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Prioritization of reproductive toxicants in unconventional oil and gas operations using a multi-country regulatory data-driven hazard assessment

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ABSTRACT

Background: Recent trends have witnessed the global growth of unconventional oil and gas (UOG) production. Epidemiologic studies have suggested associations between proximity to UOG operations with increased adverse birth outcomes and cancer, though specific potential etiologic agents have not yet been identified. To perform effective risk assessment of chemicals used in UOG production, the first step of hazard identification followed by prioritization specifically for reproductive toxicity, carcinogenicity and mutagenicity is crucial in an evidence-based risk assessment approach. To date, there is no single hazard classification list based on the United Nations Globally Harmonized System (GHS), with countries applying the GHS standards to generate their own chemical hazard classification lists. A current challenge for chemical prioritization, particularly for a multi-national industry, is inconsistent hazard classification which may result in misjudgment of the potential public health risks. We present a novel approach for hazard identification followed by prioritization of reproductive toxicants found in UOG operations using publicly available regulatory databases.

Methods: GHS classification for reproductive toxicity of 157 UOG-related chemicals identified as potential reproductive or developmental toxicants in a previous publication was assessed using eleven governmental regulatory agency databases. If there was discordance in classifications across agencies, the most stringent classification was assigned. Chemicals in the category of known or presumed human reproductive toxicants were further evaluated for carcinogenicity and germ cell mutagenicity based on government classifications. A scoring system was utilized to assign numerical values for reproductive health, cancer and germ cell mutation hazard endpoints. Using a Cytoscape analysis, both qualitative and quantitative results were presented visually to readily identify high priority UOG chemicals with evidence of multiple adverse effects.

Results: We observed substantial inconsistencies in classification among the 11 databases. By adopting the most stringent classification within and across countries, 43 chemicals were classified as known or presumed human reproductive toxicants (GHS Category 1), while 31 chemicals were classified as suspected human reproductive toxicants (GHS Category 2). The 43 reproductive toxicants were further subjected to analysis for carcinogenic and mutagenic properties. Calculated hazard scores and Cytoscape visualization yielded several high priority chemicals including potassium dichromate, cadmium, benzene and ethylene oxide.

Conclusions: Our findings reveal diverging GHS classification outcomes for UOG chemicals across regulatory agencies. Adoption of the most stringent classification with application of hazard scores provides a useful approach to prioritize reproductive toxicants in UOG and other industries for exposure assessments and selection of safer alternatives.

1. Introduction

Hazard identification is the first critical step in the assessment of chemical risks. Historically, there has been inconsistent and ineffective classification or hazard identification across countries (Pratt, 2002). The same chemical may be classified and communicated differently by the national and international schemes, which may result in unnecessarily inconsistent hazard classification and potentially lead to

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inadequate protection of human health in certain countries (Winder et al., 2005). To ensure a harmonized classification of chemicals, Chapter 19 of Agenda 21 from the Rio Earth Summit in 1992 mandated the establishment of an internationally–agreed system called the Globally Harmonized System (GHS) for classification and labeling of chemicals which provides guidance on how to classify health hazards (Silk, 2003, UN, 2017).

Since the implementation of GHS, several regulatory authorities in Europe through the European Chemicals Agency (ECHA) and other countries including China, Malaysia, Myanmar New Zealand, South Korea (Ministry of Environment) and Turkey have applied this new classification standard to establish lists of hazardous chemicals under their respective regulations (UNECE, 2017a). The hazards classified in the list are required to be communicated through safety data sheets and labels which trigger further action including risk assessment. Instead of mandatory list, several countries including Australia, Japan, South Korea (Ministry of Employment and Labor) and Taiwan have established lists for chemical classification which serve as an advisory and guidance for industry. The mandatory and advisory classification lists are established to mitigate challenges faced by chemical suppliers or manufacturers due to conflicting hazard information, data gaps and reliability of data for the purpose of hazard communication and protection of human health across the supply chain as part of sound management of chemicals (Wang et al., 2016). Though numerous countries have applied the GHS standards to develop chemical lists, there is no single, universal, harmonized hazard classification list to date.

We were interested in using these lists to classify chemicals from the emerging international industry of unconventional oil and gas (UOG), as an initial step in hazard identification. The UOG development has seen a growth not only in the United States (US) but in other regions including Asia-Pacific (Lozano-Maya, 2016, Cronshaw and Grafton, 2016). In the US, the market benefits from monetizing hydraulic fracturing have been estimated to be approximately $75 billion as a result of lower natural gas prices to consumers and a savings of $13.25 billion has been attributed to the environmental benefits from the switch from coal to natural gas by electrical utilities (Loomis and Haefele, 2017). Despite the purported economic benefits, concerns have been raised about the public health impacts from UOG activities, such as the unintended release of chemicals in hydraulic fracturing fluids (FF) and waste water (WW) into drinking water sources. FF is generally about 98–99% water and proppant (silica or quartz sand). The additional components are small percentages of chemical additives with specific properties and functions, such as biocidal properties, corrosion inhibition, oxygen scavenger and surfactants (Barcelo and Bennett, 2016; Stringfellow et al., 2017). Although the percentage of these chemical additives is small, the overall quantity may be quite large due to the high volume of FF used during the UOG operations. WW poses a higher concern as it may contain hazardous substances originating from the geologic formation water, including metals, organic compounds, hydrocarbons as well as residual chemicals from FF (Vengosh et al., 2014; Kondash et al., 2017).

Recent epidemiologic studies and reviews have been conducted on UOG operations with special emphasis on reproductive toxicity and cancer (McKenzie et al., 2014; Balise et al., 2016; Finkel, 2016; Elliott et al., 2017a, 2017b; McKenzie et al., 2017; Whitworth et al., 2017). However, a comprehensive understanding of the potential health risks from exposure to chemicals used in UOG operations and found in the ensuing WW is limited in part due to toxicology data gaps on some of these chemicals. In fact, two recent evaluations of chemicals used in hydraulic fracturing based on the US EPA list have shown that only 20–25% of approximately 1000 chemicals have information on health hazards especially for reproductive health and cancer (Elliott et al., 2017a, 2017b).

One of the major challenges in chemical prioritization is the inconsistent hazard classification, which may lead to inaccurate assessment of public health risks. In view of the growing interest in chemicals linked to reproductive health and cancer hazards found in UOG operations (Webb et al., 2014; Elliott et al., 2017a; Balise et al., 2016), the aim of this study was to use a novel approach for hazard identification of 157 UOG-related chemicals as potential reproductive or developmental toxicants reported in our previous publication using eleven government regulatory agencies' databases. The known and presumed human reproductive toxicants were further prioritized for carcinogenic and mutagenic properties followed by assignment of hazard scores. The data was further analyzed using Cytoscape resulting in visualization of high priority chemicals. Integrating the international hazard classifications and application of a scoring system provide a chemical prioritization basis to inform future exposure assessments and selection of safer alternatives in the UOG industry.

2. Methods

2.1. GHS classification using SHIELD system

We obtained data on hazard classifications and exposure limits from a global database (SAP EHS) collating such information for more than 250,000 substances from worldwide regulations. The regulatory data was downloaded from this external regulatory content provider into the PETRONAS Product Regulatory and Safety One-stop Portal database called SHIELD on a substance/substance group basis where the Chemical Abstracts Service (CAS) registry number was used as the key substance identifier. In view of changing regulatory status for substances, the external content provider delivers major updates every

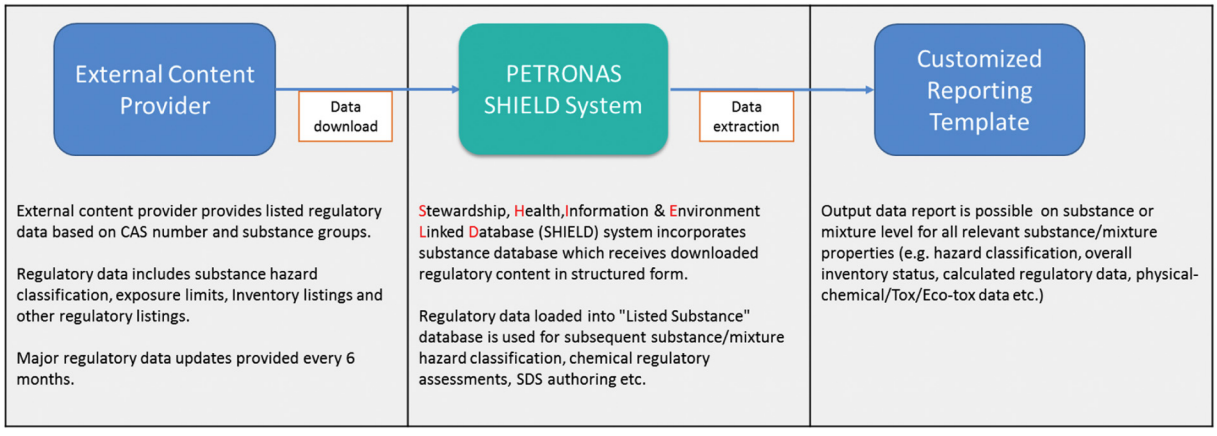

Fig. 1. SHIELD system for GHS classification of chemicals.