosis, and chronic obstructive pulmonary disease (COPD), and 2.3 from chronic renal failure) and 40.8 fewer cases of nonfatal silicosis. This equals 75.1 to 105.4 million dollars in monetized benefits from reduced health costs and increased productivity. The estimated annual cost to the hydraulic fracking industry would be 28.6 million dollars. OSHA did not provide estimates on disease morbidity nor costs associated with the use of silica in fracking.

Major provisions of the proposed standard include:

(1) Exposure assessment of employees at or above the action level of 25 μg/m^3.
(2) Regulated areas and demarcation—areas where air levels of silica are >50 μg/m^3 to will have limited access and

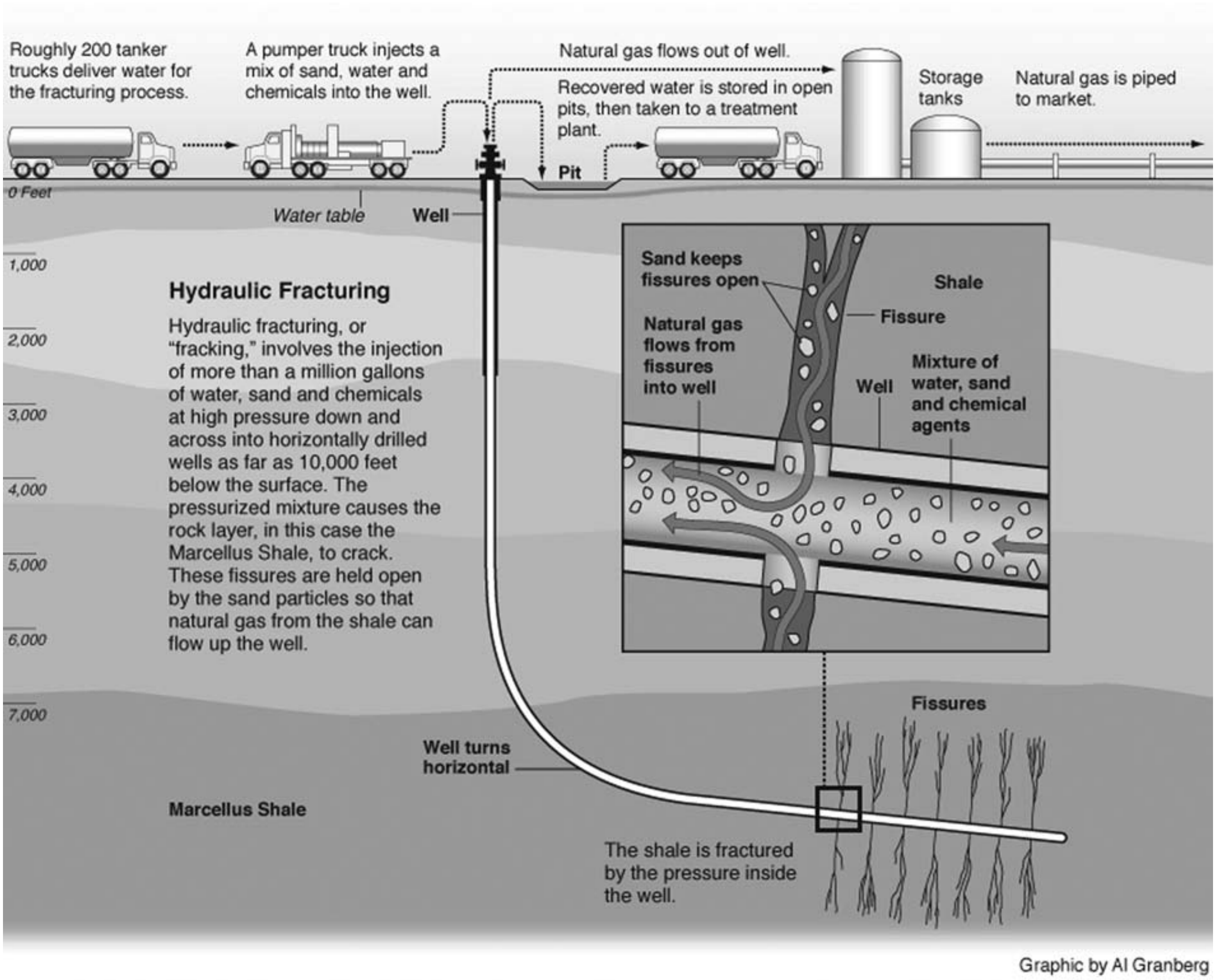


FIGURE 2. Graphic showing the process of hydraulic fracturing. *Source*: ProPublica, http://www.propublica.org/special/hydraulic-fracturing-national. Reproduced with permission.

require workers in these area wear respirators and protective clothing that is removed before the removal of the respirator.

(3) Cleaning—require high-efficiency particulate air filter vacuuming or wet methods.
(4) Ban rotating workers between high-exposure and low-exposure jobs to achieve compliance with the permissible exposure limit (PEL).
(5) Requirement that medical examinations be provided for all employees with exposure to PEL 30 or more days per year every 3 years or more frequently if recommended by the health care provider.
(6) Require inclusion of information on crystalline silica in the company's Hazard Communication Program.
(7) Ensure that employers have specific knowledge regarding the hazards of silica.
(8) As part of the proposal, regulatory alternatives are offered. For example, one alternative is to keep the PEL at 100 μg/m^3 or a second to lower the PEL even further to 25 μg/m^3. Other alternatives include requiring that medical surveillance be conducted more frequently, annually, or requiring medical surveillance for workers exposed 30 or more days to the action level of 25 μg/m^3 rather than only for those exposed to the higher 50 μg/m^3 level.

Five states (California, New Jersey, New York, Texas, and Vermont) have quantitative standards for controlling silica levels in the community around a silica user such as a fracking site. The values range from 0.06 to 3.0 μg/m^3 as averaged over a prolonged period such as annually. These values are well below those associated with the development of silicosis and those currently allowed or proposed for workers. Texas also has a short-term, 1-hour, value of 47 μg/m^3.

SUMMARY OF HEALTH EFFECTS OF SILICA

Silica exposure increases the risk of multiple conditions in addition to the fibrotic respiratory disease of silicosis.[2,3] These conditions are lung cancer, COPD, tuberculosis, end-stage renal disease, connective tissue disease, particularly scleroderma and rheumatoid arthritis.[2–5] Although individuals with the radiographic scarring of silicosis are at the highest risk for these other conditions, studies consistently show an increased risk based on the magnitude of silica exposure in the absence of the radiographic changes of silicosis. The adverse fibrotic respiratory health effects of silica typically occur >20 years after initial exposure although both acute, within months, and accelerated, within years, silicosis may occur. Lung cancer, COPD, and end-stage renal disease typically also have a

FIGURE 3. Hydraulic fracture drilling site in Texas. Photo courtesy of Eric J. Esswein, NIOSH Western States Office. Reproduced with permission.

similarly long latency period as fibrosis, whereas the increased risk of tuberculosis and connective tissue disease occurs much sooner after the initiation of silica exposure. Table 1 from the background to the new OSHA proposal shows the excess risk of death from lung cancer, silicosis and COPD, and end-stage renal disease and the incidence of nonfatal silicosis by the current allowable and new proposed permissible exposure value for silica. Table 2 shows the risk of developing the radiographic changes of silicosis at the minimum severity of 1/0 or more and at the more advanced 2/0 or more level based on the International Labor Organization scale for grading severity, with increasing severity from 1/0 to 3/+.

EXPOSURE LEVELS OF SILICA AT FRACKING SITES

Oil and gas drilling sites have previously been recognized as having safety and health hazards for workers, with the risk increased by fatigue from working long shifts, poor lighting, and working in temperature extremes. Previously recognized occupational hazards included exposure to noise from the drilling operation, exposure to diesel exhaust from the large number of trucks, and risk of injuries from being struck by a motor vehicle, fall from a height, being caught in or struck by equipment such as drilling equipment or high-pressure lines, fires or explosions, and working inside confined spaces (ie, holding tanks).

FIGURE 4. Loading sand from sand refill trucks into sand movers at a hydraulic fracture drilling site. Photo courtesy of Michael Breitenstein. Reproduced with permission.

TABLE 1. Expected Excess Deaths From Silica Exposure Per 1000 Workers[2]

Fatal Health Outcome	Current General Industry PEL (100 μg/m³)	Current Construction/Shipyard PEL (250-500 μg/m³)	Proposed PEL (50 μg/m³)
Lung cancer			
10-cohort pooled analysis	22-29	27-38	18-26
Single cohort study—lowest estimate	13	37-95	6
Single cohort study—highest estimate	60	250-653	25
Silicosis	11	17-22	7
Nonmalignant respiratory disease (including silicosis)	83	188-321	43
Renal disease	39	52-63	32

PEL indicates permissible exposure limit.

In 2010 and 2011 NIOSH initiated exposure assessments for silica at 11 fracking well drilling sites in 5 states.[6] One hundred and eleven, 12-hour full-shift personal breathing zone samples were taken for silica; 57 (51.4%) were above the OSHA permissible exposure level of 100 μg/m^3, 76 (68.5%) above the NIOSH recommended exposure level and now OSHA's proposed level of 50 μg/m^3 and 93 (83.8%) above the American Conference of Governmental Industrial Hygienists recommended threshold limit value of 25 μg/m^3. Sand refill trucks haul sand to the fracking site, which is transferred to vehicles that hold and move the sand, "sand movers." The sand is then transferred from the "sand movers" to blender hoppers on a conveyor belt assembly to be mixed with the water and chemicals (Fig. 5). Up to the time the sand is mixed with water, the sand is dry and there is visible dust in the air. Exposures to silica are high because of dust release during transfers and the large quantity of sand being handled. The workers closest to the dry sand moving operations had the highest silica exposure. Workers with the highest silica exposure were sand mover operators and T-belt operators. Workers doing the blending of sand and water, blender operator, and hydration unit operator had the next highest silica exposure, whereas sand coordinators and water tank operators had the lowest silica exposure. Workers may not identify themselves with the above job titles as they may be rotated to different positions on a shift or between shifts. Major sources of exposure were described as occurring during the filling of the sand movers, during deposit and transfer of sand on the open conveyor belts, and during the dropping of silica into the blenders. NIOSH and OSHA have described work practice and engineering changes to reduce silica levels and have in the interim, or when the implemented engineering changes are not successful, recommended the use of respirators to reduce silica exposure.[7]

TABLE 2. Risk of Nonfatal Silicosis Per 1000 Workers for 45 Years of Exposure[2]

	Current General Industry PEL (100 μg/m³)	Proposed PEL (50 μg/m³)
Silicosis		
Radiograph 1/0+*	60-773	20-170
Radiograph 2+	301	55

*Severity based on International Labor Organization scoring system with increasing severity from 1 to 3.
PEL indicates permissible exposure limit.

SAND MINING

The increase in hydraulic fracking has created an increased demand for sand; from 2009 to 2012 the amount of sand mined to be used in fracking increased from 10 to 30 million tons. Sand used for fracking is nearly pure quartz, uniform in size, and rounded. Sand used in fracking is obtained from surface mines. Sand from more recent geologic deposits and beach and river sand is generally too impure or not rounded enough for use in fracking. After mining, the sand is washed, sorted by size, and dried before shipping to the hydraulic fracturing sites.

The prime areas for mining frack sand are the midwestern states of Illinois, Indiana, Iowa, Kansas, Kentucky, Minnesota, Missouri, Michigan, Nebraska, and Wisconsin. For example, in Wisconsin from 2010 until 2013, the number of sand mines and processing facilities went from under 10 to 131, with 19 more in the proposal stage.

Workers in these sand mines and processing plants are at risk of silica-related conditions. Like the oil and gas workers, one would not expect to see the effects of silica exposure until after 10 to 20 years of work.

RECOMMENDATIONS FOR MEDICAL FOLLOW-UP

Although silicosis can occur within months (acute silicosis) or a few years (accelerated silicosis), silicosis is a disease that typically occurs after 20 or more years of exposure. There are no reports in the medical literature of silicosis from fracking consistent with the fact that the type of fracking that uses large quantities of silica began about 10 years ago and only within the last couple of years has become common. Therefore, despite the high silica exposure levels documented with hydraulic fracturing,[6] it is unlikely that health care providers will diagnose workers in the natural gas/oil drilling industry with silicosis for the next 5 to 10 years. However, it is possible given the high reported air levels of silica that workers in this industry may be at risk of developing accelerated silicosis after only 5 to 10 years of work.

The current OSHA standard does not require medical surveillance. The proposed standard would require medical testing every 3 years and would include:

(a) Medical and work history.
(b) Physical examination with emphasis on the respiratory system.
(c) Chest radiograph or equivalent diagnostic study such as a computed tomography scan interpreted by a NIOSH certified "B" reader. If the chest radiograph is 1/0 or more per the International Labor Organization system then the employer is required to refer the worker to a board certified pulmonologist.

FIGURE 5. Transfer of sand from a sand mover via transfer belt at a hydraulic fracturing drilling site. Exposure to silica measured at 27 times the allowable Occupational Safety and Health Administration permissible exposure limit. Photo courtesy of Eric J. Esswein, NIOSH Western States Office. Reproduced with permission.

(d) Spirometry.
(e) Testing for latent tuberculosis.
(f) Any other test deemed appropriate by the health care provider.

Regulatory alternatives on medical surveillance in the proposed silica standard are offered include requiring that medical surveillance be conducted annually or requiring medical surveillance for workers at lower levels of exposure, 25 $\mu g/m^3$ rather than 50 $\mu g/m^3$ level.

Physicians caring for a patient who works or has worked in the fracking industry for a number of years, should consider a chest radiograph to rule out the possibility of accelerated silicosis, particularly if the patient has worked at one of the jobs with higher exposure to silica; sand mover operator, T-belt operator, blender operator, or hydration unit operator.

Because of the increased demand for sand by the fracking industry, the number of sand mines and the number of workers employed in sand mining has increased. The increased number of workers at risk of developing silicosis in the sand mining industry has similar issues as workers at the drill sites; relatively short time since the increase has occurred and decreased likelihood of the diagnosis silicosis in the near future. However, like the workers at the drill sites, physicians caring for these individuals should consider a chest radiograph to rule out accelerated silicosis.

Whether or not the medical community sees patients with silicosis in the future will depend on how well the industry responds to recommendations for controlling silica exposure at fracking sites and whether OSHA's proposed regulations for a comprehensive standard on industries using silica is implemented and adhered to.

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