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Assessing dermal exposure risk to workers from flowback water during shale gas hydraulic fracturing activity

Bevin Durant [a], Noura Abualfaraj [b,*], Mira S. Olson [b], Patrick L. Gurian [b]

[a] Drexel University, School of Public Health, Environmental and Occupational Health Department, 3215 Market St, Philadelphia, PA 19104, USA
[b] Drexel University, College of Engineering, CAEE Department, 3141 Chestnut St., Philadelphia, PA 19104, USA

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ABSTRACT

Hydraulic fracturing is a well stimulation technique used in the production of natural gas from shale. While hydraulic fracturing has been in use for decades as a method for oil and gas recovery, recent advances in horizontal drilling techniques and fracturing fluid production have made previously unattainable natural gas reservoirs accessible and economically recoverable. Flowback water produced from the hydraulic fracturing process can pose environmental and human health risks. The objective of this study is to assess cancer risk following dermal exposure to flowback water among workers at hydraulic fracturing sites. Median, 2.5th percentile, and 97.5th percentile concentrations for high priority constituents in flowback water were collected from a previous study and used to estimate cancer risk from dermal exposure to carcinogenic agents in water compared to a target lifetime cancer risk value of 10^{-6}. Hazard quotients, which compare exposure dose to dose at which no adverse effects are expected, were also calculated for non-carcinogenic components of flowback water and compared to an acceptable value of 1. The cancer risk estimate for median concentrations did not exceed the target lifetime cancer risk of 10^{-6} except for benzo(a)pyrene where the cancer risk of full hand exposure to flowback water for 3 h (one event per week for 4 years) falls within this range ($2.9 \times 10^{-6} - 1.4 \times 10^{-5}$), which exceeds the target risk level even at the 2.5 percentile value. The upper limit of cancer risk form exposure to heptachlor also exceeds 10^{-6} in this model. Hazard quotient for barium in the same model exceeds 1 (1.7) and results in a total hazard index of 2.

1. Introduction

The United States has seen a significant increase in the development and production of natural gas over the past two decades by tapping into domestic resources (Colborn et al., 2014). While hydraulic fracturing has been in use since the mid-nineteenth century as a method for oil and gas recovery, recent advances in horizontal drilling and hydraulic fracturing techniques have made previously unattainable natural gas from shale accessible and economically recoverable. Hydraulic fracturing uses pressurized water (typically 2–5 million gallons for each fracturing operation (NYSDEC, 2015)) mixed with chemical additives that behave as friction reducers, corrosion inhibitors, gelling agent, biocides, scale inhibitors, and surfactants (Aminto and Olson, 2012). The hydraulic fracturing fluid acts to expand fractures within the shale formation and to carry the proppant (usually sand) into those fractures, which holds them open in order to allow the trapped gas to diffuse to the well (Clark et al., 2013; NYSDEC, 2015; Rozell and Reaven, 2012).

The types of chemical additives used in the hydraulic fracturing fluid will vary depending on the characteristics of the well, and the geology, biology, hydrology, and chemical and mineralogical composition of the shale (U.S. EPA, 2015). Additives in fracturing fluid typically constitute ~0.5–2% of the fracturing fluid, by weight and may contain varying amounts of acid, corrosion inhibitors, friction reducers, gelling agent, scale inhibitors, and surfactants (Aminto and Olson, 2012; NYSDEC, 2015; U.S. EPA, 2015).

After the hydraulic fracturing process, a portion of the fracturing fluid (10–30%) will return to the surface as wastewater, which includes the chemical additives from the fracturing fluid accompanied by naturally occurring salts, radioisotopes, and other elements that exist in the shale formation (Abualfaraj et al., 2014; Alley et al., 2011; Zhang et al., 2014). This wastewater is often categorized as flowback water – the water that is released with the first two weeks of completing the hydraulic fracturing process – and

* Corresponding author. 3141 Chestnut St., Philadelphia, PA 19130, USA.
E-mail address: na489@drexel.edu (N. Abualfaraj).

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produced water or production water- naturally occurring water that flows to the surface throughout the production lifespan of a well (Vidic et al., 2013). Both will be referred to as flowback water here.

As drilling activity increases, so do concerns about environmental and human health effects, such as air pollution from volatile compounds (Bloomdahl et al., 2014; Bunch et al., 2014; Colborn et al., 2014; Esswein et al., 2012), stray gas migration into shallow aquifers (Ingraffea et al., 2014; Jackson et al., 2013; Osborn et al., 2011; Siegel et al., 2015; Vengosh et al., 2014), and water resource contamination from improper disposal or accidental release of flowback water (Beaver, 2014; Brantley et al., 2014; Gordalla et al., 2013; Rozell and Reaven, 2012; Vengosh et al., 2014; Warner et al., 2013; Wilson and Van Briesen, 2013). Certain chemicals in hydraulic fracturing fluid and flowback water have the potential to cause severe adverse health effects after chronic or even acute exposure (Balaba and Smart, 2012; Colborn et al., 2014).

In the years after high-volume hydraulic fracturing came into widespread use in Pennsylvania, a large amount of data on flowback characteristics became available due to public and regulatory attention to the process. Several studies have utilized this data in order to characterize flowback water and identify potential human health hazards. These studies have found that hydraulic fracturing wastewater generally has very high concentrations of salts and total dissolved solids (TDS), as well as levels of radionuclides, metals, and organic compounds that could be harmful to human health (Abualfaraj et al., 2014; Balaba and Smart, 2012; Blauch et al., 2009; Dresel and Rose, 2010; Haluszczak et al., 2013; Hayes, 2009). When comparing hydraulic fracturing activities to those of conventional oil and gas development operations, studies have found higher incidence of failures and violations of safety and regulatory compliance for unconventional (shale gas) wells over conventional wells (Abualfaraj, Olson et al., in press; Ingraffea et al., 2014; Rahm et al., 2015). These violations illustrate possible lapses in the implementation of control measures that could pose dangerous health and safety hazards to workers and the importance of examining sources of risk during shale gas extraction.

Some studies have examined the effects of the natural gas extraction process on workers through various pathways. In 2010, the National Institute for Occupational Safety and Health (NIOSH) conducted a field study, “NIOSH Field Effort to Assess Chemical Exposure Risks to Gas and Oil Workers,” which showed that workers could be exposed to high levels of respirable crystalline silica – the occupational exposure of highest concern (Esswein et al., 2012; Occupational Safety and Health Administration, 2012). The field study focused heavily (if not exclusively) on air sampling (Esswein et al., 2012). Bloomdahl et al. (2014) examined health risks to workers due to inhalation of volatilized contaminants from on-site holding ponds using mean, 2.5 percentile, and 97.5 percentile concentrations of 12 VOCs found in flowback water and concluded that these risks were minimal under typical exposure conditions. In this risk assessment, only one VOC considered had a hazard quotient exceeding acceptable levels at the 97.5 percentile level and under the assumption of low wind speed with multiple holding pits on site. However, there are no studies assessing risk from worker exposure to flowback water through the dermal pathway.

Some researchers have applied more qualitative approaches to understanding risk from shale gas development. Resources for the Future surveyed shale gas experts in order to identify 12 high-priority risk scenarios (out of 264 potential exposure pathways and accidents that were most frequently chosen by participants as being a priority). The pathways identified include risk to surface water and groundwater, air quality, and habitat disruption (Krupnick, 2013). Human health and safety were not included in the scope of the Resources for the Future assessment but have been addressed by Abualfaraj, Gurian et al. (under review) who developed a survey asking participants with experience in the oil and gas field about specific operational failures or intentional violations of regulations that may occur during the shale gas extraction process. The results of the survey revealed that the highest concerns for public health and safety stem from releases of flowback water. In terms of worker safety, the highest concern comes from improper or inadequate use of personal protective equipment (typical oil and gas PPE requirements include eye and face protection, respiratory protection, head protection, and hand protection (OSHA, 1999)) on-site.

This highlights the lack of knowledge concerning specific hazard scenarios that can result in dermal exposure to hydraulic fracturing fluid or flowback water and the risk associated with such an exposure to workers at drilling sites. This uncertainty is significant because workers may be in situations of considerable risk that are preventable. With a better understanding of hazard scenarios – such as those resulting from errors in work practices, design, and/or engineering – as well as the health impacts of exposure to fracturing fluid, an assessment of risk can be performed in order to inform more scientifically based regulations and procedural changes at hydraulic fracturing sites.

The goal of this study is to conduct a dermal exposure risk assessment for workers at hydraulic fracturing sites for a list of carcinogenic and non-carcinogenic chemicals found in flowback water identified as high priority in Abualfaraj et al. (2014). The database utilized in this study combined all the major publically available flowback water sampling data from the Marcellus shale region (35,000 observations collected between March 2008 and December 2010) and prioritized contaminants based on their concentration in flowback water compared to Maximum Contamination Levels (MCLs), where high priority was given to constituents with concentrations that exceeded drinking water standards. This study develops an alternative, more detailed prioritization based on a specific risk assessment scenario. A comparison between the two methods is carried out in order to assess the validity of the prioritization based on drinking water standards.

Currently, there are no recommended estimates for potential worker exposure to flowback water. A literature search revealed no studies regarding health and safety hazards to oil and gas workers as a result of dermal exposure to hydraulic fracturing fluid or flowback water. Four different scenarios of occupational dermal exposure duration and frequency are examined varying the exposed skin surface area (entire hand; a few drops), and the duration of the exposure event (3 h; 30 s) to estimate excess lifetime cancer risk and hazard index from dermal exposure to flowback water and compare them to acceptable risk levels. Occupational tenure statistics were used to provide an estimate for the exposure duration (the number of years that the worker is exposed). According to the Bureau of Labor, the median occupational tenure for oil and gas related fields in 2014 was 4 years (Bureau of Labor Statistics, 2014). In this risk assessment, the worker's exposure is limited to the median tenure of a worker with their current employer and is assumed to have 1 exposure event per week for 4 years (208 total exposure events). The lifetime exposure would include any additional duration at their current employer as well as past and future employers. It was considered unlikely though possible that all positions over a career would involve weekly exposure to flowback water and so the median duration with their current employer was chosen to indicate a rough estimate of time in a particular environment with what is taken to be an unusually high frequency of spills.