# OCCUPATIONAL HAZARDS IN ONSHORE UPSTREAM UNCONVENTIONAL NATURAL GAS EXTRACTION

by

**Megan Anne Allison**

B.S. Industrial Biochemistry, Edinboro University, 2007

Submitted to the Graduate Faculty of

Environmental and Occupational Health

Graduate School of Public Health in partial fulfillment

of the requirements for the degree of

Master of Public Health

University of Pittsburgh

2013

UNIVERSITY OF PITTSBURGH

GRADUATE SCHOOL OF PUBLIC HEALTH

This essay is submitted

by

Megan Allison

on

April 15, 2013

and approved by

Essay Advisor:
James Peterson, Ph.D. ______________________________________
Associate Professor
Environmental and Occupational Health
Graduate School of Public Health
University of Pittsburgh

Essay Reader:
Xu Liang, Ph.D. ______________________________________
Associate Professor
Civil and Environmental Engineering
Swanson School of Engineering
University of Pittsburgh

James Peterson, Ph.D.

**OCCUPATIONAL HAZARDS IN ONSHORE UPSTREAM UNCONVENTIONAL NATURAL GAS EXTRACTION**

Megan Allison, MPH

University of Pittsburgh, 2013

**ABSTRACT**

Occupational hazards of the oil and gas workforce are of interest due to oilfield occupations presenting high risks, and the little known regarding chronic exposures and health effects faced by this workforce. Public health officials and media alike, centering attention around the general population, have overlooked a population likely to have higher exposure rates over longer durations than the general population, while the workforce remains underserved. As a result, this essay intends to identify and detail the public health importance of the occupational hazards of oil and gas extraction workers, specifically in onshore upstream unconventional fields as well as make recommendations for action and research.

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

# 1.0 INTRODUCTION

Unconventional wells are horizontal or vertical bores drilled into an unconventional formation. Unconventional formations include shales below the base of the Elk Sandstone or equivalent. For the purposes of this essay the formations and region of interest encompass New York, Pennsylvania, Ohio, and West Virginia shales, such as the Marcellus and Utica, etc. formations. The wells are most often stimulated (completed) by hydraulic fracturing. Such developments have transformed the oil and gas industry in the United States, the production value per unit land space is greatest in regional history, motivating both local and global companies to lease, drill, and produce. Moreover, the media has garnered attention centered on the general public while little emphasis is placed on the health hazards and exposures to the workforce.

## 1.1 PURPOSE

Occupational hazards of the oil and gas workforce are of interest because oilfield occupations present high risks, and little is known regarding chronic exposures and health effects faced by this workforce. Public health officials and media alike, centering attention around the general population, have overlooked a population likely to have higher exposure rates over longer durations than the general population. Moreover, dialogue and trust between exploration and production companies, governmental organizations, and the public is strained. In part, trust has been undermined by media sensationalism, pushing public health professionals to investigate the effects on the general population, while the workforce remains underserved. As a result, this essay intends to identify and detail the occupational hazards of oil and gas extraction workers, specifically in onshore upstream unconventional fields. The literature review will educate both the writer and the engaged.

## 1.2 SCOPE

A short explanation of unconventional well development, using hydraulic fracture as the completion method, will be presented. Understanding well development phases will provide a background for understanding potential exposures. Through governmental injury/fatality data and scientific literature review, occupational hazards in onshore upstream unconventional fields will be identified and detailed. Understanding occupational hazards is of primary importance because multiple hazards may result in multiple exposures, having the potential for additive or multiplicative effects on overall health risk. Lastly, recommendations for further study and to protect the onshore upstream unconventional oil and gas development workforce will be presented.

# 2.0 BACKGROUND

This section outlines the activities performed by the oil and gas extraction sector, occupations serving the sector, and the significance of this issue to the public health community. Additionally explored are contributing factors (demographics) to oilfield worker occupational fatality and injuries.

## 2.1 UPSTREAM OIL AND GAS EXTRACTION ACTIVITIES

Upstream, midstream, and downstream segments stratify the oil and gas production industry. Upstream is also referred to as exploration and production (E&P). Upstream activities include, but are not limited to exploration/investigation, planning, leasing, permitting, construction, drilling, completions, production, and abandonment/reclamation. Midstream activities include transmission (pipeline) and storage of upstream products. Downstream generally represents point of sale, whether it is direct to consumer (gas station, for example), utility meter, or other sale type.

Upstream activities are the focus of this essay; however, operators may have alternate activity classifications within their organizational structure. In general, the main upstream activities can be broken down into the following steps: construction (site preparation), drilling, completions, operations (referred to as s*ervicing* by the Occupational Safety and Health Administration)[i] and abandonment/reclamation. The following sections outline the general actions in each step; but onsite activities are much more complex.

### 2.1.1 SITE PREPARATION

Site Preparation occurs after exploration, leasing, and permitting. Requirements vary by operator, topography, and regulation. Permits/leases may stipulate conditions regarding almost any aspect of extraction activity including reclamation requirements. The main construction activities include leveling and building a 3½ foot berm around the site while making appropriate provisions for erosion and sediment controls. See Figure 1, featuring the liner (protects soil if a spill occurs), berm (easiest seen along tree line), and erosion and sediment controls (gravel lined channel).

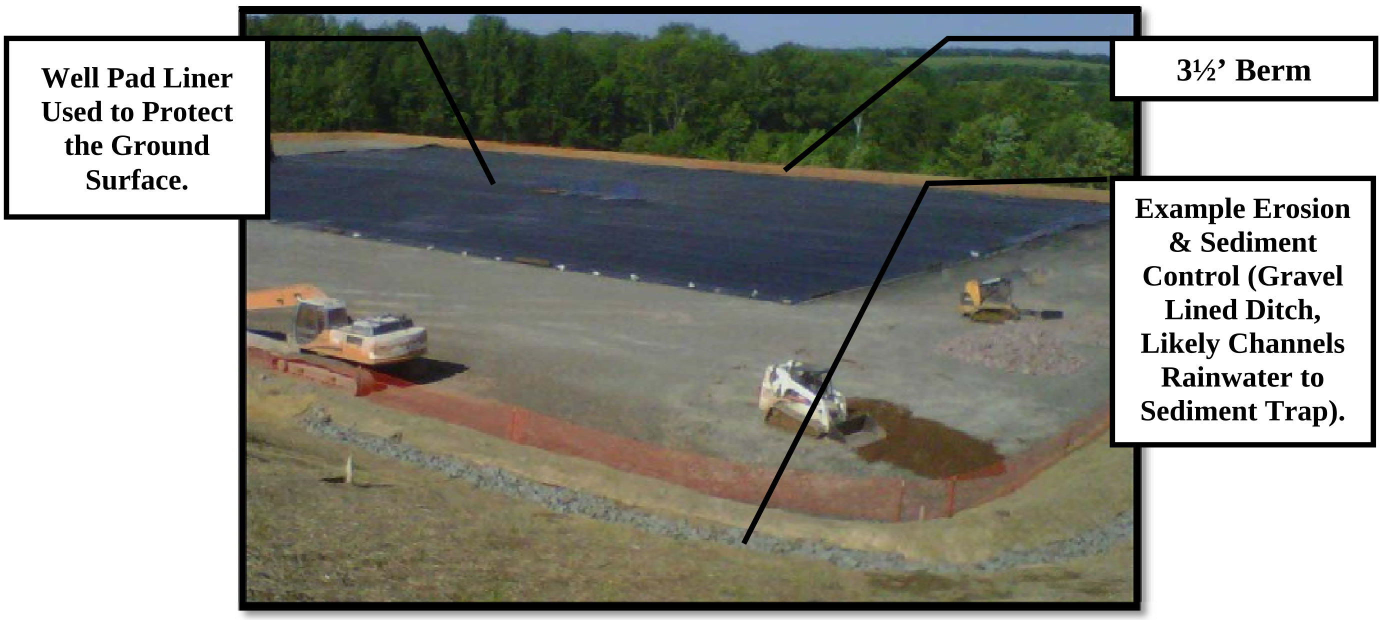


**Figure 1** Site Preparation Phase[ii]

Excavating and trenching activities create the cellar (site of borehole), reserve pits, and sediment traps. The conductor (starter hole) is set, if required by design specifications. Then, small shallow holes are drilled for equipment staging. The big rig and other equipment are transported to the site and unloaded.[iii]

### 2.1.2 DRILLING

Once the "big rig" and other equipment have reached the site, rig up begins and the rig is assembled. This process includes assembling all components of the rig, including the (drill mud) circulating system, pipe racks, railings, safety equipment, and power supply. The rig is inspected prior to commencing operations. Next, the drilling process begins and controls are implemented to monitor pressure, changing conditions, and potential hazards associated with subsurface drilling. The paragraphs below present a brief overview of the drilling process and are an oversimplification, but regardless presented in order to provide a basis for hazard identification.[iv]

Once cleared for drilling, drill ahead begins. This stage can be dangerous due to mechanical movement and heavy loads. Drilling fluids (muds) are prepared that are pumped through the pipe in order to cool the drill bit, lubricate the drill bit, and remove drill cuttings from the borehole. A section of pipe is hoisted into the staging hole where it is staged for use. The drill bit is set in place and attached to the kelly and drill string, which provide the rotary drilling force. The mud pumps are engaged and a section of the borehole is drilled. Drilling and the mud pumps stop and a section of pipe is moved into the borehole and "screwed" in place. (Industry describes this process as *making a connection*.) The process begins again as the next section of pipe is staged. This process of staging the pipe, setting the kelly, engaging the mud pump, drilling, and making a connection continue until the target depth is reached.[v] See Figure 2 for rig features and Figure 3, showing the equipment staging area.

Additional activities taking place during the drilling phase including tripping in/out, casing, and maintenance. Tripping in/out refers to removing the drill bit and pipe from the borehole to replace the drill bit, drill string, or to perform analysis on a section of the borehole. Casings are installed in the borehole to prevent collapse and to avoid contamination of groundwater. Casings are cemented in place by pumping cement between the borehole wall and outer casing.[vi] In a similar manner, production casings and tubings are set. Rig down and site clean-up begin in anticipation of the completions phase.

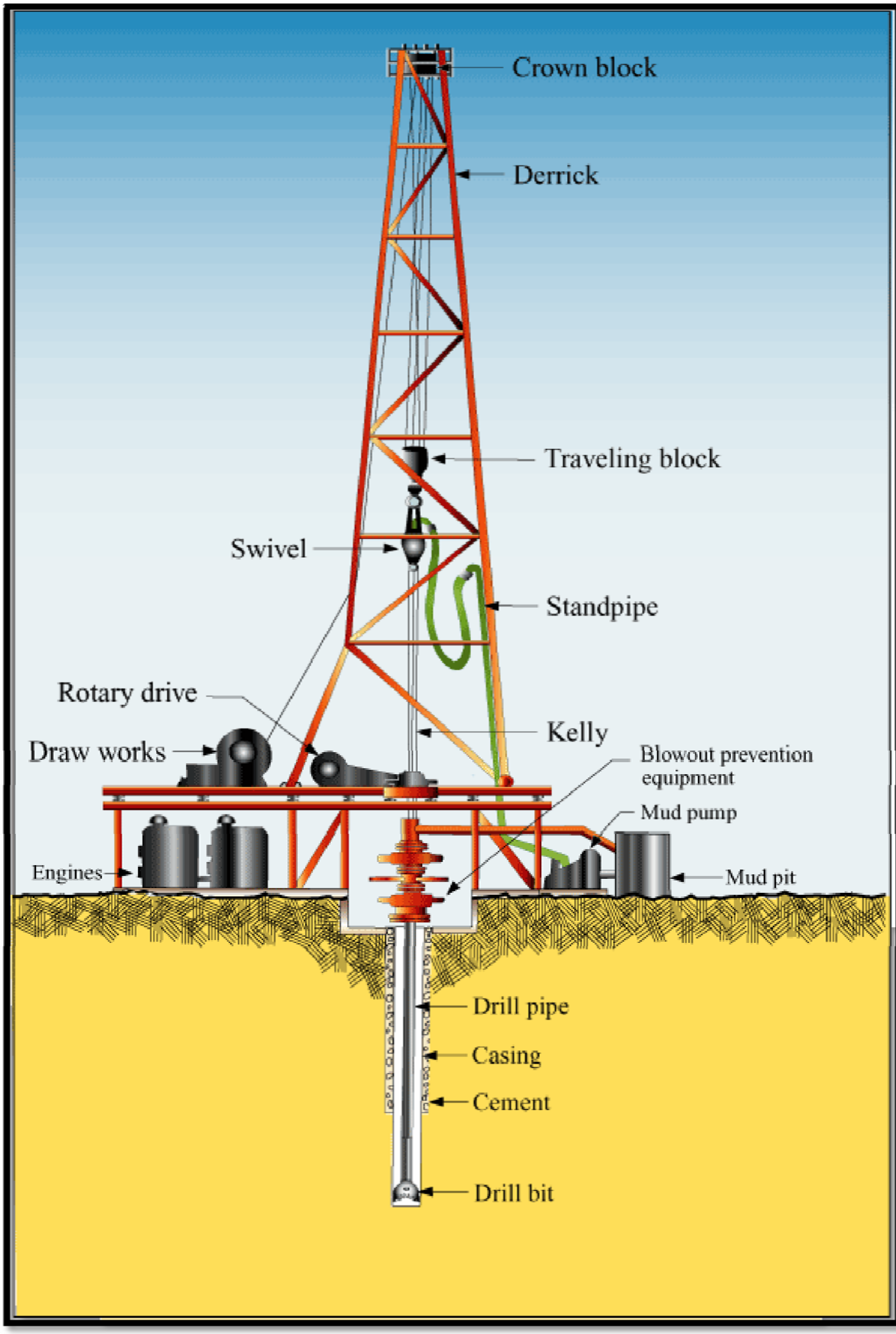


**Figure 2** Drill Rig Diagram[vii]

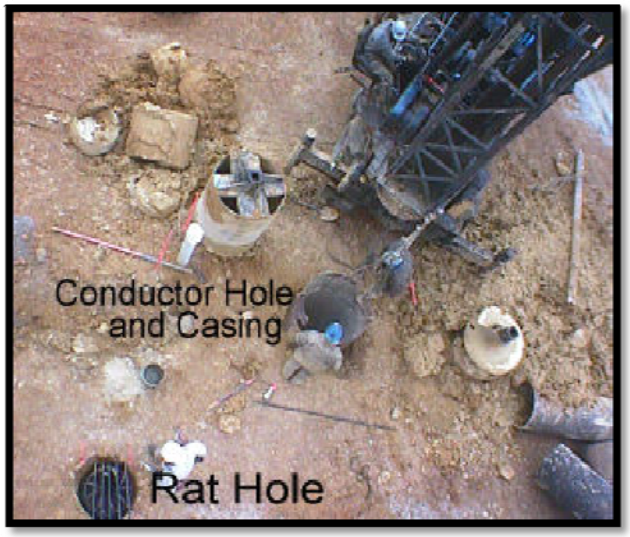


**Figure 3** Equipment Staging Area[viii]

### 2.1.3 COMPLETIONS

Most frequently, hydraulic fracture is used to *complete* unconventional wells. This method stimulates well production and is new to this region, but not new to the industry. Hydraulic fracturing experiments were conducted in 1947, used commercially in 1949, and accepted in the 1950s.[ix] Fracture fluid is site specific, and contains ~0.5% chemical additives (friction reducers, scale inhibitors, solvents, acids, gelling agents, biocides, etc.), ~90% base fluid, and ~10% proppant. "The base fluid is generally water, but can include methanol, liquid carbon dioxide, and liquefied petroleum gas." In this region, sand is used as proppant but sintered bauxite, sintered ceramics, or resin coated sand are alternatives. The fracture fluid components are mixed onsite using sand hoppers and tanks.[x]

Fracture fluid formulation often varies by location, geology, target formation, or other engineering considerations. Once mixed, the fluid is pumped downhole under high pressure into perforations created by setting off controlled explosions using electrical charge and explosive materials. The next step in the process, called flowback, is the stage where the fracture fluid and other formation waters flow back out of the well. The water is pumped into holding tanks after separation into solid and liquid fractions (flowback water and spent fracture sands/sediment) by a shaker. Dissolved gases are removed with a gas buster. Often, multi-stage fracturing occurs, setting plugs between each stage which are drilled out before production. As often as possible, the flowback water is treated and re-cycled for completing a subsequent well. See Figure 4 for an example of the hydraulic fracturing process (note that water requirements differ by location & formation).

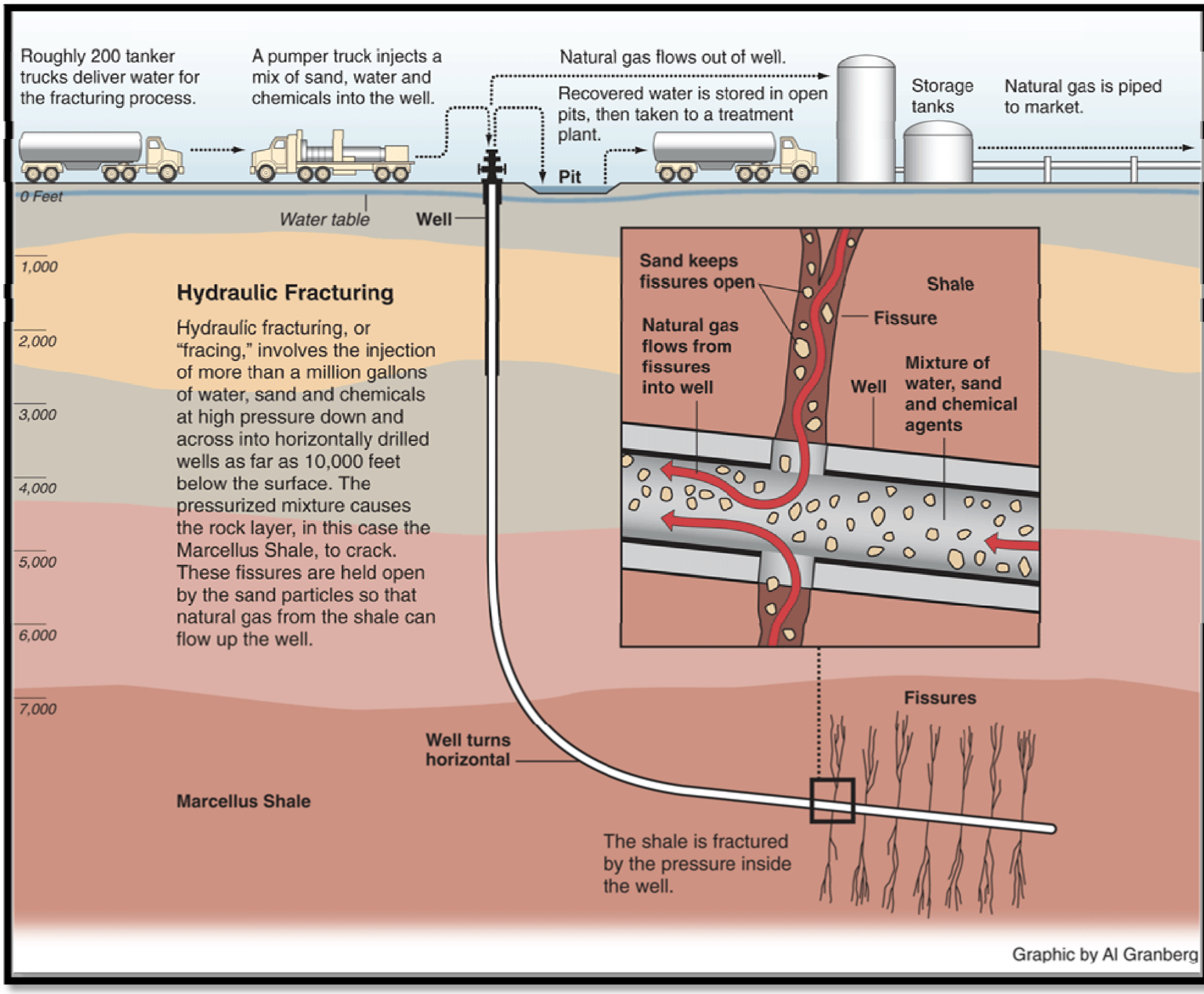


**Figure 4** The Hydraulic Fracture Process[xi]

### 2.1.4 OPERATIONS

Operations begin at production, the cessation of flowback. This transition is legally defined in Pennsylvania; however, an operator may define this transition internally to occur when field measurements indicate that the water flowing from the well reflects the expected characteristics of natural waters present in the production formation. Over the lifetime of the well, the well will continue to produce water that is hauled offsite periodically.

During the operations phase, the well requires testing and general maintenance, which might include a work-over, where a servicing rig is brought to the well site. Over time, tubing and casings require replacement and the wellhead may need service or replacement. Operating the well and ensuring maximum productivity requires maintenance on an ongoing basis.

### 2.1.5 ABANDONMENT AND RECLAMATION

Since most unconventional wells in this region are only a few years old, they are unlikely to be at the plug and abandon stage due to long lifespan of the well. Specific reasons for plugging and abandoning a well prematurely include low productivity or safety concerns. During this phase, casings are removed and cement plugs are set. The land is then reclaimed to the original condition or superior.[xii] (Reclamation to the original condition or improved condition is a regulatory requirement.)

## 2.2 OIL AND GAS EXTRACTION OCCUPATIONS

The Bureau of Labor and Statistics categorizes servicing and extraction industries under Mining, Quarrying, Oil & Gas Extraction (NAICS Code 21) using the North American Industry Classification System (NAICS). There are two subcategories of interest. They include Oil and Gas Extraction (NAICS Code 211000) and Support Activities for Mining and Oil and Gas Extraction (NAICS Code 213000)[xiii] which is comprised of Drilling Oil and Gas Wells (NAICS Code 213111) and Support Activities for Mining (NAICS Code 213112).[xiv]

Under the two subcategories of interest are a wide variety of occupations. Some occupations have a much higher potential for environmental and occupational exposure than others. For example, engineers and other scientists may perform all of their work in the office or make field visits. If engineers and scientists perform field work, their work is often divided between the office and field. Some staff may never make a field visit while others, often contractors, work entirely in the field.

Occupations of particular interest for the purpose of this investigation are those that may be loosely referred to as o*ilfield workers. Oilfield workers* is the general term used by industry which describes the employees of the oil and gas industry regardless of the extraction type or product desired. These workers generally spend the majority of their working hours onsite, often working days longer than 8 hours, and have the highest potential for occupational exposures. The Occupational Outlook Handbook describes oilfield workers as follows: “Oil and gas workers carry out the plans for drilling that petroleum engineers have designed. Drilling workers operate the equipment that drills the well through the soil and rock formation, and they prepare the well for use. Service workers then finish preparing the well and assemble the equipment that removes the oil or gas from the well."[xv]

Additionally, the Occupational Outlook Handbook identifies key roles that oilfield workers may fill. In general, most require a high school diploma, equivalent, or less.[xvi] A listing of the roles include: roustabouts, derrick operators, service unit operators, rotary drill operators, engine operators, pumpers, gas treaters, gas pumping station operators, and gas compressor operators.[xvii] Appendix A features the duties associated with each of the roles. See Section 2.3.5 for demographic characteristics of oilfield workers.

## 2.3 PUBLIC HEALTH SIGNIFICANCE

The long-term and short-term health outcomes of oilfield workers are of primary importance for several reasons, including: shale oil and natural gas production is increasing; hydraulic fracture is the stimulation technology of choice; oilfield workers have high exposure potential; fatality and injury rates are high for the industry; and characteristics of oilfield workers contribute to health outcome. Below, each reason is discussed.

### 2.3.1 SHALE OIL AND NATURAL GAS PRODUCTION IS INCREASING

While production is dependent upon economic performance, estimates from agencies studying the potential amount of shale oil and gas vary; however, shale oil production increased fivefold from 2007 to 2011 with shale gas production increasing fourfold from 2007 to 2011. Substantial increases are likely to continue as estimates of recoverable oil and gas within the United States continuing to increase.[xviii] It is reasonable to expect that as production increases, so will the likelihood of occupational hazards and exposures.

### 2.3.2 HYDRAULIC FRACTURE, THE TECHNOLOGY OF CHOICE

In 2003, the National Petroleum Council estimated that 60-80% of gas wells drilled within the next decade would require hydraulic fracture[xix]; however, in 2010, the American Exploration and Production Council has identified that this technology is used in approximately 90% of natural gas wells drilled in the United States.[xx] It serves to follow that any occupational health impacts related to unconventional extraction should be investigated and mitigated/eliminated as soon as possible.

### 2.3.3 OILFIELD WORKERS HAVE HIGH EXPOSURE POTENTIAL

It is reasonable to assume that on-site workers are likely to have the potential for highest repetitive exposure to physical hazards and concentrated process chemicals. Oilfield workers are potentially exposed to undiluted chemicals (for fracture fluid), silica sand, diesel exhaust, moving machinery, confined spaces, naturally occurring radiological material, moving vehicles, etc. while working days extending beyond 8 hours.[xxi] Such exposures may be unique to workers with limited (temporal and/or less concentrated exposures) or no exposure risk to area residents. Moreover, long and short-term outcomes of oilfield workers due to chemical exposure are not well described or known.[xxii]

Until recently, few studies have undertaken the task of characterizing hazards posed to oilfield workers. The National Institute of Occupational Safety and Health (NIOSH) has recognized this shortfall, stating: “There currently exists little published information identifying or characterizing potential health risks to U.S. oil and gas extraction workers. This is an area that needs further research, particularly in material inventory, exposure characterization, and surveillance.”[xxiii]

This is particularly troubling because oilfield workers seem to be underrepresented by public health agencies. Bernard Goldstein et al. reviewed advisory board members, established in 2011 by federal and state leaders, tasked with reviewing drilling for natural gas with respect to pubic/environmental health. The group found that “Despite recognition of the environmental public health concerns related to drilling in the Marcellus Shale, neither state nor national advisory committees selected to respond to these concerns contained recognizable environmental public health expertise.”[xxiv]

### 2.3.4 HIGH FATALITY AND INJURY RATES FOR THE INDUSTRY

#### 2.3.4.1 FEDERAL DATA

"During 2003-2008, 648 oil and gas extraction workers were killed on the job (onshore and offshore, combined), resulting in an annual fatality rate of 29.1 deaths per 100,000 workers, over seven times the rate for all US workers." 89% of these incidents occurred onshore.[xxv] In 2008, 120 fatal work injuries occurred in the oil and gas extraction industry. Main fatal events included transportation incidents (41%), contact with objects and equipment (25%), and fires and explosions (15%).

"Support activities for oil and gas operations (NAICS 213112) account for about half of fatal work injuries from 2004 to 2008 in oil and gas industries on average, with 69 fatal work injuries recorded in 2008. Drilling oil and gas wells (NAICS 213111) averaged 34 fatal work injuries over the five-year period, with 37 percent of fatal work injuries resulting from contact with objects of equipment. Oil and Gas Extraction (NAICS 211111) had an average of 21 fatal work injuries."[xxvi] Table 1, presents the most current data from the Bureau of Labor Statistics. It features preliminary data from 2011.

**Table 1 Fatal and Non-Fatal Injuries by Industry**

| Industry | Total Recordable Non-Fatal Injuries (Rate per 100 Full-Time Workers)[xxvii] | Number of Non-Fatal Injuries[xxviii] | Number of Fatal Injuries[xxix] |
|---|---|---|---|
| **Oil & Gas Extraction (211)** | **0.9** | **1400** | **11** |
| **Support Activities for Mining (213)** | **2.3** | **8500** | **106** |

#### 2.3.4.2 PENNSYLVANIA STATE DATA

This section refers to injuries in Pennsylvania, specifically. Pennsylvania was selected for comparison because operators are most active in this state. However, limited information was available for 2011. The incidence rate of non-fatal injuries in the Support Activities for Mining (213) occupations was 2.9 per 100 full-time workers. Rates for the Oil & Gas Extraction Industry (211) occupations were not separate from Mining (21) occupations, which had an incidence rate of 3.7 non-fatal injuries per 100 full-time workers. Overall, Pennsylvania's incidence rate of occupational injuries is higher than the national average, 4.3 and 3.5 injuries per 100 full-time workers, respectively.[xxx] There were six fatalities in the Mining (21) sector, 5 of which were from the Support Activities for Mining (213) sector.[xxxi] This corresponds to approximately 3% of the Mining (21) workforce.

### 2.3.5 CHARACTERISTICS OF OILFIELD WORKERS

Characteristics of oilfield workers may be, in part, to blame for elevated incidence of injury and fatality. Ethnographic studies of the British Columbia (BC Study) oilfield workforce have found that education, addiction, and housing are characteristics of individuals living and working in a resource extraction community. Study findings show that the on-site/field workforce is educationally deficient and areas in which oil and gas industry reign display elevated spending per capita on alcohol and increased arrest rates for (non-cannabis) drug related offenses. Moreover, housing for the workforce is very limited and expensive, resulting in temporary lodging at hotels and houses of acquaintances.[xxxii] The BC study findings are likely similar to United States oil and gas boomtowns, evidence follows as major demographic features of the workforce are presented.

To begin characterizing the United States oilfield workforce, racial and ethnic demographic data was obtained. Sex and racial/ethnic demographic data show that in the United States, the workforce of interest is mainly comprised of white males. Table 2, features race and sex data for the industries of interest.[xxxiii]

**Table 2 Race and Sex Profile for Mining and Extraction Industries**

| Industry | Percentage Employed | | | |
|---|---|---|---|---|
| | Women | Black/African American | Asian | Hispanic or Latino |
| Mining, quarrying, and oil & gas extraction | 12.1 | 4.5 | 1.6 | 16 |
| Oil and gas extraction | 19.6 | 8.4 | 5 | 7.2 |
| Support activities for mining | 13.9 | 5.8 | 1.9 | 20 |

Locally, news outlets have reported that some cities in Pennsylvania have seen an increase in Driving Under the Influence (DUI) and assault arrests with the influx of out of state oilfield workers. This is complemented with anecdotal reports of prostitution and unaffordable housing.[xxxiv]

Also demonstrated by the BC study, educational attainment by oilfield workers is low compared to the U.S. average. Educational attainment data was obtained all major oilfield occupations, reflecting workers 25 years of age and older. At the time of the study, approximately 50% of the workforce had attained a high school diploma or equivalent, while approximately 25% of the workforce had not achieved this level. Approximately 20% of the workforce had completed some college coursework, with few attaining a degree.[xxxv] Educational achievement for this sector is lower than the national average (approximately 9.9% of the general workforce over 25 years of age had attained less than a high school diploma or equivalent).[xxxvi] Likely, the industry draws undereducated support due to the relatively high pay for unskilled labor.[xxxvii] See Table 3, below for educational achievement of oilfield workers by occupation.[xxxviii]

**Table 3 Educational Attainment by Occupation**

| Occupation (Percent Attainment) | Less than high school diploma | High school diploma or equivalent | Some college, no degree | Associate Degree or Beyond |
|---|---|---|---|---|
| **Derrick Operators, Oil and Gas** | **24.7** | **48.3** | **18.2** | **8.9** |
| **Rotary Drill Operators, Oil and Gas** | **24.7** | **48.3** | **18.2** | **8.9** |
| **Service Unit Operators, Oil, Gas, and Mining** | **24.7** | **48.3** | **18.2** | **8.9** |
| **Roustabouts, Oil and Gas** | **31.2** | **41.7** | **18.7** | **8.4** |
| **Helpers--Extraction Workers** | **28.6** | **46.6** | **18.0** | **6.8** |
| **Extraction Workers, All Other** | **25.3** | **47.9** | **17.8** | **9.1** |
| **Gas Compressor and Gas Pumping Station Operators** | **13.0** | **52.6** | **21.8** | **12.7** |
| **Pump Operators, Except Wellhead Pumpers** | **13.0** | **52.6** | **21.8** | **12.7** |
| **Wellhead Pumpers** | **13.0** | **52.6** | **21.8** | **12.7** |

Smoking is another factor that may be correlated with health outcome and lifestyle. Smoking may exacerbate effects of environmental exposures. Prevalence of smoking is generally higher in Caucasian males with an education of high school diploma/equivalent or less. Not surprisingly, this group (construction and extraction) had the highest smoking prevalence of all industry groups, 31.4%.[xxxix]

Another potential contributor to the injury/fatality rate as well as exposure duration is shift length. Many oilfield workers typically work extended shifts, up to 12 hours and may have a rotating schedule where an employee works up to 14 days in a row followed by a number of days off.[xl] This work schedule may contribute to overexertion injuries, exacerbated by adverse weather conditions (heat/cold stress). In fact, some researchers suggest that extended work shifts should be avoided, especially for occupations already considered dangerous.[xli]

So, what about salary? While, the workforce is compensated well in comparison to their educational attainment, it is not clear, though, whether oilfield workers are adequately compensated for their years of service, length of work day, and occupational hazard exposure. Figure 5 displays the employment rate and median salary for all levels of experience by occupation.

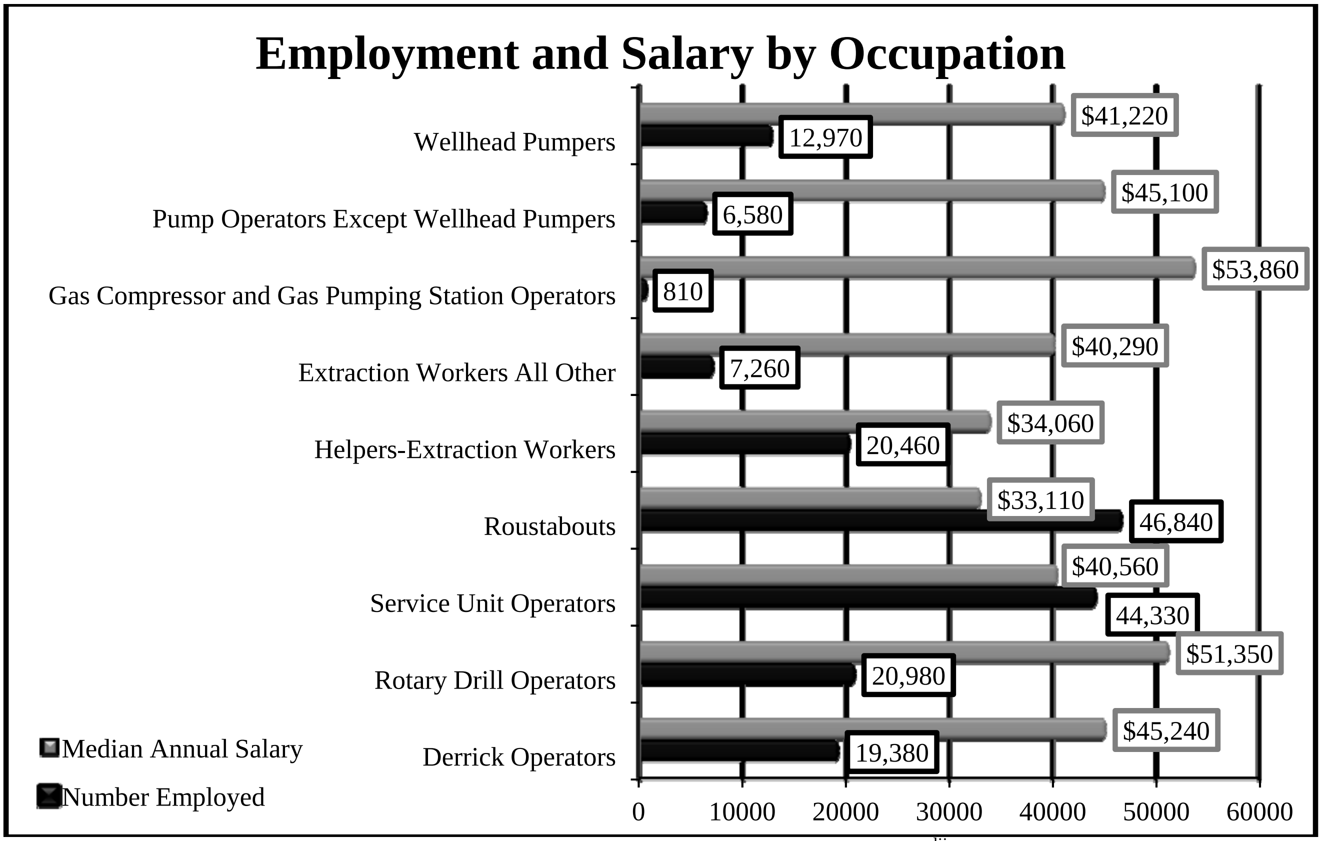


**Figure 5** Employment and Salary by Occupation[xlii]

# 3.0 ANALYSIS

A literature review identified the potential occupational exposures in onshore upstream unconventional natural gas extraction activities. Because limited information is available specific to onshore upstream unconventional natural gas extraction activities, in some cases literature findings detailing hazards that are sufficiently similar in nature to the onshore upstream unconventional activity are presented. Results of the literature review are shown on the following pages, classified as either delayed onset or immediate onset.

The reason for the differential classification is due to the historical perspective of occupational health and safety. Historically, most *known and easily recognizable* hazards encountered by oilfield workers cause immediate threats to life or limb, or include hazards that may result in a lifelong disability. Such injuries are easily identifiable, quantifiable, and are generally not subject to the cumulative effects of other lifetime exposures. Such hazards are classified as immediate onset hazards.

Through advances in science, technology, and occupational health & safety, much more is known regarding the impact of less visible hazards; although, the occupational health effects are not as well described, documented, or researched as the immediate and obvious hazards. These hazards are classified as delayed onset hazards, and they require much more research in order to determine the magnitude of exposures and health effects.

## 3.1 HAZARDS CAUSING IMMEDIATE HEALTH EFFECTS

The exposures discussed in this section describe the dangers oilfield workers face that may result in immediate loss of life, amputations, and other mental or physical impairments. NIOSH has identified the main causes of fatal injuries to include: Motor Vehicle Accidents, Struck-By Accidents, Explosions, Caught-In Accidents, and Falls to Lower Levels.[xliii] Other accidents of note include Confined Space Entry and Overexertion (exacerbated by heat/cold stress and UV radiation).

**MOTOR VEHICLE ACCIDENTS**

The leading cause of death in the industry is motor vehicle accidents (MVA).[xliv] Analysis of data from the Bureau of Labor Statistics Census of Fatal Occupational Injuries shows that "…increases in oil and gas extraction activity were correlated with an increase in the rate of fatal occupational injuries in this industry, with an annual fatality rate of 30.5 per 100,000 workers (404 fatalities) during 2003-2006, approximately seven times the rate for all workers (4.0 per 100,000 workers). Nearly half of all fatal injuries among these workers were attributed to highway motor-vehicle crashes and workers being struck by machinery or equipment."[xlv]

Incidence of fatalities in the industry is directly correlated with rig count. Of these fatalities, 27% from 2003-2006 were attributed to MVA. Most fatalities occurred in vehicles classified as light trucks and semi-tractor trailers. Seatbelt usage was also a significant factor in MVA fatalities. 35% of workers killed in highway MVA were not wearing seatbelts, and 12% of workers killed in MVA were ejected upon impact. Likely, this group was not wearing seatbelts either.[xlvi]

More recent studies confirm that MVA are still the lead cause of death in oil and gas extraction occupations.[xlvii] Small E&P companies demonstrate a larger share of fatalities than the super majors. Additional risk factors include: "…frequent travel between well sites, travel on rural roads which often lack firm shoulders and rumble strips, low levels of safety belt use, and long and irregular hours of work that contribute to driver fatigue. Oil and gas extraction workers often work up to 12-Hr shifts, and 7–14 days in a row."[xlviii] Long commute distances is another factor to consider.

MVA may occur at any phase of the E&P process, but certain development phases require more transportation services than other phases. However, drilling and completions phases may see the highest incidence of MVA due to the nature of the phase. Drilling requires the moving of heavy equipment with many vehicles moving on and off of the pad daily. The completions phase is likely to see an elevated incidence of MVA also due to the number of trucks transporting water as either source material or a waste/recyclable material.

**STRUCK-BY ACCIDENTS**

'Struck-by' accidents are the second most common injury resulting in death per the Bureau of Labor Statistics Census of Fatal Occupational Injuries for 2003-2006.[xlix] The same observation continues in data reviewed through 2009.[l] Phases of E&P most at risk for struck-by incidents include drilling, including rig up and drilling itself; and completions, primarily during drill stem testing and installation of production tubing. Site preparation likely has the least potential for struck-by incidents, with well servicing, and abandonment/reclamation having similar potential for "struck-by" incidents as drilling and completions.

During rig up and equipment installation, the potential exists for being struck by heavy equipment such as cranes, suspended loads, swinging equipment, falling tools, trucks, and forklifts. The drilling process, itself, presents a number of struck-by hazards. The number and severity of struck-by incidents are related to the level of rig sophistication. For example, some rigs require oilfield workers to make the connection, while other rigs are sufficiently mechanized to perform this task. Some examples of struck-by hazards include: piping (tubulars) moving into staging positions, movement of the kelly, tongs, and piping, movement of high pressure lines associated with casing/cementing.

During completions, a drill stem test is completed in order to determine the production potential of the well. During this process, the drill stem and test tools may pose struck-by hazards. Additionally, setting production tubing requires the use of elevators, both the tubing and elevators pose as struck-by hazards.

**EXPLOSIONS**

Between 2003-2009 8% of fatalities were a result of explosions.[li] Flash fires and explosions, while infrequent, may occur at nearly any stage of development, but are most likely to occur during drilling, after rig-up, completions, well servicing, and production. Control is nearly always maintained by the blowout preventer (BOP) and other engineering controls; however, if control is lost, ignition sources as simple as static electricity may ignite a flash fire. Additionally, hydraulic fracture relies on the use of explosives to perforate the casing during completions. OSHA requires the use of flame-resistant clothing (FRC) as a protective measure during certain phases and processes of well development.[lii] (However, the maintenance of FRC is generally the responsibility of the employee.)[liii] Gas detectors, when used on-site, may also help prevent flash fires and explosions by recognizing conditions that pose a threat.

**CAUGHT-IN ACCIDENTS**

Between 2003-2009 7% of fatalities were a result of "caught-in" accidents.[liv] Caught-in accidents occur when a worker is caught-in or caught-between objects. Accidents of this nature are most likely to occur during the movement and installation of heavy equipment, especially equipment with pinch points. Rigging up; installation of auxiliary equipment; drilling (especially when connections are made manually); handling tubulars (piping); and, installing casing, maintenance of the wireline, maintenance of the mud circulating system, and use of ropes/chains can all lead to a caught-in event. Employees can protect themselves from caught-in accidents by maintaining awareness of their surroundings, never entering spaces between heavy objects or machinery, and by engaging in proper training.

**FALLS TO LOWER LEVELS**

Between 2003-2009 6% of fatalities were a result of falls to lower levels.[lv] Falls resulting in landing below the walking or work surface are often the result of falling from the rig floor (stabbing board, monkey board, ladder, etc.) to grade.[lvi] Such falls are generally preventable by proper installation of fall prevention such as railings, harnesses, safety nets, and ensuring that work surfaces are clean, dry, and ice free.

**CONFINED SPACE ENTRY**

Confined space is defined by OSHA as a space that "…has limited openings for entry or exit, is large enough for entering and working, and is not designed for continuous worker occupancy. Confined spaces include underground vaults, tanks, storage bins, manholes, pits, silos, underground utility vaults and pipelines."[lvii] Risks of working in confined spaces include: fire and explosion, loss of consciousness due to asphyxiation or increase in body temperature, drowning in liquid, and asphyxiation resulting from free flowing solid.[lviii] Such activities are regulated by OSHA and may require a permit to work (PTW) dependent upon conditions. Confined space entry is encountered in E&P activities during cellar cleanout, well servicing, tank cleanouts and during various other processes. See Figures 6 and 7, featuring the fenced area around the well cellar, cellar, and tubing head that supports the Christmas tree. The cellar fills with rainwater, debris, and sediment, which must routinely be cleaned.

**Figure 6** Fenced Area Around the Well Cellar

**Figure 7** Well Cellar and Tubing Head

Confined space entry is dangerous, but does not constitute a large percentage of injuries and fatalities in oil and gas extraction occupations. However, 2005 data from OSHA shows that during federal inspections, it was the second most frequently cited violation in the industry, outranked only by hazard communication.[lix]

**OTHER HEALTH AND SAFETY ISSUES**

Site workers, working outside, generally with little or no access to warming/cooling areas, are inherently at risk for heat and cold stress.[lx,lxi] Additionally, as a safety precaution, all site workers are required to wear flame resistant clothing. This clothing can be very hot in the summer, thus exacerbating conditions on particularly warm days. FRC is expensive which may deter some low earning employees from purchasing properly insulated clothing for winter. Moreover, because site workers are outside nearly all day, they are highly exposed to UV radiation unless they take appropriate precautions.

Working outside in all conditions is the nature of the industry, simple actions can be taken by both the employer and the employee to reduce the risk of injuries related to heat, cold, and UV radiation. Frequent breaks; warming/cooling in an on-site trailer, when available; staying hydrated; using sunscreen appropriately; and, knowing the early signs of distress can all help aid in reducing the incidence and severity of injuries caused by physical work conditions.[lxii,lxiii,lxiv]

## 3.2 HAZARDS CAUSING DELAYED ONSET HEALTH EFFECTS

Overall, this section focuses on chronic exposures and delayed onset health effects. Generally, such hazards are due to chemicals (process chemicals as well as *the 0.5%)*, but in the oil and gas extraction occupations, one must also consider crystalline silica, exhaust from heavy machinery, Naturally Occurring Radioactive Material (NORM), noise, and fugitive emissions.

Federal law requires that information regarding chemical exposures and health hazard be available to employees, however, the average worker may not recognize the hazards of muds and fluids present on-site nor know what questions to ask in order to determine exposure risks. Employers must develop a hazard communication program to inform and train employees regarding "…any chemical which is known to be present in the workplace in such a manner that employees may be exposed under normal conditions of use or in a foreseeable emergency."[lxv] However, this same regulation, 29 C.F.R. 1910.1200, was the number one cited violation (based on 2005 data from OSHA).[lxvi]

### 3.2.1 CHEMICAL EXPOSURE AND THE 0.5%

Chemicals are used to increase performance and production of wells. For example, chemicals can enhance well recovery, enable drillers to reach new onshore depths, assist in directional drilling, and maintain flow in water - oil separators. Each chemical added to a complex mixture (examples include drill mud, hydraulic fracture fluid, cement, production brine) serves to modify or stabilize a characteristic of the mixture. Complex mixtures of chemicals might be used to drill a single well, and the mixtures are generally formulated on a well by well basis.

While some chemicals used in oil and gas extraction processes are used in other industries, a number of chemicals are specific to the oil and gas industry where, because of narrowly focused application, few studies have been performed regarding health risk.[lxvii] An exhaustive inventory of chemical exposures is outside of the scope of this essay; however, the following paragraphs provide a few examples. See also Appendix B for a listing of chemicals that are commonly used in fracture fluid. As previously noted, these chemicals represent approximately 0.5% of the fracture fluid mixture. On-site, workers have the potential to be exposed to both the concentrated form as well as the dilute form; however, with proper personal protective equipment (PPE) and in the absence of an undesirable event, exposure to concentrated forms is unlikely. Two examples of chemical exposures follow, selected because they may not initially come to mind when discussing oilfield hazards.

### 3.2.1.1 LUBRICANTS & OIL MIST

Lubricants, common to many industries, but also used in drill muds and other processes, are irritants and sensitizers, generally leading to eczematous dermatitis, contact dermatitis, and allergic sensitization. Infection may also result. Other outcomes of repetitive exposure include, but are not limited to folliculitis, chloracne, granulomata, metallic contamination, oil granuloma, melanosis, neoplasms (both benign and malignant).[lxviii]

Additionally, the Canadian Associate of Petroleum Producers developed an Oil Mist Monitoring Protocol in 2004 to protect their workforce. Their guidance suggests that without proper monitoring and PPE, workers may be at risk for cancers associated with the use of drilling fluids. Cancer risk is dependent upon the composition of drilling fluids, risk of inhalation or dermal exposure.[lxix] Employers should minimize dermal contact with lubricants and ensure that the company is compliant with all applicable standards recommended or instituted by the American Conference for Governmental Industrial Hygienists, OSHA, and NIOSH. Currently, NIOSH and OSHA set Time Weighted Average (TWA) exposure limits for Mineral Oil Mist at 5 $mg/m^3$.[lxx] However, note that mists at oil and gas extraction sites may vary in component by process and application.

### 3.2.1.2 METHANOL

Methanol is commonly used in the extraction industries to keep lines from freezing in cold weather, to ensure that gas hydrates do not form in cold weather, and it may even be used to hydraulically fracture wells, although perhaps not in the region of interest (while it is still a component of fracture fluid). Methanol, when ingested, is extremely toxic; however, inhalation and dermal contact are the most likely exposure routes. Acute doses of significant concentration may result in eye, skin, and respiratory irritation, headache, drowsiness, dizziness, nausea, vomiting, visual disturbance, optic nerve damage (blindness), and/or dermatitis.[lxxi]

Chronic low-level exposures may go unnoticed but later in life, may manifest health effects. "Chronic poisoning from repeated exposure to methanol vapor may produce inflammation of the eye (conjunctivitis), recurrent headaches, giddiness, insomnia, stomach disturbances, and visual failure. The most noted health consequences of longer-term exposure to lower levels of methanol are a broad range of effects on the eye. Inflammatory changes and skin irritation (dermatitis), occurs with chronic or repeated exposure to methanol."[lxxii]

To avoid both acute and chronic effects of methanol exposure air monitoring should be employed for operations utilizing methanol. Precautions should be taken when using methanol as a cleaning solvent and any time that skin or clothing may come in contact with methanol. Case studies of patients performing tank-cleaning operations using methanol have presented severe symptoms after dermal absorption.[lxxiii] Appropriate PPE should be used and the following threshold should not be exceeded for both dermal and inhalation exposure routes: 200 ppm Time Weighted Average (TWA). Note also that the NIOSH Immediately Dangerous to Health and Life (IDHL) level is 6,000 ppm.[lxxiv]

### 3.2.2 AIR QUALITY: FUGITIVE EMISSIONS AND EXHAUST

Air quality is a primary concern in the United States today. However, there are certain air pollutants that may specifically affect oilfield workers. Constituents of diesel exhaust and other emissions may be problematic for aspects of oil and gas extraction industries if not properly controlled.

#### 3.2.2.1 DIESEL EXHAUST

Many engines run at any one-time onsite. These engines maintain compression, provide power to the rig, allow transport of materials and persons on and offsite, and perform a myriad of other functions. The engines are generally diesel fueled and the resulting exhaust has recently been classified as a Group 1 Carcinogen by the World Health Organization (WHO). This classification was assigned after the WHO evaluation found sufficient evidence to implicate diesel exhaust as a cause of lung cancer and limited to implicate diesel exhaust as a cause of bladder cancer.[lxxv]

The study that resulted in the above classification was based on human subjects with exposures to Traditional Diesel Exhaust (TDE) engine exhaust or, at best, Transitional Diesel Exhaust engine exhaust. Such engine types were subject to less stringent emission controls. The following statement provides evidence based on year of diesel machinery introduction, and knowledge of regulations influencing the composition of diesel engine emissions. "Eligible subjects included all workers who were ever employed in a blue-collar job for at least 1 year after introduction of diesel equipment into the mining facility (year of introduction: 1947 – 1967 across the eight facilities) until the end of follow-up on December 31, 1997."[lxxvi]

In recent years, advancements in diesel engine emission control technology have changed the chemical profile of diesel exhaust. New Technology Diesel Exhaust (NTDE) has near zero emission levels, thus significantly decreasing the cancer risk associated with diesel exhaust inhalation.[lxxvii]

Currently, no exposure limits are set for diesel emissions;[lxxviii] however, Pennsylvania, under Act 124, prohibits idling a diesel-powered motor vehicle with a gross weight of 10,001 pounds or more, engaged in commerce, from idling for more than five minutes in any continuous 60-minute period, except as exempt under Title 35 of PA Statutes, Chapter 23B, Section 4603(c).[lxxix] Other ways for E&P's to take action include restricting access to areas with high concentrations of diesel emissions, phasing out older engines opting for NTDE engine designs, and switching to natural gas engines. Significant risk reduction will occur as older engines are phased out and replaced with NTDE engines but new risks may arise.

### 3.2.2.2 OTHER EMISSIONS

Emissions of concern include volatile organic compounds (VOCs)/hydrocarbons or toxic substances that are released into the air. Such emissions might include flared or vented gases as well as any emissions from the well/borehole during any phase of development. This also includes (but is not limited to) air emissions from leaks at gas-gathering systems and batteries. (A battery is a facility that provides support functions to a set of wells, not a power source.) Fugitive emissions, which are unintentional releases of gas from connections or valves at wells, compressor sites, or gathering stations, are also a concern. The Code of Federal Regulations defines fugitive emissions as those emissions which could not reasonably pass through a stack, chimney, vent, or other functionally-equivalent opening.[lxxx]

Little data is available to assess air emissions health risk specific to the oil and gas industry workforce, let alone the unconventional onshore upstream workforce. NIOSH identifies completions as being a phase of development with increased risk of emissions exposure;[lxxxi] however, a Canadian study showed that benzene/hydrocarbon exposure is dependent upon product type. Crude and conventional operations often have higher concentrations of benzene.[lxxxii]

Still though, the studied Canadian conventional operations observed very low incidence of exposure greater than the benzene occupational exposure limit, 1 ppm TWA (equivalent to OSHA PEL).[lxxxiii] However, NIOSH sets an exposure limit at 0.1 ppm TWA.[lxxxiv] The conventional industry studied may have difficulty attaining the NIOSH REL without PPE; however, until additional data is obtained, the exposure risks should be regarded as unquantified. No exposure limits are set for Total Petroleum Hydrocarbons (TPH), but OSHA has set an exposure limit for petroleum distillates at 500 ppm TWA and NIOSH at 350 ppm TWA.[lxxxv]

Employers should monitor employee workspaces for VOC concentrations, in particular, benzene, and take any necessary precautions to ensure that workers are not exposed to an unacceptable level. Such monitoring may be especially important in "rich" gas fields where gas contains methane as well as significant amounts of ethane, propane, butane, pentane, hexane, heptane, or other constituents. Additionally, since no limits are set for TPH, employers should know the warning signs of over exposure, including headaches, dizziness, and peripheral neuropathy at high levels. Long-term effects are less specific but have various effects on the body.

### 3.2.3 HYDROGEN SULFIDE

Hydrogen sulfide is a primary hazard of natural gas production since it quickly leads to knockdown and loss of consciousness at 1000 ppm within one to two breaths. At concentrations of 1-5 ppm symptoms include nausea, tearing of eyes, headaches, and loss of sleep. Various other symptoms may occur at lower level exposures such as eye and lung irritation, eye damage, digestive upset, and pulmonary edema. Beyond emissions during drilling, other tasks may place workers at risk for exposure. For example, confined space entry for tank cleanout may be complicated by hydrogen sulfide.[lxxxvi]

Luckily, in this region, the concentration of natural sulfur is low, as is the risk to our workforce, comparatively. This makes the problem of hydrogen sulfide one of a chronic low-level nature. Still though, it is important to monitor for hydrogen sulfide onsite, especially during processes that pose the highest risk for exposure. Examples of high risk scenarios include drilling, where a pocket of hydrogen sulfide could be encountered, or in scenarios where egress is limited and appreciable levels of hydrogen sulfide could build up. Little research has been done to investigate the chronic effects of hydrogen sulfide exposure but existing studies suggest that hydrogen sulfide exposure may result in respiratory symptoms consistent with airway hyper-reactivity.[lxxxvii] More research is needed to describe chronic low-level health effects following hydrogen sulfide exposure. This project will be confounded by past exposures such as chemical exposure, silica exposure, and smoking. The concentration and frequency of hydrogen sulfide exposure must be considered.

### 3.2.4 MERCURY

Mercury is naturally present in geologic formations and concentration varies with location, geology, and production (crude, condensates, natural gas, etc.). Additionally, mercury is present in many forms including, but not limited to: elemental mercury, dissolved organic mercury, mercury salts, complexed mercury, mercuric sulfide, and adsorbed mercury.[lxxxviii] While each mercury compound has unique exposure and toxicity risks, accounting for all species of mercury is important to determine the total mercury exposure. However, the task of speciating mercuric compounds is analytically challenging.[lxxxix]

The concentration of mercury is low in the produced gas (1-200 ng/L)[xc]; however, workers may be exposed to concentrated materials through inhalation or dermal exposure during maintenance processes. This means that the risk of exposure may be limited to only a few job functions. Such functions include cleaning out pipeline segments, replacing/maintaining equipment, such as at compressor stations, or any job function where there is exposure to sludges, such as tank bottoms from production tanks. More research is necessary to determine if health risk exists and what precautions can be taken to protect workers.

### 3.2.5 NATURALLY OCCURRING RADIOACTIVE MATERIAL

“Oil and gas extraction and processing operations sometimes accumulate naturally occurring radioactive materials (NORM) at elevated concentrations in by-product waste streams… production waste streams most likely to be contaminated by elevated radium concentrations include produced water, scale, and sludge.”[xci] Occupational exposure pathways include “…external gamma exposure, dust inhalation, skin beta exposure, and radon inhalation.”[xcii]

The highest NORM exposure to oilfield workers occurs during equipment cleaning and maintenance where inhalation is a main concern due to spray and aerosolized material.[xciii] Commonly, equipment with the highest NORM concentrations would include tanks (produced/flowback water with sludge tank bottom), gas-busters, spent hydraulic fracture sands, produced water, or flowback water filters. Areas in close proximity to injection wells or associated equipment may also be contaminated.

Occupational exposure limits for radiation are set by the United States Nuclear Regulatory Commission. Regarding occupational exposures, the total effective dose equivalent should not exceed 5 rems (0.05 Sv) per year. Additionally, the sum of the deep-dose equivalent and the committed dose equivalent to any individual organ or tissue other than the lens of the eye must not exceed 50 rems (0.5 Sv) per year.[xciv] Assuming full-face masks and respirators are used during cleaning and maintenance, eye exposure should not be of particular concern.

Assessing the exposure to workers is particularly problematic since exposure and dose vary with formation, geography, product produced, and contact material (sludge, produced water, drill cuttings, etc.). United State governing agencies have not explicitly concluded that occupational limits for radiation exposure are a concern in oil and gas extraction activities, but the Department of Energy and Argonne National Laboratory studies have not revealed concerns, only the need for additional data.[xcv] International studies have concluded that, in general, effective doses of workers in the oil and gas industries are below the limit for occupational exposure, even for high exposure occupations.[xcvi] While the psychological effects of potential NORM exposures seem to outweigh actual health risk, it would be a prudent decision for each operator or employer to evaluate risk to their workforce and respond appropriately to the study findings.

### 3.2.6 NOISE

The Occupational Safety and Health Administrations requires that an "…employer must administer a continuing, effective hearing conservation program whenever employee noise exposures are at or above an eight hour time-weighted average (TWA) of 85 dBA or, equivalently, a dose of 50 percent."[xcvii] Couple this requirement with noise exposure concerns during most every phase of development; and, one may conclude that additional studies to evaluate noise exposure at each development stage are necessary. Sources of noise include, but are not limited to, flares, helicopters (during seismic operations), heavy machinery during site preparation, drilling rigs, completion rigs, work over rigs, compressors, and maintenance machinery (sand blasters, etc).

Bolstering the need for exposure studies at each development phase, in 1998, NIOSH estimated that 94.4% of workers in crude petroleum and natural gas industries are exposed to noise above 85 dBA at least once per week for 90% of workweeks in a year.[xcviii] This problem may be compounded by difficulty workers, and even supervisors, may have understanding the mathematical relationships describing noise dose and exposure. Distance from source, sound wave frequency, exposure frequency, duration of exposure, and level of exposure are all considerations when calculation dosage. (Exposure level is generally measured in dBA, decibels on an "A" weighted response curve). See Appendix C for a comparison chart of common noises and their place on the decibel scale.[xcix]

Health effects of noise exposure include hearing loss and development of non-audiological diseases. Such effects include "…dilated pupils, changes in heart rhythm, problems of balance and changes in the rate of gastric acid secretions." [c] Most commonly, irritation and increased stress results. Moreover, excess noise exposure may impede work efficiency and decrease the accuracy of task performance. This inherently enhances the hazardous nature of occupational settings, affecting communication. Misunderstandings and inability to discern warning signals may increase injury rates.[ci]

Clearly, employers must develop and implement programs to assess the noise level at worksites. This information should inform training and protection of their employees from excess noise exposure based on phase of development and work site type.

### 3.2.7 RESPIRABLE CRYSTALLINE SILICA

The knowledge base surrounding respirable crystalline silica (silica sand) exposure is much more substantial. "Respirable crystalline silica is the portion of crystalline silica that is small enough to enter the gas-exchange regions of the lungs if inhaled…"[cii] The main health effect of concern following respirable crystalline silica exposure is silicosis. This disease is incurable and is the result of past exposures.[ciii] Silicosis is classified as chronic, accelerated, or acute. Chronic silicosis develops after 10-20 years of low to moderate exposure. Accelerated silicosis develops after about 5-10 years of high exposures and progresses more rapidly. Acute silicosis develops after a few months or years of extremely high crystalline silica exposure. Acute silicosis is less common than other forms, however, it is much more deadly.[civ] Moreover, meta-analysis of existing data sets concluded that individuals with known silica exposures (Pooled RR=1.32), developed silicosis (Pooled RR=2.37), non-smokers with silicosis (Pooled RR=2.24), and smokers with silicosis (Pooled RR=4.47) have elevated risk of lung cancer.[cv]

Exposure prevention and early recognition are extremely important in avoiding this disease and curbing the long term health effects.[cvi] In pursuit of decreasing the incidence of this disease, OSHA and NIOSH jointly issued a Hazard Alert in 2012, alerting operators, their employees, and contractors regarding the risk of sand inhalation due to the high exposure potential during hydraulic fracturing (completions). This hazard alert identified seven primary sources of silica dust exposure during hydraulic fracture, shown below.[cvii]

1. *Dust ejected from thief hatches (access ports) on top of the sand movers during refilling operations while the machines are running (hot loading);*
2. *Dust ejected and pulsed through open side fill ports on the sand movers during refilling operations;*
3. *Dust generated by on-site vehicle traffic;*
4. *Dust released from the transfer belt under the sand movers;*
5. *Dust created as sand drops into, or is agitated in, the blender hopper and on transfer belts;*
6. *Dust released from operations of transfer belts between the sand mover and the blender; and*
7. *Dust released from the top of the end of the sand transfer belt (dragon's tail) on sand movers.*

Air monitoring analysis, completed as part of NIOSH's air monitoring program at hydraulic fracture sites, showed that 47% of samples exceeded the OSHA PEL (0.1 mg/m$^3$) and 79% exceeded the NIOSH REL (0.05 mg/m$^3$).[cviii] Therefore, it is important for operators to protect their employees and contractors by performing air-monitoring studies and provide training/PPE to ensure that workers are not over exposed. Additionally, if measures are feasible, upgrade equipment to institute engineering controls.

# 4.0 CONCLUSION

The scope of this essay extended to the identification of occupational hazards posed to oil and gas extraction workers; therefore, this essay has not evaluated the positive effects of employment in the oil and gas industry. For example, workers with little post-secondary education or work experience are able to provide for themselves and their families in ways they may never be able to with lower wage jobs. Other positive considerations for research include, but are not limited to: physical activity which may help protect against cardiovascular diseases; better mood/decreased incidence of depression associated with employment; and the effect of camaraderie of co-workers faced with the similar stressors. However, until positive impacts of employment in the oil and gas industry are documented, the following general recommendations may ameliorate occupational hazards: assess the spectrum of chemical hazards to oilfield workers; consider phasing-in more sophisticated/safer equipment; set standards for oilfield worker off-hours behavior; and perform additional ethnographic studies to inform the development of relevant training programs.

Through this literature review, the most concerning observation is the number of exposures that threaten lung health. Individual behaviors, such as smoking, taken with occupational exposures, such as oily mists, emissions, silica sands, diesel exhaust, and NORM, even if at low levels, may, together, increase the lifetime cancer risk of workers. Much more research is needed to fully describe, quantify, mitigate and/or eliminate hazards. Sub-populations of workers must be considered during such assessments, because workers are often divided into crews based on development phase. While studying each hazard individually is a great start, in order to improve long term health outcomes for workers subject to multiple exposures, chronic effects must be viewed from the perspective of cumulative effects of multiple exposures over a lifetime. This also means that workers should be informed of the effect of voluntary behaviors, such as smoking, coupled with occupational exposures.

Secondly, to protect worker safety, an inventory of current regulation and enforced regulation should be made for comparison. Gaps in regulations should be addressed, informed by balanced studies and fatality, injury, and illness data. Conclusions may result in regulations to phase out equipment where more sophisticated/mechanized equipment is available as a replacement to significantly reduce injuries/fatalities where worker error is at fault (stuck-by and caught-in). Operators may participate in hazard assessments and standardized documentation requirements for high-risk tasks, repeated periodically and after near-miss incidents, or after confirmed incidents. Changes to reduce risk should be implemented after reviewing the results of hazard assessments; such changes may include reduced working hours.

Thirdly, additional ethnographic studies focused on oilfield workers should inform training material development. All workers should undergo mandatory training in a way that speaks to the cultural norms of the industry. Over time, working to change the cultural norms of oilfield workers and improving living conditions may result in decreased use of alcohol, drugs, and tobacco, thereby improving long-term health outcome and reducing the incidence of injuries that threaten life and limb. It may be helpful for industry to encourage change in cultural norms; however, consideration should be given to hold oilfield workers accountable for their own welfare and actions. On-site random drug tests and breathalyzer tests should be performed frequently, suspending/eliminating workers with confirmed positive tests. Regulations to prohibit drinking alcohol within 8 hours of shift start should be adopted, similar to FAA regulations stipulating eight hours *from bottle to throttle.*[cix]

Lastly, liability could be better assessed. Perhaps industry should be at least partially released of liability under certain circumstances, for example, circumstances when workers' behavior is completely or partially at fault. Why should industry alone be responsible for lung cancers after crystalline silica exposure in smokers? The evidence is clear that smoking significantly (~4x) increases the risk of lung cancer in patients with silicosis, and smoking is a conscious choice of the individual. Similarly, should industry be fully responsible when, after proper training, an employee or contractor makes a clearly negligent decision resulting in loss of life or limb to himself or others? Perhaps consideration should be given to individual worker liability for personal behaviors that increase the incidence of disease, injury, or fatality.

# APPENDIX A: OCCUPATIONS

# Oil and Gas Workers



## What Oil and Gas Workers Do

About this section

Oil and gas workers repair oil field machinery.

Oil and gas workers carry out the plans for drilling that petroleum engineers have designed. Drilling workers operate the equipment that drills the well through the soil and rock formation, and they prepare the well for use. Service workers then finish preparing the well and assemble the equipment that removes the oil or gas from the well.

### Duties

Oil and gas workers include roustabouts, derrick operators, service unit operators, and rotary drill operators.

Roustabouts typically do the following:

- Clean equipment and keep the work area orderly and free of debris
- Use electronic detectors and make visual inspections in flow lines to locate leaks
- Use truck winches and motorized lifts to move pipes to and from trucks or move the pipes by hand
- Dismantle and repair oil field machinery, boilers, and steam engine parts
- Guide cranes that move loads
- Attach lifting slings to loads moved by cranes or by other special equipment, such as gin-pole trucks

Derrick operators typically do the following:

- Inspect derricks, or order their inspection, before they are raised or lowered
- Make sure the drilling fluid continues to flow correctly
- Repair pumps and other equipment related to the drilling fluid system
- Ensure that rig pumps and other drilling systems are working properly
- Use harnesses and platform climbing devices to position and align derrick elements
- Supervise crew members and help train them
- Guide lengths of pipe into and out of elevators
- Help maintain other rig equipment

Service unit operators typically do the following:

- Maintain wells by removing tubes or rods from the hole that is drilled into the ground
- Observe load variations on gauges, pumps, and pressure indicators
- Inspect engines, rotary chains, and other equipment to detect faulty operations or unusual equipment conditions
- Drive truck-mounted units to well sites
- Install pressure-control devices onto wellheads
- Thread cables through derrick pulleys
- Operate pumps that circulate water, oil, or other fluids through wells to remove sand or other materials obstructing the free flow of oil
- Operate controls that raise derricks or level rigs

Rotary drill operators, also known as drillers, typically do the following:

- Oversee maintenance of the drill rig and implementation of the well plan
- Train crews and introduce procedures to make operations safe and effective

- Observe pressure gauges and move throttles and levers, both to control the speed of rotary tables and to regulate the pressure of tools at the bottoms of drill holes
- Observe gauges that monitor well flow to prevent an overflow
- Keep records of footage drilled, locations and the nature of layers drilled, materials and drilling tools used, services performed, and time required
- Start and examine pump operations to ensure circulation and consistency of drilling fluids or mud in wells
- Use special tools to locate and recover lost or broken bits, casings, and drill pipes from wells

Rotary drilling crews do most of the work in oil fields. Most workers involved in gas processing are known as operators.

Additional occupations on drilling crews are as follows:

**Engine operators** are in charge of engines that provide the power for well site operations. They also do general maintenance of the engines and keep the rig equipment lubricated.

**Pumpers** operate and maintain the equipment that regulates the flow of oil out of the well.

**Gas treaters** oversee automatic treating units that remove water and other impurities from natural gas.

**Gas-pumping-station operators** tend compressors that raise the pressure of gas to send it through pipelines.

**Gas-compressor operators** often assist gas treaters and gas-pumping-station operators.

<- Summary    Work Environment ->

## APPENDIX B: CONSTITUENTS OF FRAC FLUID

## Appendix II
## Chemicals Commonly Found in the 0.5%

| Chemical Name | CAS | Product Function | Chemical Purpose |
|---|---|---|---|
| Hydrochloric Acid | 007647-01-0 | Acid | Helps dissolve minerals and initiate cracks in the rock. |
| Glutaraldehyde | 000111-30-8 | Biocide | Eliminates bacteria in the water that produces corrosive by-products. |
| Ammonium Chloride | 012125-02-9 | | |
| Quaternary Ammonium Chloride | 061789-71-1 | | |
| Tetrakis Hydroxymethyl-Phosphonium Sulfate | 055566-30-8 | | |
| Sodium Chloride | 007647-14-5 | Breaker | Product Stabilizer. |
| Ammonium Persulfate | 007727-54-0 | | Allows a delayed break down of the gel. |
| Magnesium Peroxide | 014452-57-4 | | |
| Magnesium Oxide | 001309-48-4 | | |
| Calcium Chloride | 010043-52-4 | | Product Stabilizer. |
| Choline Chloride | 000067-48-1 | Clay Stabilizer | Prevents clays from swelling or shifting. |
| Tetramethyl ammonium chloride | 000075-57-0 | | |
| Sodium Chloride | 007647-14-5 | | |
| Isopropanol | 000067-63-0 | Corrosion Inhibitor | Product stabilizer and / or winterizing agent. |
| Methanol | 000067-56-1 | | |
| Formic Acid | 000064-18-6 | | Prevents the corrosion of the pipe. |
| Acetaldehyde | 000075-07-0 | | |
| Petroleum Distillate | 064741-85-1 | Crosslinker | Carrier fluid for borate or zirconate crosslinker. |
| Hydrotreated Light Petroleum Distillate | 064742-47-8 | | |
| Potassium Metaborate | 013709-94-9 | | Maintains fluid viscosity as temperature increases. |
| Triethanolamine Zirconate | 101033-44-7 | | |
| Sodium Tetraborate | 001303-96-4 | | |
| Boric Acid | 001333-73-9 | | |
| Zirconium Complex | 113184-20-6 | | |
| Borate Salts | N/A | | |
| Ethylene Glycol | 000107-21-1 | | Product stabilizer and / or winterizing agent. |
| Methanol | 000067-56-1 | | |
| Polyacrylamide | 009003-05-8 | Friction Reducer | "Slicks" the water to minimize friction. |
| Petroleum Distillate | 064741-85-1 | | Carrier fluid for polyacrylamide friction reducer. |
| Hydrotreated Light Petroleum Distillate | 064742-47-8 | | |
| Methanol | 000067-56-1 | | Product stabilizer and / or winterizing agent. |
| Ethylene Glycol | 000107-21-1 | | |
| Guar Gum | 009000-30-0 | Gelling Agent | Thickens the water in order to suspend the sand. |
| Petroleum Distillate | 064741-85-1 | | Carrier fluid for guar gum in liquid gels. |
| Hydrotreated Light Petroleum Distillate | 064742-47-8 | | |
| Polysaccharide Blend | 068130-15-4 | | Thickens the water in order to suspend the sand. |
| Methanol | 000067-56-1 | | Product stabilizer and / or winterizing agent. |
| Ethylene Glycol | 000107-21-1 | | |
| Citric Acid | 000077-92-9 | Iron Control | Prevents precipitation of metal oxides. |
| Acetic Acid | 000064-19-7 | | |
| Thioglycolic Acid | 000068-11-1 | | |
| Sodium Erythorbate | 006381-77-7 | | |
| Lauryl Sulfate | 000151-21-3 | Non-Emulsifier | Used to prevent the formation of emulsions in the fracture fluid. |
| Isopropanol | 000067-63-0 | | Product stabilizer and / or winterizing agent. |
| Ethylene Glycol | 000107-21-1 | | |
| Sodium Hydroxide | 001310-73-2 | pH Adjusting Agent | Adjusts the pH of fluid to maintains the effectiveness of other components, such as crosslinkers. |
| Potassium Hydroxide | 001310-58-3 | | |
| Acetic Acid | 000064-19-7 | | |
| Sodium Carbonate | 000497-19-8 | | |
| Potassium Carbonate | 000584-08-7 | | |
| Copolymer of Acrylamide and Sodium Acrylate | 025987-30-8 | Scale Inhibitor | Prevents scale deposits in the pipe. |
| Sodium Polycarboxylate | N/A | | |
| Phosphonic Acid Salt | N/A | | |
| Lauryl Sulfate | 000151-21-3 | Surfactant | Used to increase the viscosity of the fracture fluid. |
| Naphthalene | 000091-20-3 | | Carrier fluid for the active surfactant ingredients. |
| Methanol | 000067-56-1 | | Product stabilizer and / or winterizing agent. |
| Ethanol | 000064-17-5 | | |
| Isopropyl Alcohol | 000067-63-0 | | |
| 2-Butoxyethanol | 000111-76-2 | | Product stabilizer. |

The following websites provide information on health effects on many of the above listed chemicals.

***OSHA Occupational Chemical Database***
http://www.osha.gov/chemicaldata/

***EPA Chemical Fact Sheets***
http://www.epa.gov/chemfact/

***The Chemical Database***
http://ull.chemistry.uakron.edu/erd/

Data obtained from FracFocus (http://fracfocus.org/chemical-use/what-chemicals-are-used) on February 2, 2012.

# APPENDIX C: NOISE COMPARISONS

## Noise Sources and Their Effects

| Noise Source | Decibel Level | comment |
|---|---|---|
| Jet take-off (at 25 meters) | 150 | Eardrum rupture |
| Aircraft carrier deck | 140 | |
| Military jet aircraft take-off from aircraft carrier with afterburner at 50 ft (130 dB). | 130 | |
| Thunderclap, chain saw. Oxygen torch (121 dB). | 120 | Painful. 32 times as loud as 70 dB. |
| Steel mill, auto horn at 1 meter. Turbo-fan aircraft at takeoff power at 200 ft (118 dB). Riveting machine (110 dB); live rock music (108 - 114 dB). | 110 | Average human pain threshold. 16 times as loud as 70 dB. |
| Jet take-off (at 305 meters), use of outboard motor, power lawn mower, motorcycle, farm tractor, jackhammer, garbage truck. Boeing 707 or DC-8 aircraft at one nautical mile (6080 ft) before landing (106 dB); jet flyover at 1000 feet (103 dB); Bell J-2A helicopter at 100 ft (100 dB). | 100 | 8 times as loud as 70 dB. Serious damage possible in 8 hr exposure |
| Boeing 737 or DC-9 aircraft at one nautical mile (6080 ft) before landing (97 dB); power mower (96 dB); motorcycle at 25 ft (90 dB). Newspaper press (97 dB). | 90 | 4 times as loud as 70 dB. Likely damage 8 hr exp |
| Garbage disposal, dishwasher, average factory, freight train (at 15 meters). Car wash at 20 ft (89 dB); propeller plane flyover at 1000 ft (88 dB); diesel | 80 | 2 times as loud as 70 dB. |

+

| | | |
|---|---|---|
| truck 40 mph at 50 ft (84 dB); diesel train at 45 mph at 100 ft (83 dB). Food blender (88 dB); milling machine (85 dB); garbage disposal (80 dB). | | Possible damage in 8 h exposure. |
| Passenger car at 65 mph at 25 ft (77 dB); freeway at 50 ft from pavement edge 10 a.m. (76 dB). Living room music (76 dB); radio or TV-audio, vacuum cleaner (70 dB). | 70 | Arbitrary base of comparison. Upper 70s are annoyingly loud to some people. |
| Conversation in restaurant, office, background music, Air conditioning unit at 100 ft | 60 | Half as loud as 70 dB. Fairly quiet |
| Quiet suburb, conversation at home. Large electrical transformers at 100 ft | 50 | One-fourth as loud as 70 dB. |
| Library, bird calls (44 dB); lowest limit of urban ambient sound | 40 | One-eighth as loud as 70 dB. |
| Quiet rural area | 30 | One-sixteenth as loud as 70 dB. Very Quiet |
| Whisper, rustling leaves | 20 | |
| Breathing | 10 | Barely audible |

[modified from **http://www.wenet.net/~hpb/dblevels.html**] on 2/2000. SOURCES: Temple University Department of Civil/Environmental Engineering (www.temple.edu/departments/CETP/environ10.html), and *Federal Agency Review of Selected Airport Noise Analysis Issues*, Federal Interagency Commitee on Noise (August 1992). Source of the information is atributed to *Outdoor Noise and the Metropolitan Environment*, M.C. Branch et al., Department of City Planning, City of Los Angeles, 1970.

# BIBLIOGRAPHY


[i] United States Department of Labor Occupational Health and Safety Administration. (n.d.). Oil and Gas Well Drilling and Servicing eTool. Retrieved August 26, 2012, from http://www.osha.gov/SLTC/etools/oilandgas/index.html

[ii] Albert Sprays Solutions. (2013). Retrieved on January 25, 2013, from http://www.albertsspraysolutions.com/bp23.php.

[iii] United States Department of Labor Occupational Health and Safety Administration. (n.d.). Oil and Gas Well Drilling and Servicing eTool. Retrieved August 26, 2012, from http://www.osha.gov/SLTC/etools/oilandgas/index.html

[iv] United States Department of Labor Occupational Health and Safety Administration. (n.d.). Oil and Gas Well Drilling and Servicing eTool. Retrieved August 26, 2012, from http://www.osha.gov/SLTC/etools/oilandgas/index.html

[v] United States Department of Labor Occupational Health and Safety Administration. (n.d.). Oil and Gas Well Drilling and Servicing eTool. Retrieved August 26, 2012, from http://www.osha.gov/SLTC/etools/oilandgas/index.html

[vi] United States Department of Labor Occupational Health and Safety Administration. (n.d.). Oil and Gas Well Drilling and Servicing eTool. Retrieved August 26, 2012, from http://www.osha.gov/SLTC/etools/oilandgas/index.html

[vii] State of California Department of Conservation. (2007). Picture of a Drill Rig. Retrieved on April 7, 2013, from http://www.conservation.ca.gov/dog/picture_a_well/Pages/qh_drill_rig.aspx.

[viii] United States Department of Labor Occupational Health and Safety Administration. (n.d.). Oil and Gas Well Drilling and Servicing eTool. Retrieved April 8, 2013, from http://www.osha.gov/SLTC/etools/oilandgas/site_preparation/conductor_rathole_mousehole.html.

[ix] United States Government Accountability Office. (2012). Oil and Gas Information on Shale Resources, Development, and Environmental and Public Health Risks. Retrieved December 30, 2012, from http://www.gao.gov/products/GAO-12-732.

[x] United States Department of Labor Occupational Health and Safety Administration, & Centers for Disease control Nation. (2010). Worker Exposure to Silica during Hydraulic Fracturing. Retrieved from http://www.osha.gov/dts/hazardalerts/hydraulic_frac_hazard_alert.pdf.

[xi] Layette College. (n.d.) Hydraulic Fracturing in the Lehigh Valley. Retrieved April 7, 2013, from http://sites.lafayette.edu/egrs251-fa11-fracking/what-is-hydraulic-fracturing/.

[xii] United States Department of Labor Occupational Health and Safety Administration. (n.d.). Oil and Gas Well Drilling and Servicing eTool. Retrieved August 26, 2012, from http://www.osha.gov/SLTC/etools/oilandgas/index.html

[xiii] United States Department of Labor Bureau of Labor Statistics. (2012). Industries at a Glance: Mining, Quarrying, and Oil and Gas Extraction: NAICS 21. Retrieved December 31, 2012, from http://www.bls.gov/iag/tgs/iag21.htm#about.

[xiv] Centers for Disease Control National Institute for Occupational Safety and Health. (2012). NIOSH Program Portfolio Oil and Gas Extraction Sector Description. Retrieved August 26, 2012, from www.cdc.gov/niosh/programs/oilgas/sector.html

[xv] The United States Department of Labor Bureau of Labor Statistics. (2012). Occupational Outlook Handbook: Construction and Extraction, Oil and Gas Workers. Retrieved on January 12, 2013, from http://www.bls.gov/ooh/construction-and-extraction/oil-and-gas-workers.htm#tab-2.

[xvi] The United States Department of Labor Bureau of Labor Statistics. (2012). Employment Projections: Educational attainment for workers 25 years and older by detailed occupation. Retrieved on January 12, 2013, from http://www.bls.gov/emp/ep_table_111.htm.

[xvii] The United States Department of Labor Bureau of Labor Statistics. (2012). Occupational Outlook Handbook: Construction and Extraction, Oil and Gas Workers. Retrieved on January 12, 2013, from http://www.bls.gov/ooh/construction-and-extraction/oil-and-gas-workers.htm#tab-2.

[xviii] United States Government Accountability Office. (2012). Oil and Gas Information on Shale Resources, Development, and Environmental and Public Health Risks. Retrieved December 30, 2012, from http://www.gao.gov/products/GAO-12-732.

[xix] Garrison, E., Hill, L., & Mark, N. (2011). Proceedings of The National Conference on Undergraduate Research. Ithaca College. March 31-April2, 2011.

[xx] American Exploration and Production Council. (2010). The Real Facts about Fracture Stimulation: The Technology Behind America's New Natural Gas Supplies. Retrieved January 6, 2013, from http://www.axpc.us/download/issues_and_info/natural%20gas/nat_gas_14apr2010.pdf.

[xxi] Centers for Disease Control National Institute for Occupational Safety and Health. (2012). NIOSH Program Portfolio Oil and Gas Extraction Emerging Issues. Retrieved on February 2, 2013, from http://www.cdc.gov/niosh/programs/oilgas/emerging.html.

[xxii] Centers for Disease Control National Institute for Occupational Safety and Health. (2010) NIOSH Field Effort to Assess Chemical Exposure Risks to Gas and Oil Workers. Retrieved January 6, 2012, from http://www.cdc.gov/niosh/docs/2010-130/pdfs/2010-130.pdf.

[xxiii] Centers for Disease Control National Institute for Occupational Safety and Health . (2012). NIOSH Program Portfolio Oil and Gas Extraction Inputs: Occupational Safety and Health Risks. Retrieved January 15,2013, from http://www.cdc.gov/niosh/programs/oilgas/risks.html.

[xxiv] Goldstein, B. Kriesky, J. and Pavliakova, B. (2012). Missing from the Table: Role of the Environmental Public Health Community in Governmental Advisory Commissions Related to Marcellus Shale Drilling. Environmental Health Perspectives. 120(4), 483-486.

[xxv] Centers for Disease Control National Institute for Occupational Safety and Health. (December 12, 2012) NIOSH Program Portfolio: Oil and gas Extraction. Retrieved January 6, 2013, from http://www.cdc.gov/niosh/programs/oilgas/projects.html.

[xxvi] United States Department of Labor Bureau of Labor Statistics. (2010) Fact Sheet Oil and Gas Industry: Oil and Gas Industry Fatal and Nonfatal Occupational Injuries. Retrieved January 7, 2012 from http://www.bls.gov/iif/oshwc/osh/os/osar0013.htm.

[xxvii] United States Department of Labor Bureau of Labor Statistics. (2012). Injuries, Illnesses, and Fatalities: Summary News Release, 2011. Retrieved January 12, 2013 from http://www.bls.gov/iif/oshwc/osh/os/ostb3191.pdf.

[xxviii] United States Department of Labor Bureau of Labor Statistics. (2012). Injuries, Illnesses, and Fatalities: Summary News Release, 2011. Retrieved January 12, 2013 from http://www.bls.gov/iif/oshwc/osh/os/ostb3191.pdf.

[xxix] United States Department of Labor Bureau of Labor Statistics (2012). Census of Fatal Occupational Injuries (CFOI) - Current and Revised Data. Retrieved January 12, 2013, from http://www.bls.gov/iif/oshwc/cfoi/cftb0259.pdf.

[xxx] Pennsylvania Department of Labor and Industry. (2012). Survey of Occupational Injuries and Illnesses (SOII) Pennsylvania Workplace Injuries and Illnesses for 2011. Retrieved on January 12, 2013, from http://www.portal.state.pa.us/portal/server.pt?open=514&objID=1296068&mode=2.

[xxxi] United States Department of Labor Bureau of Labor Statistics.  (2013). Workplace Fatalities in Pennsylvannia – 2011. Retrieved on January 12, 2013, from http://www.bls.gov/ro3/cfoipa.htm.

[xxxii] Goldenberg, S.M. et al.  (2010). And They Call this Progress?  Consequences for Young People of Living and Working in Resource-Extraction Communities.  Critical Public Health, 20(2), 157-168.

[xxxiii] The United States Department of Labor Bureau of Labor Statistics (2011). Labor Force Statistics from the Current Population Survey.  Retrieved on January 12, 2013, from http://www.bls.gov/cps/cpsaat18.htm.

[xxxiv] Huffington Post.  (2011).  Oil Boomtowns See Rise In Drunken Driving And Bar Fights, Threatening To Overwhelm Law Enforcement.  Retrieved on January 26, 2013, from  http://www.huffingtonpost.com/2011/10/26/oil-drilling-boom-towns-increases-drunkenness-rowdy-behavior_n_1032326.html.

[xxxv] The United States Department of Labor Bureau of Labor Statistics. (2012). Employment Projections: Educational attainment for workers 25 years and older by detailed occupation.  Retrieved on January 12, 2013, from http://www.bls.gov/emp/ep_table_111.htm.

[xxxvi] The United States Department of Labor Bureau of Labor Statistics. (2012). Employment Projections: Educational attainment for workers 25 years and older by detailed occupation.  Retrieved on January 12, 2013, from http://www.bls.gov/emp/ep_table_111.htm.

[xxxvii] Goldenberg, S.M. et al.  (2010). And They Call this Progress?  Consequences for Young People of Living and Working in Resource-Extraction Communities.  Critical Public Health, 20(2), 157-168.

[xxxviii] The United States Department of Labor Bureau of Labor Statistics. (2012). Employment Projections: Educational attainment for workers 25 years and older by detailed occupation.  Retrieved on January 12, 2013, from http://www.bls.gov/emp/ep_table_111.htm.

[xxxix] Centers for Disease Control. (2011).  Current Cigarette Smoking Prevalence Among Working Adults (2004-2010). Morbidity and Mortality Weekly, 60(38), 1305-1309.

[xl] Centers for Disease Control National Institute for Occupational Safety and Health.  (2012).  NIOSH Program Portfolio Oil and Gas Extraction Emerging Issues.  Retrieved on February 2, 2013, from http://www.cdc.gov/niosh/programs/oilgas/emerging.html.

[xli] Rosa, R. (1995). Extended Workshifts and Excessive Fatigue.  Journal of Sleep Research, 4(2), 51-56.

[xlii] United States Department of Labor Bureau of Labor Statistics. (2011). Occupational Employment Statistics Query System. Retrieved on January 12, 2013, from http://www.bls.gov/data/#employment.

[xliii] Centers for Disease Control National Institute for Occupational Safety and Health. (2012). NIOSH Program Portfolio Oil and Gas Extraction Inputs: Occupational Safety and Health Risks. Retrieved January 15, 2013, from http://www.cdc.gov/niosh/programs/oilgas/risks.html.

[xliv] Centers for Disease Control National Institute for Occupational Safety and Health. (2012). NIOSH Program Portfolio Oil and Gas Extraction Sector Description. Retrieved January 13, 2013, from www.cdc.gov/niosh/programs/oilgas/projects.html

[xlv] Centers for Disease Control. (2008).  Fatalities Among Oil and Gas Extraction

Workers --- United States, 2003—2006.  Morbidity and Mortality Weekly, 57(16), 429-431.

[xlvi] Centers for Disease Control. (2008).  Fatalities Among Oil and Gas Extraction

Workers --- United States, 2003—2006.  Morbidity and Mortality Weekly, 57(16), 429-431.

[xlvii] Centers for Disease Control National Institute for Occupational Safety and Health. (2012). NIOSH Program Portfolio Oil and Gas Extraction Inputs: Occupational Safety and Health Risks. Retrieved January 15, 2013, from http://www.cdc.gov/niosh/programs/oilgas/risks.html.

[xlviii] Retzera, K., Hill, R., Pratt, S. (2012). Motor Vehicle Fatalities Among Oil and Gas Extraction Workers. Accident Analysis and Prevention, 51(2013), 168– 174.

[xlix] Centers for Disease Control. (2008). Fatalities Among Oil and Gas Extraction Workers --- United States, 2003—2006. Morbidity and Mortality Weekly, 57(16), 429-431.

[l] Centers for Disease Control National Institute for Occupational Safety and Health. (2012). NIOSH Program Portfolio Oil and Gas Extraction Inputs: Occupational Safety and Health Risks. Retrieved January 15, 2013, from http://www.cdc.gov/niosh/programs/oilgas/risks.html.

[li] Centers for Disease Control National Institute for Occupational Safety and Health . (2012). NIOSH Program Portfolio Oil and Gas Extraction Inputs: Occupational Safety and Health Risks. Retrieved January 15,2013, from http://www.cdc.gov/niosh/programs/oilgas/risks.html.

[lii] The United States Department of Labor Occupational Health and Safety Administration. (2010). Enforcement Policy for Flame-Resistant Clothing in Oil and Gas Drilling, Well Servicing, and Production-Related Operations. Retrieved on February 2, 2013, from http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=INTERPRETATIONS&p_id=27296

[liii] The United States Department of Labor Occupational Health and Safety Administration. (2010). Enforcement Policy for Flame-Resistant Clothing in Oil and Gas Drilling, Well Servicing, and Production-Related Operations. Retrieved on February 2, 2013, from http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=INTERPRETATIONS&p_id=27296

[liv] Centers for Disease Control National Institute for Occupational Safety and Health . (2012). NIOSH Program Portfolio Oil and Gas Extraction Inputs: Occupational Safety and Health Risks. Retrieved January 15,2013, from http://www.cdc.gov/niosh/programs/oilgas/risks.html.

[lv] Centers for Disease Control National Institute for Occupational Safety and Health . (2012). NIOSH Program Portfolio Oil and Gas Extraction Inputs: Occupational Safety and Health Risks. Retrieved January 15,2013, from http://www.cdc.gov/niosh/programs/oilgas/risks.html.

[lvi] United States Department of Labor Occupational Health and Safety Administration. (2005). Profile: Oil and Gas Well Drilling and Servicing. Retrieved February 2, 2013, from http://www.osha.gov/dep/industry_profiles/p_profile-138.html.

[lvii] United States Department of Labor Occupational Health and Safety Administration. (2012). OSHA Quick Card Permit-Required Confined Spaces in General Industry. Retrieved on February 2, 2013, from http://www.osha.gov/Publications/3214-10N-05-english-06-27-2007.html.

[lviii] Cook, N. (2009). The RoSPA Occupational Safety and Health Journal, May 2009, 35-39.

[lix] United States Department of Labor Occupational Health and Safety Administration. (2005). Profile: Oil and Gas Well Drilling and Servicing. Retrieved February 2, 2013, from http://www.osha.gov/dep/industry_profiles/p_profile-138.html.

[lx] Centers for Disease Control National Institute for Occupational Safety and Health. (2012). Workplace Health and Safety Topics, Hazards and Exposures, Cold Stress. Retrieved January 15, 2013, from http://www.cdc.gov/niosh/topics/coldstress/.

[lxi] Centers for Disease Control National Institute for Occupational Safety and Health. (2012). Workplace Health and Safety Topics, Hazards and Exposures, Heat Stress. Retrieved January 15, 2013, from http://www.cdc.gov/niosh/topics/heatstress/.

[lxii] Centers for Disease Control National Institute for Occupational Safety and Health. (2012). Workplace Health and Safety Topics, Hazards and Exposures, Cold Stress. Retrieved January 15, 2013, from http://www.cdc.gov/niosh/topics/coldstress/.

[lxiii] Centers for Disease Control National Institute for Occupational Safety and Health. (2012). Workplace Health and Safety Topics, Hazards and Exposures, Heat Stress. Retrieved January 15, 2013, from http://www.cdc.gov/niosh/topics/heatstress/.

[lxiv] Centers for Disease Control National Institute for Occupational Safety and Health. (2012). Workplace Health and Safety Topics, Hazards and Exposures, UV Radiation. Retrieved January 15, 2013, from http://www.cdc.gov/niosh/topics/uvradiation/.

[lxv] 29 C.F.R. 1910.1200 (May 25, 2012).

[lxvi] United States Department of Labor Occupational Health and Safety Administration. (2005). Profile: Oil and Gas Well Drilling and Servicing. Retrieved February 2, 2013, from http://www.osha.gov/dep/industry_profiles/p_profile-138.html.

[lxvii] Cottle, M. K., & Guidotti, T. L. (1990). Process chemicals in the oil and gas industry: Potential occupational hazards. Toxicology and Industrial Health, 6(1), 41-56.

[lxviii] Hodgson, G. (1969). Cutaneous Hazards of Lubricants. The Transactions of the Society of Occupational Medicine, 19, 19-15.

[lxix] Canadian Association of Petroleum Producers. (2004). Guide: Oil Mist Monitoring Protocol. Retrieved on July 8, 2012, from www.capp.ca/getdoc.aspx?docid=85721&DT=pdf.

[lxx] Centers for Disease Control National Institute for Occupational Safety and Health. (2011). NIOSH Pocket Guide to Chemical Hazards: Oil Mist (Mineral). Retrieved on February 3, 2013, from http://www.cdc.gov/niosh/npg/npgd0472.html.

[lxxi] Centers for Disease Control National Institute for Occupational Safety and Health. (2011). NIOSH Pocket Guide to Chemical Hazards: Methyl Alcohol. Retrieved on February 3, 2013, from http://www.cdc.gov/niosh/npg/npgd0397.html.

[lxxii] Centers for Disease Control National Institute of Occupational Safety and Health. (2011). The Emergency Response Safety and Health Database: Methanol: Systemic Agent. Retrieved on February 3, 2013, from http://www.cdc.gov/niosh/ershdb/EmergencyResponseCard_29750029.html.

[lxxiii] Downie, A. et al. (1992). A Case of Percutaneous Industrial Methanol Toxicity. Occupational Medicine, 42, 47-49.

[lxxiv] Centers for Disease Control National Institute of Occupational Safety and Health. (2011). The Emergency Response Safety and Health Database: Methanol: Systemic Agent. Retrieved on February 3, 2013, from http://www.cdc.gov/niosh/ershdb/EmergencyResponseCard_29750029.html.

[lxxv] World Health Organization International Agency for Research on Cancer. (2012). Press Release Number 213 IARC: Diesel Engine Exhaust Carcinogenic. Retrieved on September 8, 2012 from, http://www.iarc.fr/en/media-centre/pr/2012/pdfs/pr213_E.pdf.

[lxxvi] Silverman, D. et al. (2012). The Diesel Exhaust in Miners Study: A Nested Case – Control Study of Lung Cancer and Diesel Exhaust. Journal of the National Cancer Institute, 104(11), 855-868.

[lxxvii] McClellan, R. et al. (2012). Evaluation of Carcinogenic Hazard of Diesel Engine Exhaust Needs to Consider Revolutionary Changes in Diesel Technology. 63, 225-258.

[lxxviii] Centers for Disease Control National Institute for Safety and Health. (2010). NIOSH Pocket Guide to Chemical Hazards: Diesel Exhaust. Retrieved on February 16, 2013, from http://www.cdc.gov/niosh/npg/npgd0207.html.

[lxxix] 35 P.S. § 4603. Restrictions on Idling.

[lxxx] 40 C.F.R. 70.2 (1992).

[lxxxi] Centers for Disease Control National Institute for Safety and Health. (2012). NIOSH Field Effort to Assess Chemical Exposures in Oil and Gas Workers: Health Hazards in Hydraulic Fracturing. Retrieved on February 16, 2013, from

http://www.iom.edu/~/media/Files/Activity%20Files/Environment/EnvironmentalHealthRT/2012-04-30/Esswein.pdf.

[lxxxii] Verma, D., Johnson, D., McLean, J. (2000). Benzene and Total Hydrocarbon Exposures in the Upstream Petroleum Oil and Gas Industry. American Industrial Hygiene Association, 61, 255-263.

[lxxxiii] Verma, D., Johnson, D., McLean, J. (2000). Benzene and Total Hydrocarbon Exposures in the Upstream Petroleum Oil and Gas Industry. American Industrial Hygiene Association, 61, 255-263.

[lxxxiv] Centers for Disease Control National Institute of Occupational Safety and Health. (2010). NIOSH Pocket Guide to Chemical Hazards: Benzene. Retrieved on February 16, 2013, from http://www.cdc.gov/niosh/npg/npgd0049.html.

[lxxxv] Agency for Toxic Substances and Disease Registry. (1999) Agency for Toxic Substances and Disease Registry ToxFAQs Total Petroleum Hydrocarbons (TPH). Retrieved on February 16, 2013, from http://www.atsdr.cdc.gov/toxfaqs/tfacts123.pdf.

[lxxxvi] Guidotti, T. Occupational Exposure to Hydrogen Sulfide in the Sour Gas Industry: Some Unresolved Issues. (1994). International Archives of Occupational and Environmental Health. 1994(66), 153-160.

[lxxxvii] Hessel, P. et al. (1997). Lung Health in relation to Hydrogen Sulfide Exposure in Oil and Gas Workers in Albert, Canada. American Journal of Industrial Medicine. 31, 554-557.

[lxxxviii] Wilhelm, M. Process Safety Progress. (1999). Avoiding Exposure to Mercury During Inspection and Maintenance Operations in Oil and Gas Processing, 18(3), 178-188.

[lxxxix] Wilhelm, M., Bloom, M. Review: Mercury in Petroleum. (2000). Fuel Processing Technology, 63(2000), 1-27.

[xc] Ryzhova, V. et al. Regular Variations of the Mercury Concentration in Natural Gas. (2003). The Science of the Total Environment. 304(2003), 145–152.

[xci] Argonne National Laboratory, Smith, K. et al. (1996).Radiological Dose Assessment Related to Management of Naturally Occurring Radioactive Materials Generated by the Petroleum Industry. Retrieved on February 16, 2013, from http://www.evs.anl.gov/pub/doc/anlead2.pdf.

[xcii] Argonne National Laboratory, Smith K. (1992). An Overview of Naturally Occurring Radioactive Materials (NORM) in the Petroleum Industry. Retrieved on December 15, 2012 from http://www.evs.anl.gov/pub/doc/ANL_EAIS_7.pdf.

[xciii] Argonne National Laboratory, Smith, K. et al. (1996). Radiological Dose Assessment Related to Management of Naturally Occurring Radioactive Materials Generated by the Petroleum Industry. Retrieved on February 16, 2013, from http://www.evs.anl.gov/pub/doc/anlead2.pdf.

[xciv] 10 C.F.R. 20.1201 (May 21, 1991).

[xcv] Argonne National Laboratory, Smith, K. et al. (1996).Radiological Dose Assessment Related to Management of Naturally Occurring Radioactive Materials Generated by the Petroleum Industry. Retrieved on February 16, 2013, from http://www.evs.anl.gov/pub/doc/anlead2.pdf.

[xcvi] Hamlat, M., Dejeffal, S., Kadi, H. (2001). Assessment of Radiation Exposures from Naturally Occurring Radioactive Materials in the Oil and Gas Industry. Applied Radiation and Isotopes, 55(2001), 141-146.

[xcvii] United States Department of Labor Occupational Safety and Health Administration. Noise and Hearing Conservation Appendix II:A. General Industry Standard. Retrieved on February 16, 2013, from http://www.osha.gov/dts/osta/otm/noise/standards_more.html.

[xcviii] Centers for Disease Control National Institute for Occupational Safety and Health. (1998). DHHS (NIOSH) Publication Number 98-126 Occupational Noise Exposure. Retrieved on January 1, 2013, from http://www.cdc.gov/niosh/docs/98-126/default.html.

[xcix] Purdue University. (2011). PPE Online Hearing Protection Noise Comparison Chart. Retrieved on February 16, 2013, from http://www.chem.purdue.edu/chemsafety/Training/PPETrain/dblevels.htm.

[c] Grima, F. (1986). Industrial City in the Desert. Journal of the Society of Occupational Medicine, 36, 45-50.

[ci] Grima, F. (1986). Industrial City in the Desert. Journal of the Society of Occupational Medicine, 36, 45-50.

[cii] United States Department of Labor Occupational Safety and Health Administration & Centers for Disease Control National Institute of Occupational Safety and Health. (2012). Hazard Alert: Worker Exposure to Silica During Hydraulic Fracture. Retrieved on February 5, 2013, from http://www.osha.gov/dts/hazardalerts/hydraulic_frac_hazard_alert.html.

[ciii] Wagner, G. (1997). Asbestosis and Silicosis. The Lancet. 349(9061), 1311-1315.

[civ] United States Department of Labor Occupational Safety and Health Administration & Centers for Disease Control National Institute of Occupational Safety and Health. (2012). Hazard Alert: Worker Exposure to Silica During Hydraulic Fracture. Retrieved on February 5, 2013, from http://www.osha.gov/dts/hazardalerts/hydraulic_frac_hazard_alert.html.

[cv] Kurihara, N., Wada, O. (2004). Silicosis and Smoking Strongly Increase Lung Cancer Risk in Silica-Exposed Workers. Industrial Health, 42, 303-314.

[cvi] Wagner, G. (1997). Asbestosis and Silicosis. The Lancet. 349(9061), 1311-1315.

[cvii] United States Department of Labor Occupational Safety and Health Administration & Centers for Disease Control National Institute of Occupational Safety and Health. (2012). Hazard Alert: Worker Exposure to Silica During Hydraulic Fracture. Retrieved on February 5, 2013, from http://www.osha.gov/dts/hazardalerts/hydraulic_frac_hazard_alert.html.

[cviii] United States Department of Labor Occupational Safety and Health Administration & Centers for Disease Control National Institute of Occupational Safety and Health. (2012). Hazard Alert: Worker Exposure to Silica During Hydraulic Fracture. Retrieved on February 5, 2013, from http://www.osha.gov/dts/hazardalerts/hydraulic_frac_hazard_alert.html.

[cix] FAR Part 91.17. General Operating and Flight Rules: Alcohol or Drugs.