Science of the Total Environment 576 (2017) 138–147

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Unconventional oil and gas development and risk of childhood leukemia: Assessing the evidence

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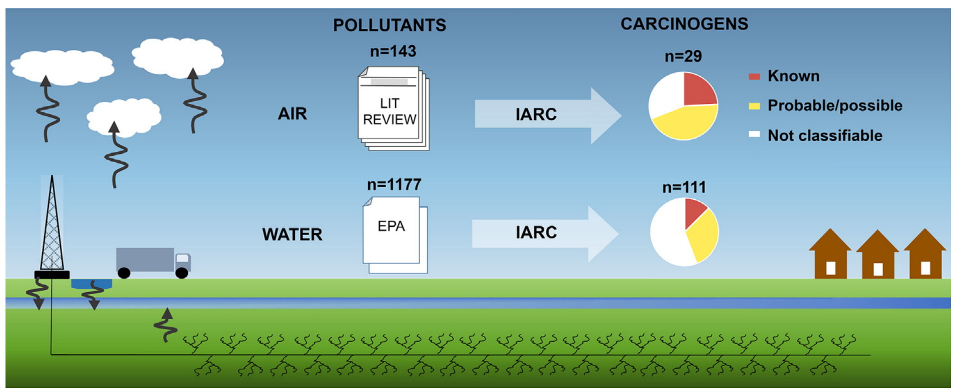
HIGHLIGHTS

- Concerns exist about carcinogenic effects of unconventional oil & gas development.
- We evaluated the carcinogenicity of 1177 water pollutants and 143 air pollutants.
- These chemicals included 55 known, probable, or possible human carcinogens.
- Specifically, 20 compounds had evidence of leukemia/lymphoma risk.
- Research on exposures to unconventional oil & gas development and cancer is needed.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 25 August 2016
Received in revised form 9 October 2016
Accepted 10 October 2016
Available online xxxx

Editor: D. Barcelo

Keywords:
Air pollution
Carcinogens
Hydraulic fracturing
Shale
Wastewater
Water contamination

ABSTRACT

The widespread distribution of unconventional oil and gas (UO&G) wells and other facilities in the United States potentially exposes millions of people to air and water pollutants, including known or suspected carcinogens. Childhood leukemia is a particular concern because of the disease severity, vulnerable population, and short disease latency. A comprehensive review of carcinogens and leukemogens associated with UO&G development is not available and could inform future exposure monitoring studies and human health assessments. The objective of this analysis was to assess the evidence of carcinogenicity of water contaminants and air pollutants related to UO&G development. We obtained a list of 1177 chemicals in hydraulic fracturing fluids and wastewater from the U.S. Environmental Protection Agency and constructed a list of 143 UO&G-related air pollutants through a review of scientific papers published through 2015 using PubMed and ProQuest databases. We assessed carcinogenicity and evidence of increased risk for leukemia/lymphoma of these chemicals using International Agency for Research on Cancer (IARC) monographs. The majority of compounds (>80%) were not evaluated by IARC and therefore could not be reviewed. Of the 111 potential water contaminants and 29 potential air pollutants evaluated by IARC (119 unique compounds), 49 water and 20 air pollutants were known, probable, or possible human carcinogens (55 unique compounds). A total of 17 water and 11 air pollutants (20 unique compounds) had evidence of increased risk for leukemia/lymphoma, including benzene, 1,3-butadiene, cadmium, diesel exhaust, and several polycyclic aromatic hydrocarbons. Though information on the carcinogenicity of compounds associated with UO&G development was limited, our assessment identified 20 known or suspected carcinogens that could be measured in future studies to advance exposure and risk assessments of cancer-causing agents. Our findings

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http://dx.doi.org/10.1016/j.scitotenv.2016.10.072

support the need for investigation into the relationship between UO&G development and risk of cancer in general and childhood leukemia in particular.

1. Introduction

Unconventional oil and gas (UO&G) development is a complex, multiphase process of extracting oil and natural gas from low-permeable rock formations that were inaccessible prior to recent technological advances in hydraulic fracturing and directional drilling. It has expanded rapidly in the past decade and now occurs in as many as 30 states within the United States, with millions of people living within 1 mile of a hydraulically fractured well (US EPA, 2015). Concerns have been raised about the potential exposures to water and air pollutants and related health impacts (Adgate et al., 2014). Chemicals involved in or produced by UO&G development may include reproductive/developmental toxicants (Elliott et al., 2016; Kahrilas et al., 2015; Wattenberg et al., 2015), endocrine disruptors (Kassotis et al., 2014), or known or suspected carcinogenic agents (McKenzie et al., 2012). The limited epidemiologic studies of UO&G development have observed an increase in adverse perinatal outcomes (Casey et al., 2016; McKenzie et al., 2014; Stacy et al., 2015), asthma exacerbations (Rasmussen et al., 2016), dermal irritation (Rabinowitz et al., 2015), hospitalization rates (Jemielita et al., 2015), and nasal, headache, and fatigue symptoms (Tustin et al., 2016).

Childhood leukemia in particular is a public health concern related to UO&G development, and it may be an early indicator of exposure to environmental carcinogens due to the relatively short disease latency and vulnerability of the exposed population (Rothwell et al., 1991; Shy et al., 1994). The age-adjusted incidence rate of leukemia in the United States for children under the age of 15 was 5.3 per 100,000 persons in 2011, the highest among all types of childhood cancer, and the peak age of incidence is 2–5 years (CDC, 2015). The U.S. incidence rates for acute lymphocytic leukemia, the most common subtype of childhood leukemia, increased annually by 1.4% from 2000 to 2010 (Gittleman et al., 2015). Environmental exposures, such as ionizing radiation, benzene, traffic exhaust, tobacco smoke, and pesticides, have been linked to childhood acute lymphoblastic leukemia, though evidence is generally limited or inconsistent (Bailey et al., 2015a; Bailey et al., 2015b; Tong et al., 2012; Ward et al., 2014; Wiemels, 2012; Zachek et al., 2015). A comprehensive review of the carcinogens and leukemogens associated with UO&G development is not available and could inform future environmental and biological monitoring and human health studies. In this analysis, we aimed to systematically assess the evidence for a possible carcinogenic/leukemogenic role of (1) water contaminants and (2) air pollutants associated with UO&G development.

1.1. Unconventional oil and gas development: description of the process

In oil and gas extraction, a well pad must first be constructed. This involves the use of construction vehicles, heavy equipment, and diesel generators in continuous operation to create roads, clear and set up a well site, and transport materials to the site (Moore et al., 2014). After well pad construction is complete, drilling rigs drill vertically past the deepest freshwater aquifer down to the level of the source formation, such as shale rock, turn and drill horizontally for distances up to 3000 m (Laurenzi and Jersey, 2013). After drilling, the well is hydraulically fractured. In this step, large volumes of fracturing fluids consisting of water, chemicals, and proppants (sand or ceramic beads) are forced into wells under high pressure, creating fissures or fractures in the rock along the horizontal section of the wellbore to release oil or gas. Typically, about 15–100 million l of fluid are used for each well, of which approximately 1–2% are chemical additives, representing a substantial volume of chemicals used per well (estimated as upwards of 114,000 l) (US DOE, 2013; US EPA, 2012). Chemical additives in fracturing fluids include biocides, surfactants, and anti-corrosive agents (US EPA, 2015). After fracturing, wastewater flows up the wells. Within 1–4 weeks about 30% of injected fracturing fluids rapidly return to the surface through the well as "flowback" water; subsequently, "produced" water returns up the well more slowly. The produced water includes the injected fluids along with mobilized, naturally-occurring compounds (e.g., heavy metals, bromides, radionuclides) (Ferrar et al., 2013; Vidic et al., 2013). Flowback and produced wastewater are stored in large open pits or storage tanks until they can be treated, reused, or disposed of offsite, such as in injection wells. Oil, gas, and produced water flow up the well for years or decades during the production phase of the well (Barbot et al., 2013; Nicot et al., 2014). During production, diesel-power trucks may be used to maintain the wells or transport oil or gas off the well pad. This stage also includes the processing and distribution of the produced oil and gas at other facilities (NYS DEC, 2011).

1.2. Possible pathways of environmental exposure to carcinogenic agents

Possible pathways of water contamination during fracturing and production include faulty or deteriorating well casings, equipment failure, surface spills of fracturing fluids or wastewater on-site or from tanker trucks transporting these liquids, migration of chemicals from fractures to shallow aquifers, leakage from wastewater pits, and unauthorized discharge and release of inadequately treated wastewater into the environment (Adgate et al., 2014; Brantley et al., 2014; Ferrar et al., 2013; Gross et al., 2013; Jackson et al., 2013b; Osborn et al., 2011; Rozell and Reaven, 2012; Shonkoff et al., 2014; US EPA, 2015; Vengosh et al., 2014; Vengosh et al., 2013; Warner et al., 2012). Surface activities may pose the greater potential threat in the near-term (Drollette et al., 2015), with sub-surface activities potentially presenting a hazard over a longer period of time. Several water quality studies have measured total dissolved solids, isotopes, and other chemicals to characterize a geochemical fingerprint of UO&G development (Jackson et al., 2013a; Vengosh et al., 2013; Warner et al., 2013; Warner et al., 2012); these studies are not necessarily focused on compounds with evidence of toxicity to humans. Studies measuring concentrations of health-relevant chemicals in drinking water sources are emerging (Harkness et al., 2015; Hildenbrand et al., 2015; Llewellyn et al., 2015), but data are limited.

UO&G development activities that could generate air pollution include operation of diesel-powered equipment, use of vehicles to transport materials and waste to and from the site, addition of sand (silica) to the fracturing fluid mixture, volatilization of compounds from wastewater, and processing and distribution of the oil and gas (Moore et al., 2014). Air pollutants, such as diesel exhaust, fine and coarse air particulates, crystalline silica, and polycyclic aromatic hydrocarbons (PAHs), are a few examples commonly cited as being generated as part of the various phases of UO&G development (Burnham et al., 2012; McCawley, 2015; Moore et al., 2014). To our knowledge, no comprehensive list of air pollutants potentially related to UO&G development is available in the published literature or government reports.

1.3. Epidemiologic studies of unconventional oil and gas development

Knowledge of the health risks of UO&G development is sparse, though epidemiologic studies on this topic are emerging. Studies