Society of Toxicology
Creating a Safer and Healthier World by Advancing the Science of Toxicology

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Society of Toxicology Executive Summary

"The Role of Toxicological Science in Meeting the Challenges and Opportunities of Hydraulic Fracturing" *Toxicological Sciences* 139.2 (2014): 271-283; DOI:10.1093/toxsci/kfu061

Introduction

Advances in the technology of hydraulic fracturing of shale to produce natural gas and oil offers the United States welcome opportunities to enhance domestic energy options and promote energy independence. The efficiency of natural gas for electric power generation also gives us the opportunity to reduce greenhouse gas emissions, as well as decrease the level of toxic airborne pollutants. North America has vast reserves of natural gas that are commercially viable as a result of advances in engineering technology that allows directional horizontal drilling in shale layers deep underground and advances in the injection of water containing chemical and physical agents to fracture rock formations that lack permeability and release the natural gas tightly held within these shale layers — a process known as hydraulic fracturing.

Policymakers and the public are seeking assurance that the rapidly increasing hydraulic fracturing effort is being developed in a manner that maximizes benefits while minimizing risks to public health and the environment. In this brief review of toxicological issues, we consider upstream activities related to bringing chemical and physical agents to the site; on-site activities, including the drilling of wells and containment of agents injected into or produced from the well; and downstream activities, including the flow/removal of hydrocarbon products and produced water from the site. A broad variety of chemical and physical agents are involved, and this has raised public concern, particularly as the industry expands. Hydraulic fracturing was developed from conventional oil and gas production, and as such, many of the processes and chemicals involved have been the subject of earlier public, environmental, and occupational health studies and risk assessments. These will not be detailed in this document.

The purpose of this document is to briefly outline how toxicology can inform the discussion and debate of the merits of hydraulic fracturing by providing information on the potential toxicity of the chemical and physical agents associated with this process. These data are essential for developing a reliable assessment of the potential risks to human health and the environment. Toxicological input will be most effective when employed early in the process — before there are unwanted consequences to human health and the environment or economic losses due to the need to abandon or retool costly initiatives.

Hydraulic Fracturing

The process of hydraulic fracturing involves injecting large volumes of water, sand, and chemicals into a drilled well at high pressure to produce an array of fractures primarily in shale formations allowing enhanced recovery of oil and gas. The sand or "proppant" is driven into these fractures to keep them open. A substantial amount of the water (estimates of 10–70 percent) flows back to the surface relatively rapidly. The rest is absorbed by the bedrock. Much smaller amounts are produced continuously during the lifetime of the well. The term "produced water" can be used to describe all the fluid that returns from the well. The most frequently used mixtures for fracturing shale to produce gas are about 75 percent water and 24% proppant (typically silica), and the remainder consists of chemical additives comprising 0.5 to two percent by volume. Chemical additives encompass a wide range of chemicals including those classified as acids, biocides, breakers, buffers, clay stabilizers, corrosion inhibitors, crosslinkers, foaming agents, friction reducers, gelling agents, iron control agents, pH adjusters, scale inhibitors, solvents, and surfactants. Not all chemical functions are needed for every fracturing job, and although there are perhaps hundreds of chemicals that have been used, only a limited number are routinely used. Depending upon state law and company practice, information about the specific hydrofracturing agents used in an individual well is often, but not always, obtainable. Disclosure of the natural components brought up in produced water or any products of chemical reactions among the different agents is less likely to be available or required by state law.

The properties of produced water vary with geologic formation, fracturing fluid composition, and the time since drilling. The naturally present chemicals in the rocks that can be brought to the surface in the produced water may pose a concern. Total dissolved solids — often present at concentrations exceeding those allowed to be discharged into surface water — contain components such as chloride, bromide, barium, calcium, iron, magnesium, strontium, and others. They may also contain other naturally present components, such as arsenic and radionuclides. Produced water is often disposed of in underground injection control wells, particularly in locations such as Texas where the geology supports deep well injection. In other locations, produced water may be stored on-site, be recycled, or otherwise contained in off-site collecting ponds. Disposition of produced water must be achieved in a manner that does not adversely impact human health or the environment.

Potential Pathways of Contamination and Toxicological Effects

Water Pollution

Surface or groundwater contamination by hydraulic fracturing fluids can result from incidents related to delivery of the agents to the site, storage and transfer, the injection process, or the eventual disposal of the produced waters. Potential issues include accidental spills or leaks from storage tanks, surface impoundment failures, leaching, overfills, vandalism, or improper operations, including well failure. As a result, fluids could contaminate nearby surface waters or migrate to groundwater. In areas of shallow production, the induced fracture array may release natural gas, crude oil, and other fracture-related fluids into an overlying aquifer. However, there are currently few confirmed cases of groundwater contamination.

Aquatic ecosystems may be at particular risk to the high brine content of produced waters. It is possible that constituents of hydraulic fracturing fluids may degrade environmental quality directly or indirectly by modifying aquatic habitats, for example by increasing the likelihood of harmful algae blooms. It has been suggested that groundwater contamination may impact the health of farm animals and pets; additional studies may be needed to determine whether such effects can be verified.

Careful management of produced water is required, especially in areas containing sensitive groundwater resources. Potential exposure routes to aquatic and terrestrial ecosystems require careful consideration. Alteration of landscape features with resultant effects on terrestrial ecosystems also needs to be considered. Further, oil and gas development can modify watersheds and adversely affect water availability, which may be important in semi-arid, drought-susceptible, and humid areas.

Air Pollution
Sources of air pollution as a result of direct activities associated with the hydraulic fracturing process include the release of methane gas at well heads, controlled burning of natural gas, and the presence of volatile organic chemicals (VOCs) in the produced water that can evaporate from storage in open pits. VOCs include benzene, toluene, ethylbenzene, and xylene, which are toxic and, when reacting with nitrogen oxides and sunlight, can also increase ground level ozone. Air pollution may also result indirectly from the reliance of the operation on diesel engines in natural gas compressor stations and in trucks. Diesel exhaust has been associated with an increased risk of childhood asthma attacks and other respiratory diseases and, based upon studies of workers exposed to older diesel technology, is carcinogenic. Ongoing industry transition to new, less-polluting diesel fuels and engines and to natural gas for vehicles and other equipment used in the hydraulic fracturing process should lessen this source of pollution. A study of air emissions from shale gas development in Colorado predicted a cumulative increase of six to 10 per million for lifetime cancer risk from benzene, depending on residential distance from the site. The study also predicted increases of risk other than cancer, primarily from exposure to trimethylbenzenes, xylenes, and aliphatic hydrocarbons. Additionally, there may be a human health benefit associated with hydraulic fracturing as the increased availability of natural gas may decrease exposures to particulate, polycyclic aromatic hydrocarbons, mercury, and other known air pollutants by replacing coal as a fuel source for industry and electricity generation.

Occupational Health
Workers can be exposed to drilling fluid or mud at various locations in a typical drilling operation — in the shaker house, at the mixing hopper, at the fluid pit system, on the drill floor, and in the laboratory. Risks of inhalation, dermal, and eye injuries occur throughout the process, particularly when additives are loaded manually. Some of the components of drilling mud may include silica, sensitizers, and other noxious dusts. Potential for exposures on the rig drilling floor includes vapors and aerosols from drilling fluids, cleaning fluids, hydraulic oils, lubricants, and emissions from the shale shaker. The National Institute for Occupational Safety and Health (NIOSH) is currently conducting field studies to gather occupational exposure information for a number of airborne contaminants. Their studies have identified exposure to respirable silica (when sand is used as a proppant) at levels above allowable concentrations.

Radiation and Noise
Rock units that contain hydrocarbons also typically contain naturally occurring radioactive material, particularly uranium and thorium. These elements and their decay products, notably radium-226 and radium-228, can be brought to the surface in drill cuttings and produced water. Radon-222, a gaseous decay product of radium, can be distributed in pipelines along with the natural gas. There is controversy over the possibility that relatively high levels of radon in natural gas from the Marcellus shale located in the northeastern US can persist in the gas to home usage and lead to an increase in lung cancer. Noise pollution has been noted as a source of community and individual concern, but has not been systematically studied.

Information Needs and Challenges
Understanding exposure pathways so as to predict worker, community, and ecosystem effects requires a broad evaluation of all activities, including the trucking of materials to and from the site, all efforts at the site, and the disposition of the produced water. It will be beneficial to include measurements of air, water, and soil and of biological markers of exposure and effect in ecosystems and humans. Exposure assessments should be coupled with toxicological studies of the potential impacts using accepted toxicological methodologies as well as newer computational modeling approaches.

Chemicals need to be identified and subjected to preliminary exposure and risk assessment estimates. The agents to be considered include those used in hydraulic fracturing; the petroleum and natural gas components in the underground rock units; and naturally occurring compounds brought to the surface as part of the process. One of the most difficult challenges facing toxicologists is predicting the effects of mixtures. Adding to this challenge is that the mixtures will vary from location to location based upon the choice of hydraulic fracturing agents, as well as local geology which will determine hydrocarbon and natural background constituents. Special attention needs to be paid to potential toxicity occurring due to the interaction of these many compounds in producing adverse health effects. In addition, the possibility of chemical reactions among the diverse components producing unwanted chemical products requires consideration.

Continued development and validation of predictive models and tiered assessment approaches are warranted to move the field forward. This will permit better definition of the relative risks associated with exposures to the complex mixtures of chemicals used in hydraulic fracturing processes and, thereby, provide information that will be important to minimizing any negative impact of this enterprise on human and environmental health. Green chemistry principles (i.e., sustainable molecular design of less toxic substances) and similar alternative analyses appear useful for the suite of chemicals currently used in fracturing fluids.

Finally, but most importantly, toxicological evaluation of chemical and physical agents associated with hydraulic fracturing should be accelerated. The US Environmental Protection Agency (EPA) has a study underway to partially evaluate some of the toxicological and exposure issues related to hydraulic fracturing compounds, but will not consider issues such as mixtures or natural compounds present in the flowback fluids in this phase. The science of toxicology and the professionals who study mechanisms of toxicity and carry out complex risk assessments associated with chemical evaluation need to be part of the state and federal advisory committees that are tasked with responding to the potential health impacts of shale gas drilling. Addressing these important health and environmental topics requires collaboration between all stakeholders to sustainably develop this valuable energy resource so as to maximize its benefits while minimizing its environmental and public health risks.

Conclusion

Toxicological research identifies toxicological hazards and characterizes risks associated with human and environmental exposures to chemical substances. This approach has a long history of minimizing risk to human health and the environment in our modern industrial era, and the evolution of hydraulic fracturing requires sound scientific input on the identification of potential hazards, exposure assessment and risk characterization, and management of the chemicals and processes associated with this technology. Such efforts are most effective and beneficial when used in a predictive manner rather than to define toxicological causality after adverse consequences have occurred. By advancing the science, toxicologists can provide the requisite knowledge and expertise to minimize detrimental effects to human health and the environment from advanced hydraulic fracturing enterprise. Appropriate and timely integration of the science of toxicology into the larger public and governmental discussions of this enterprise is critical to a rational and balanced outcome that protects public and environmental health and ensures progress for cleaner energy development.

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About SOT

Founded in 1961, the Society of Toxicology (SOT) is a professional and scholarly organization of more than 7,700 scientists from academic institutions, government, and industry representing the great variety of individuals who practice toxicology in the US and abroad. SOT is committed to creating a safer and healthier world by advancing the science of toxicology. The Society promotes the acquisition and utilization of knowledge in toxicology, aids in the protection of public health, and has a strong commitment to education in toxicology and to the recruitment of students and new members into the profession. For more information about SOT and toxicology, visit the Society online at www.toxicology.org, follow us on Twitter @SOToxicology, and like us on Facebook.

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