

**Potential Exposure-Related Human Health Effects of Oil and Gas Development:
A Literature Review (2003-2008)**

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Introduction and Background

The purpose of the literature review is to:

1. Review the known contaminants associated with oil and gas exploration, drilling, extraction and production.
2. Review the available medical literature regarding the health effects associated with oil and gas extraction and the health effects of the hazardous substances associated with oil and gas extraction and production.
3. Review the community and occupational injury rates associated with oil and gas extraction and production.
4. Review the literature regarding the potential social and psychological risks of increased oil and gas drilling on a community.

The United States and global energy needs have driven up prices for fossil fuels, with no relief in sight. In addition, political instability in major energy producing countries around the world has driven a US energy policy to increase domestic production of all types of energy, in particular fossil fuels. The combination of skyrocketing demand, interest in domestic supplies and new technology has made fuels previously unattainable or too costly now worthy of recovery. The American West has large reserves of extractable oil and gas. The West has therefore seen a dramatic increase in drilling for oil, gas, coal, and coal bed methane.

As pressures for increased fossil fuel production rises, areas that had previously been considered too sensitive for drilling are now being drilled. These previously sensitive sites have included an increasing number of oil and gas drills that are in close proximity to native and local populations. Human residence and activity close to oil and gas production sites increases the likelihood that people will be exposed to the hazardous chemicals, emissions and pollutants associated with these activities.

Hazardous chemicals are known to be used and produced by oil and gas extraction processes. Subsurface land formations are “fractured” (known as “fracking or frac’ing) by injection of fluids and/or solids into the ground under high pressure. Some of the chemicals used in this process are brought to the surface, potentially contaminating soil, air and water, while some of the chemicals are left underground, potentially contaminating subsurface aquifers. Other chemicals may also be used in the drilling fluids. These fluids may be fresh or salt water based muds, oil based muds or synthetic materials that contain esters, olefins, paraffins, ethers and alkylbenzenes, among others. The drilling fluids may also contain additives such as metals, acrylic polymers, organic polymers, surfactants, and biocides.(Occupational Safety and Health Administration)

Drilling sludge brought to the surface can contain fracking fluid, drilling mud, radioactive material from the subsurface land formation, hydrocarbons, metals, volatile organic compounds. When left to dry on the surface in waste pits, sludge can potentially contaminate air, water and soil. Sludge may also be removed to waste disposal sites (but usually not hazardous wastes sites) or sludge may be tilled into the soil in “land farms”. These practices potentially contaminate soil, air and surface water.

Produced water can be brought to the surface during the extraction process. This water is usually contaminated with salts, hydrocarbons, radioactive material, metals, drilling fluids and muds. The produced water is often left on the surface to evaporate, or it may be re-injected into the ground or released into surface waters. All of these disposal methods threaten air, water and soil quality. Additionally, spills of oil and gas wastes and/ or chemicals used in production can pollute ground and surface water and soil.

Air surrounding oil and gas production areas is particularly vulnerable to toxic emissions. Fugitive natural gas emissions may contain many contaminants. Some of these such as methane and other hydrocarbons (ethane, propane, butane) and water vapor are of relatively low human toxicity. Others such as hydrogen sulfide (H₂S) are of more significant toxicity. Some natural gas wells produce a condensate which can contain complex hydrocarbons and aromatic hydrocarbons such as benzene, toluene, ethyl benzene and xylene (BTEX). These substances are important human toxics with multiple non-cancer and cancer endpoints. Natural gas flaring can produce many hazardous chemicals including polycyclic aromatic hydrocarbons (PAHs, including naphthalene), benzene, toluene, xylenes, ethyl benzene, formaldehyde, acrolein, propylene, acetaldehydehexane. Glycol dehydrators, used to remove water from natural gas can produce BTEX leaks into the air.

Most of the hazardous chemicals associated with oil and gas production are well documented to produce adverse health effects in individuals. Some literature exists that demonstrates adverse health effects on populations exposed to these chemicals in other industrial or in urban settings. However, little research exists regarding the effects of these exposures on local populations as a whole in the setting of oil and gas extraction. Our review is an attempt to summarize what is known about these hazardous chemicals' effects on populations and to identify gaps medical and public health knowledge. A list of contaminants derived from the Oil and Gas Accountability Project website is listed in the next section. (Oil and Gas Accountability Project 2006) Our review may not include chemicals used in drilling muds and fracking fluids as these compounds are often considered proprietary and not available to the public.

Oil and gas drilling is associated with an influx of workers and resources to often rural or isolated communities. These changes can bring about stresses to the local people and may be reflected in changes in crime, social diseases, and psychological outcomes. We reviewed available literature regarding the psychosocial effects of oil and gas drilling on local communities. We also identified significant gaps in knowledge regarding the demographics and the psychosocial effects of oil and gas drilling on local populations.

Oil and Gas Contaminants

| Contaminant Inventory | |
|---|---|
| Particulates | PM10 (diameter <= 10 microns) PM2.5 (diameter <= 2.5 microns) Ultrafine particles (diameter <= 1 micron) |
| Nitrous oxides (NOx) | |
| Sulfuric oxides (SOx) | |
| Ozone | |
| Hydrogen Sulfide (H2S) | |
| Volatile Organic Compounds (VOC) | BTEX (Benzene, Toluene, Ethyl benzene, Xylene) Methylene Chloride Tetrachloroethene Trichloroethene 1,4-dichlorbenzene m,p-xylenes 2-hexanone |
| Diesel fuel/exhaust | |
| Metals | Arsenic Barium Cadmium Chromium Lead Mercury Selenium Zinc |
| Polyaromic hydrocarbons (PAH) | |
| Produced water | |
| Fracturing chemicals (Fracking, Frac'ing chemicals) | |
| Radiation | Radon Radium Uranium |
| Noise pollution | |
| Light pollution | |

Methodology

Literature Search

The literature search was performed by Paul Blomquist at the University of Colorado Denver Health Sciences Library after discussion with the work group to define the scope and extent of the searches. The bibliographic retrieval on May 13, 2008 included four different searches related to oil and gas drilling as follows: search 1 covered adverse reactions to various chemicals and events; search 2 retrieved impacts of fracking and fracturing; search 3 covered implications of produced water; and finally search 4 retrieved injuries related to oil and gas drilling. All searching in Ovid Medline excluded the pre-indexed component of Medline.

The first search covering adverse reactions to various chemicals and events related to oil and gas drilling was limited to the years 2003 through 2008 and for humans only. In this search, an initial set, limited by the subheading for adverse effects, was created for MeSH (Medical Subject Headings) terms that included “air pollution” and the subjacent MeSH term “air pollution, radioactive”, the exploded term “Particulate matter,” and the exploded term “environmental pollution.” Also, “Waste products” included all subjacent MeSH terms other than “medical waste.” Other exploded MeSH terms with adverse effects subheading included “water pollution,” “noise,” and “light.” Finally three subheadings--adverse effects, poisoning, and toxicity--were applied to MeSH terms for both “vehicle emissions” and the exploded “Environmental Pollutants”. From this initial aggregated set, citations were eliminated for the exploded MeSH terms of “household articles,” “household products,” “pest control,” “swimming pools,” “seasons,” “weather,” “smoking,” “tobacco,” and “tobacco smoke pollution.” Also citations were eliminated with truncated free text terms for “offshore\$” and “cigarette\$.”

The final aggregated retrieval for the first search strategy was parsed into 28 sets by concepts for adverse events or chemicals related to oil and gas drilling that included truncated full text terms, acronyms, and exploded MeSH terms supplemented with chemical registry numbers where appropriate. The MeSH terms used for parsing did not limit with subheadings except for the concept of diesel fuel in which the subheadings for toxicity, poisoning and adverse effects were applied to MeSH terms “vehicle emissions” and “gasoline.” It is suggested that alternate searching could be formulated that applies subheadings for poisoning, toxicity, or adverse effect to the MeSH terms for the chemicals that comprised a large portion of the 28 concepts.

In the second search on the impact of fracking and fracturing in oil and gas drilling, an initial set was created of full text terms for “fracturing” or the truncated “frack\$.” This retrieval was narrowed to citations with exploded MeSH terms for either “environmental pollution” or “water supply.” This set was further narrowed to citations pertaining to oil and gas drilling with a combination of fulltext terms and MeSH terms as follows: restriction to citations that contain exploded MeSH terms for both “extraction and processing industry” or “petroleum”; or restriction to citations containing fulltext terms for either “oil” or “gas” adjacent to any of the three truncated terms “drill\$” or “indust\$” or “explor\$.” Citations with truncated fulltext term “offshore\$” was excluded from the final set of this retrieval.

For the third search on the implications of produced water in oil and gas drilling, an initial retrieval of citations included exploded MeSH terms for either “water supply,” or “environmental pollution.” Added to this set were citations that had both exploded MeSH terms for “extraction and processing industry” and “petroleum.” A final aggregation included citations with fulltext terms of either “oil” or “gas” adjacent to any of three truncated terms: “drill\$” or “indust\$” or “explor\$.” This final set was narrowed to only citations containing the fulltext term “produced water,” and citations containing the truncated term “offshore\$” were eliminated.

In the fourth search on injuries related to gas and oil drilling, an initial set of retrieved citations of exploded MeSH terms for “extraction and processing industry” combined with “petroleum.” To this set was added citations with full text terms of “oil” or “gas” adjacent to any of three truncated terms: “drill\$” or “industry\$” or “explore\$.” The aggregated set was narrowed to citations that had exploded MeSH terms for either “wounds and injuries” or “accidents.” Finally, citations containing the truncated term “offshore\$” were eliminated.

Summary of databases searched:

U.S. National Library of Medicine: Ovid Medline (R) 1950 to present.
Social/Psychological Databases: Psychological: PyschInfo, Web of Science
Medical: ScienceDirect, PubMed, MEDLINE OCLC, CINAHL
Public Health: American Journal of Public Health, Annual Reviews
Educational: EBSCO Academic Search Premier, ERIC, OCLC

Refining the Literature Review

After identifying potentially relevant literature, each paper was reviewed at the abstract or full text level for relevance. We reviewed English language, human studies published between 2003 and the present. Papers were excluded from further review based on the following criteria: foreign language literature; animal research; publication prior to 2003; laboratory based, experimental research studies; off shore drilling and exploration studies; reviews other than meta analyses; case reports; commentaries, editorials, letters to the editor and other opinion pieces. Exceptions to these rules are specifically noted in each subsection.

Having refined the list of potentially relevant literature, papers were reviewed and summarized according to exposure category. These reviews are a summary of relevant literature, taking into account the strength of evidence and study design. No attempt was made to rate individual articles.

Table 1. Overview of search results and literature reviewed

| Category | Initial number of references identified by Search | Number of references Excluded (see criteria above) | Total number of references Reviewed | Appendix |
|------------------------------------|--|--|--|-----------------|
| VOC | 247 | 147 | 100 | 1 |
| Diesel Exhaust | 197 | 144 | 53 | 2 |
| Nitrogen oxides (NO _x) | 243 | 192 | 51 | 3 |
| Sulfuric oxides (SO _x) | 118 | 85 | 33 | 3 |
| Ozone | 217 | 125 | 94 | 3 |
| Particulate matter | 510 | 183 | 327 | 3 |
| PAH | 276 | 245 | 31 | 4 |
| Metals | 299 | 224 | 75 | 5 |
| H ₂ S | 85 | 65 | 20 | 6 |
| Fossil Fuels | 305 | 279 | 26 | 7 |
| Fracking | 234 | 234 | 0 | - |
| Noise | 881 | 857 | 24 | 8 |
| Light | 297 | 291 | 6 | 9 |
| Occupational Injuries | 40 | 31 | 9 | 10 |
| Social/Psychological | 1114 | 1093 | 21 | 11 |
| Total | 5063 | 4239 | 831 | |

Limitations

This literature review has a number of possible limitations:

- It relied on single reviewers for each section.
- It only considered literature published within the past 5 years, possibly missing important, relevant literature published prior to 2003.
- It may have excluded meritorious research published in foreign languages.
- Studies were considered without reference to their funding sources or their potential conflicts of interest.
- Use of additional search terms may have generated different results.
- Use of additional databases may have yielded different results.
- It did not use formal criteria to assess each individual paper for strength of evidence and study design.
- It relied on the major, known exposures of potential concern. There may be other exposures that should have been considered.
- Additional chemicals, used in proprietary formulas, may not have been included.
- In many cases papers focused on single exposures. This may fail to take into account potential health effects of these exposures when they are part of a complex mixture.

Contaminants and Health

Volatile Organic Compounds (VOCs)

Volatile organic hydrocarbon exposures as a result of emissions from production in the oil and gas industries are complex. These are composed of materials used in the production activities, and emissions from the produced material. Both point source releases at the well pads, and transportation activities to and from the drilling sites contribute volatile hydrocarbon loads to the resident and transient populations in the drilling regions. Because there is limited information on the distribution of population in the affected regions, it is not possible to define the distances of interest from the well heads and traffic patterns of concern. This makes it difficult to search the literature for exposure concentrations by source distance. Since dose and dose rate are important in assessing the relevance of the literature of VOCs to human information, the absence of this demographic information limits the interpretation of the found literature.

Terms utilized in the search are summarized above. A total of 247 studies were recovered. One-hundred and forty-seven studies were eliminated from further review following our criteria for inclusion in this literature review (i.e. published within the past 5 years, English language, human; excluding basic mechanistic studies and excluding review articles unless they are meta-analyses.). Because reviews and comments were excluded for this study, known and theoretical issues of diseases suspected or proved to be causally associated with the materials of interest in past studies are not included in this paper. The search for VOC literature included the BTEX chemicals (benzene, toluene, and xylenes) and also included low molecular weight halogenated hydrocarbons. A total of 62 studies were selected for review dealing with benzene. Four relevant studies were reviewed for xylene. Studies relating to toluene were subsumed under the benzene and xylene rubric. No meaningful studies that dealt with dichlorobenzene were found. Two studies that met the search criteria were reviewed for dichloromethane [methylene chloride]. Ten relevant studies were reviewed for perchloroethylene. Twenty-two relevant studies were reviewed for trichloroethylene. These citations are collected in Appendix 1.

Chronic, low level exposure

The literature on the impact of volatile organic compounds including the BTEX group, and the low molecular weight halogenated hydrocarbons were reviewed for cancer and non-cancer endpoints in humans. Although there is an extensive occupational toxicology literature on these substances, little meaningful information on chronic, low level, exposure in the general environment has been developed.

High Concentration Exposure

It is well known that all of the chemicals in this group are neurotoxins. They impact the central and peripheral nervous system. They have significant cognitive and behavioral effects in

occupationally exposed groups. They are known hepatotoxins. Most have been identified as reproductive toxins both in males and females. They are recognized as fetotoxins, and have been associated with teratogenesis and fetal wastage following large or critically timed occupational or accidental exposures. All are dermatotoxins. These effects have primarily been identified in persons who had exposures at levels or dose rates that are not found in the general environment, although widespread general environmental exposure to these chemicals occurs, few studies have been conducted at environmental exposure concentrations.

Occupational Exposures

Although much of the toxicological information on benzene in particular has been developed in the downstream petrochemical industries such as shipping, processing and refining, and distribution of the finished products, no studies on the impact of the BTEX group or the low molecular weight halogenated hydrocarbons in the upstream petrochemical industries were found. No data on exposure to these substances to occupational groups in the process of exploration or production were recovered. No studies of exposures to adjacent populations were found. This is a major data gap. All relevant studies selected for review and relevance then are removed from the oil and gas production activities and must be used as analogous to these activities.

A number of very low level occupational exposure studies that demonstrate positive outcomes are likely relevant to the exposures to resident local populations in the oil and gas exploration and extraction areas. For example, a statistically significant incidence of acute myeloid leukemia at doses and dose rates as low as 0.8ppm and 2ppm/years was demonstrated in the case control study portion of the Australian Health Watch Study. This important finding suggests that benzene may have adverse health effects at lower dose rates than previously thought and current exposure limits may not be protective.

It is necessary to extrapolate the occupational information which has been developed in healthy, midlife, mostly male workers to the broader universe of humans, including women, children, and the infirm. Because the body of literature recovered in the searches is not informative on these populations, it is immediately apparent that a major data gap exists in any attempt to characterize risk beyond the workplace. Broad general assumptions must be made about adjustments to dose response curves for use in risk assessment in non-occupational populations such as the target groups of concern in this review. Physical and psychological stressors that may influence the impact of exposure and outcome are unaddressed.

Biomarkers

A growing literature on the identification and quantification of biomarkers of exposure to volatile organics, and sub-clinical effect of these exposures was developed in this review. This literature offers some hope that biomarkers may provide meaningful data on exposure at very low levels to non-occupational populations. Papers recovered that deal with genetic diversity and metabolic variations in the handling of these chemicals in large groups of humans may indicate that in the future such measurable parameters will give early clues to adverse effects. Because there is a peer reviewed body of information that indicates that children are at increased

risk for adverse toxicological outcomes following exposure to many synthetic organic chemicals, including the volatile organics, the absence of environmental toxicology data on childhood environmental exposure and outcome is particularly troubling.

Molecular epidemiologic investigation of biomarkers that have been identified in the occupational and para-occupational groups as a result of exposure to the BTEX and low molecular weight halogenated hydrocarbons should be done in the environmentally exposed persons based upon the material recovered in this review. Molecular epidemiologic studies may prove to be of great value. Such investigation may yield exposure information not currently available for these environmentally exposed persons. If registries of these findings are developed, maintained and properly analyzed, and linked to long term outcome follow up studies, they may prove to be characteristic and predictive of adverse health outcomes.

Epidemiology

Extensive epidemiologic, basic science, and mechanistic information has been collected and peer reviewed about each of the materials of concern in this part of the review. More of this information supports the classification of benzene as a known human carcinogen, trichloroethylene as a probable human carcinogen, and dichloromethane as a probable human carcinogen, than addresses the non-cancer endpoints that have been identified following occupational exposure to this group of chemicals. In the material recovered in this review, some of the well-known cancer endpoints and some of the lesser known toxic endpoints have been demonstrated in low level exposures in occupational or para-occupational populations. A few studies of exposure at low, general environmental exposure have also shown increased occurrence of the non-cancer endpoints, particularly in the neurological system.

Most of the studies that are relevant to the issues at hand in this review identify serious cancer and non-cancer endpoints in low level, long term occupational or para-occupational studies. For example, benzene or benzene and other volatile organic compound exposure in traffic police and the outcomes in these persons have been analyzed. Some studies have identified biomarker variants in these exposures that might also be found in persons who reside close to a point source of analogous VOC emissions. The biomarkers and outcomes in para-occupational groups provide insight into research findings that may predict outcomes in the environmentally exposed groups.

Summary

Based upon the material reviewed in this study, some conclusions are appropriate:

1. Benzene is a human leukemogen at airborne exposures lower than have been reported in past times. This may imply that persons residing close to sources of benzene from oil and gas production are at risk of leukemia from those exposures. Some evidence for the occurrence of a broad spectrum of hematological disorders exists. The scope of these diseases should be the subject of study. In addition, the low molecular weight halogenated hydrocarbons are noted to cause liver, kidney and neurological disease, and

likely increase renal and other cancers. Persons exposed to these materials in the oil patch should be evaluated for adverse effects.

2. Biomarkers that may be clinically relevant have been identified in numerous studies of human exposure to most of the chemical compounds in this review. An evaluation of the relevance and predictive value of these biomarkers should be undertaken. Selection and examination of the most useful biomarkers in this population and a registry of the findings should be developed for this population. The biomarkers may be indicative of exposure to the materials of interest and therefore may be predictive of increased risk of adverse outcome in the exposed population.
3. Evidence of cognitive and behavioral abnormalities, alterations in special sense function such as impairment of color vision and perception have been reported in occupationally exposed workers from these materials. Screening for cognitive function impairment, behavioral disorders and disorders of the special senses is appropriate in the population exposed to oil and gas activities.
4. Very limited evidence that children are at increased risk of adverse outcomes and that fetal and neonatal impact of these chemicals was found. Screening for such effect in early childhood and registry of birth outcomes in the exposed population is advised.

Diesel exhaust

As discussed above, diesel exhaust exposures from both stationary and mobile sources are among the categories of exposures of concern. Diesel exhaust is a complex mixture of diesel exhaust particulate matter (see section on particulate matter), metals, thousands of organic compounds especially solvents, and other chemicals. As such, we have examined the medical literature to identify published research on the human health impact of diesel exhaust a) specifically in relation to oil and gas exploration activities and b) generally in relation to people with environmental exposure to diesel exhaust. Much of this literature comes from studies of occupationally exposed individuals as well as studies of those exposed environmentally because of their proximity to major roads and diesel exhaust sources.

Key search terms are summarized in the methods section above. A total of 197 studies were recovered. One-hundred and forty-four studies were eliminated from further review following our criteria for inclusion in this literature review (i.e. published within the past 5 years, English language, human; excluding basic mechanistic studies and excluding review articles unless they are meta-analyses.) A total of 53 papers were reviewed. See the list of these citations in Appendix 2.

As elsewhere in this literature review, this section will focus on those published studies that directly examine the human health impact of oil and gas exploration – generated diesel exhaust. Much of this exposure is anticipated to be related to increased vehicular traffic. In addition, we provide an overview of the body of evidence regarding diesel exhaust-related health effects in the general population. The section will include a set of conclusions based on this literature review.

Among the 53 reviewed papers published between 2003 and 2008, we identified no research studies that directly examined the human health impact of diesel exhaust emissions associated

with oil and gas exploration activities. However, a number of studies are noteworthy because they reflect the health impact on communities when diesel vehicular traffic rises.

Notably, numerous epidemiologic and experimental studies have shown generally consistent relationships between diesel exhaust exposure and adverse human health outcomes. Health effects may vary some by the source of diesel exhaust as well as the chemical composition of the diesel fuel, metal content, and chemical composition. Diesel particulate matter has a center core of carbon and a variety of adsorbed organic compounds that include some known human carcinogens such as polycyclic aromatic hydrocarbons (PAH) and nitro-PAHs, as well as nitrate, sulfate, trace elements, and metals. Diesel particulate matter is composed of small particles including a high percentage of ultrafine particles (≤ 1 micron diameter) which are of particular concern. These particles easily enter deep into the respiratory tract and have a large surface area where organic compounds can easily attach. Both stationary (e.g. industrial sources) as well as mobile sources (e.g. diesel fuel combustion emissions from vehicles and traffic density) contribute to risk. In some circumstances, increased risk may be due to a combined effect of diesel exhaust and the myriad of other pollutants that may also be in the air. Exposure to diesel exhaust can cause irritant symptoms, neurological, respiratory, and asthma-like symptoms, and can both increase the risk for developing allergic disorders and worsen allergenic responses to known environmental allergens. Lung cancer risk (independent of smoking status) is elevated among those with occupations where diesel engines have been used.

The majority of the studies reviewed are relevant in considering how increases in diesel exhaust from oil and gas exploration activities may affect health outcomes. The data are generally consistent. They show that many of the health risks that are associated with various forms of diesel exhaust disproportionately affect susceptible populations including those with lung disease, those with allergic disorders, and the elderly. As a major contributor to ambient particulate air pollution, the section in this document that refers to particulate matter is generally applicable to diesel exhaust as well.

Several references in the literature are particularly noteworthy. In 2002, the U.S. EPA released a health assessment document regarding diesel engine exhaust, based on data from the 1990s. This assessment concluded that long-term exposure to inhaled diesel exhaust is a lung cancer hazard in humans, based on epidemiologic and animal research. In addition, non-cancer chronic human health risks identified included lung inflammation, irritation, allergies, and asthma.

Although not specific to diesel exhaust emissions from oil and gas exploration and extraction, a paper by Gabrovska and Friedman (2004) is relevant to the concept of how increased diesel exhaust due to traffic around an industrial site affects health. In that study, community respiratory complaints were assessed during the closure of a community dump, in relation to dust exposure and measured or estimated diesel emissions. People living nearest to and downwind of the site were at increased risk of having respiratory symptoms. After the site closed, one-third of residents reported improvement of symptoms. The authors linked the rates of respiratory symptoms to changes in diesel emission and ambient dust levels.

In a study published in the New England Journal of Medicine in 2007, McCreanor and Cullinan demonstrated the respiratory effects of exposure to diesel traffic in people with asthma. They observed that increased diesel traffic is associated with worse lung function and worse lung inflammation in asthmatics.

In addition to these reports, the body of literature reviewed is sufficient to conclude that as exposures to airborne diesel exhaust rise, human risks increase for the following:

- **Cardiovascular disease:** See section on “Particulate matter.”
- **Respiratory disease:** Including respiratory disease-related hospital admission, mortality due to respiratory disease, premature death from respiratory disease including lung cancer, worsening of illness in people with lung disorders (e.g. asthma, chronic obstructive pulmonary disease), asthma, bronchiolitis and respiratory infections, reduced lung function (especially in asthmatic children), allergic lung inflammation, allergies, symptoms (e.g. cough)
- **Allergic diseases**
- **Genotoxicity** Damage to chromosomes and DNA
- **Childhood illnesses:** Pediatric allergies and respiratory disorders, exacerbation of existing asthma

Conclusions

1. We identified no published studies in the past five years that directly examined the health impact of diesel exhaust in the population living and working in the vicinity of oil and gas exploration activities. This is a major gap and calls for additional research.
2. No data on the impact of diesel exhaust at environmental concentrations on special populations such as the elderly, pregnant women, healthy and asthmatic children and other special groups was found. This is a major gap and calls for additional research.
3. The absence of studies directly examining diesel’s effects in populations surrounding oil and gas exploration facilities does not mean an absence of risk. The independent and generally consistent body of scientific evidence on diesel exhaust that we reviewed provides strong support for the relationship to human disease.
4. Based on the available evidence, it is highly likely that as diesel exhaust exposures rise due to exploration sites and associate diesel vehicular traffic, the health of the surrounding community will be adversely affected.

Criteria Pollutants

Nitrogen oxides (NO_x), sulfuric oxides (SO_x), ozone, and particulate matter

Sources

Nitrogen oxides (NO_x) are released into the air from oil and gas production during flaring, and in exhaust from diesel and gas compressor engines. NO_x are also released in automobile exhaust and play a major role in the formation of photochemical smog.

Sulfuric oxides (SO_x) are formed during the combustion of coal and oil. SO_x may be released during flaring of natural gas, or when fossil fuels are burned to provide power to the pump jack or compressor engines at oil and gas sites.

Ozone is among the exposures of possible concern. A potent respiratory irritant, ozone results from sunlight-driven reactions involving the oxides of nitrogen and volatile organic compounds that are generated by stationary and mobile sources. It is the principal component of photochemical smog.

Particulate matter exposures from both stationary and mobile sources are among the categories of exposures of possible concern.

Review

Terms utilized in the search are summarized above in the methods section. A total of 243 studies were recovered for NO_x. One-hundred and ninety-two papers were eliminated from further review following our criteria for inclusion in this literature review (i.e. published within the past 5 years, English language, human; excluding basic mechanistic studies and excluding review articles unless they are meta-analyses.). A total of 51 studies were selected for review of NO_x exposure. A total of 118 studies were recovered from SO_x. Eight-five studies were eliminated from further review following our criteria for inclusion in this literature review. A total of 33 studies were selected for review dealing with SO_x. A total of 217 ozone studies were recovered. One-hundred and twenty-five were eliminated from further review following our criteria for inclusion in this literature review. A total of 94 studies for ozone were reviewed. A total of 510 studies were recovered from particulate matter. One-hundred and eighty-three were eliminated from further review following our criteria for inclusion in this literature review. In total, we reviewed a total of 327 studies for particulate matter. These citations are collected in Appendix 3.

As discussed above, these pollutants are among the exposures of possible concern. As such, we have examined the medical literature to identify published research on the human health impact of these air pollutants a) specifically in relation to oil and gas exploration activities and b) generally in relation to people with environmental exposure to ambient particulate matter.

Among the reviewed papers published on NO_x, SO_x, ozone and particulate matter between 2003 and 2007, we identified no research studies that examined directly the human health impact of these pollutants produced during oil and gas exploration activities. However, in contrast to other parts of this review there is extensive data about general exposure to these substances in the environment outside the workplace, and its impacts on non-occupational populations.

Health Effects

NO_x, SO_x, and ozone:

Notably, numerous epidemiologic and experimental studies have shown generally consistent relationships between all of these pollutants and adverse human health outcomes. Both stationary (e.g. industrial sources) as well as mobile sources (e.g. fossil fuel combustion emissions from vehicles and traffic density) of ground-level pollutants contribute to risk. Risk may, in some circumstances, be due to a combined effect of these pollutants. In some instances, it has been difficult to separate the independent contribution of each of these pollutants to health risk.

There is clear evidence that nitrogen oxides, sulfur dioxide, and ozone exposures are significant contributors to respiratory disease. There is reasonably strong evidence for its contribution to cardiovascular illness as well. The majority of the studies reviewed are relevant in considering how increases in these pollutants along with other air pollutants from oil and gas exploration activities may affect health outcomes. Special consideration is needed for the young (especially those with asthma) and the elderly (especially those with chronic obstructive pulmonary disease and/or cardiac disease). The data are generally consistent in showing that many of the health risks that are associated with these pollutants disproportionately affect these susceptible populations. In particular, ozone has been clearly associated with increased mortality. (Gryparis 2004, Bell 2005, Bell 2008). The body of literature reviewed is sufficient to conclude that with even small increases in exposure to these pollutants, human risks increase for the following:

- **Respiratory disease:** Including respiratory disease-related hospital admission, mortality due to respiratory disease, worsening of illness in people with lung disorders (e.g. asthma, chronic obstructive pulmonary disease), asthma, bronchiolitis and respiratory infections, reduced lung function (especially in asthmatic children), allergic nasal and airways inflammation, allergies, symptoms (e.g. cough, wheeze, shortness of breath, eye irritation, headache). (Galan 2004, Simpson 2005, Ostro 2006, Quian 2007, Chen 2007, Lee 2007, Yang 2003, Yang 2007, Pacini 2003, Hoffman 2004, Sienra-Monge 2004, Vagaggini 2007, Sole 2007, Kim 2004, Chan 2005, Tager 2005, Qian 2005, Kim 2007, McDonnell 2007, Rojas-Martinez 2007, Alexeeff 2007, Henrotin 2007, Penard-Morand 2005)
- **Childhood Asthma:** Some of the most compelling evidence, reinforced by publications in the past five years, relates to ozone's impact on children with asthma. While there is evidence for some 'adaptation' to the effects of ozone as people age, and heterogeneity in peoples' responses to ozone (that may be related to genetics), the overall impact of ozone related to childhood asthma is noteworthy. It includes increases in pediatric emergency room visits and pediatric hospital admissions, asthma exacerbations of symptoms and use of rescue inhalers, impaired lung development, and airways inflammation in addition to asthma, including bronchiolitis. (Lin 2003, Gent 2003, Sanhueza 2003, Lewis 2005, Hwang 2005, Calderon-Garciduenas 2006)
- **Cardiovascular disease:** Including cardiovascular hospital admission, mortality due to cardiovascular disease, arrhythmias (heart rhythm disturbances, heart rate variability), blood pressure elevation. (Holguin 2003, Ruidavets 2005, Urch 2005, von Klot 2005, Rich 2006, Zhang 2006, Ballester 2006, Sarnat 2006, Larrieu 2007, Peel 2007, Park 2008)
- **Genotoxicity:** Damage to chromosomes and DNA. (Pacini 2003, Tovalin 2006)
- **Fetal and neonatal health:** Preterm birth, low birth weight, hospitalization of newborns, and respiratory illness in infants born to asthmatic mothers who were exposed to ozone during pregnancy. (Dales 2006, Hansen 2006, Triche 2006, Salam 2005)

Particulate matter:

Health effects may vary somewhat by the size of particles. Recent data demonstrates that while particles with diameters ≤ 10 microns (PM10) pose health risks, particles with diameters ≤ 2.5 microns (PM2.5) and particles with diameters ≤ 1 micron (ultrafine particles) contribute disproportionately to human health risks. Due to their small size and large surface area, these smaller particles are carried deeper into the lungs when inhaled, and are capable of carrying toxic pollutants to the lung and elsewhere in the body as they enter the bloodstream. Both stationary (e.g. industrial sources) as well as mobile sources (e.g. fossil fuel combustion emissions from vehicles and traffic density) of particulate matter contribute to risk. Traffic density has, in particular, been confirmed now in multiple studies to confer additional risk, especially for respiratory health consequences. Additional research is needed to better determine the components of particulate matter that induce inflammation and disease. The majority of the studies reviewed are relevant in considering how increases in particulate matter from oil and gas exploration activities may affect health outcomes. The data are generally consistent in showing that many of the health risks that are associated with various forms of particulate matter air pollution disproportionately affect susceptible populations including children, the elderly. The body of literature reviewed is sufficient to conclude that with even small increases in airborne particulate matter exposure, human risks increase for the following:

- **Cardiovascular disease:** Including cardiovascular hospital admission, mortality due to cardiovascular disease, premature death from heart disease, cardiac ischemia (reduce blood flow to the heart), arrhythmias (heart rhythm disturbances, heart rate variability), hypercoagulability, atherosclerosis, myocardial infarction (heart attack), blood pressure.
- **Respiratory disease:** Including respiratory disease-related hospital admission, mortality due to respiratory disease, premature death from respiratory disease including lung cancer, worsening of illness in people with lung disorders (e.g. asthma, chronic obstructive pulmonary disease), asthma, bronchiolitis and respiratory infections, reduced lung function (especially in asthmatic children), allergic lung inflammation, allergies, symptoms (e.g. cough).
- **Fetal and neonatal health:** Preterm birth, restricted fetal growth, lower infant term birth weight, and increased neonatal death especially when it is associated with respiratory illness.
- **Childhood illnesses:** Pediatric allergies, ear/nose/throat and respiratory infections early in life, pediatric emergency room visits and pediatric hospital admissions, impaired lung development in children that affects lung function in adulthood, asthma, bronchiolitis, exacerbation of existing asthma and exacerbation of cystic fibrosis.
- **Geriatric illnesses:** Including exacerbation of chronic obstructive pulmonary disease, congestive heart failure, heart conduction disorders, myocardial infarction and coronary artery disease, and diabetes in the elderly.

Summary

Based upon the material reviewed in this section, some conclusions are appropriate:

1. We identified no published studies in the past five years that directly examined the health impact of nitrogen dioxides, sulfur dioxide, particulate matter, or ozone, in the population living and working in the vicinity of oil and gas exploration activities. This is a major gap in the literature and calls for additional research.
2. The absence of studies directly examining the above air pollutants and effects in populations surrounding oil and gas exploration facilities does not mean an absence of risk. The independent and generally consistent body of scientific evidence on these air pollutants that we reviewed provides strong support for the relationship between sulfur dioxide, nitrous oxides, particulate matter, and ozone, and human disease.
3. Based on the available evidence, it is highly likely that as exposures rise, either alone or along with other air pollutants due to exploration sites and associated vehicular traffic, the respiratory health of the surrounding community will be adversely affected.

Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons are a large group (>100) of organic chemicals, which usually exist as a mixture containing two or more compounds. Airborne PAHs are a result of combustion of fossil fuels, tobacco, and other organic materials. Both point source releases and transportation activities to and from the drilling sites contribute PAH loads to the resident and transient populations in the drilling regions. PAHs of concern include: benz[a]anthracene, benzo[b]fluoranthene, benzo[j]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, dibenz[a,h]anthracene, and indeno[1,2,3-c,d]pyrene.

Terms utilized in the search are summarized above. A total of 276 studies recovered. Two-hundred and forty-five studies were eliminated from further review following our criteria for inclusion in this literature review (i.e. published within the past 5 years, English language, human; excluding basic mechanistic studies and excluding review articles unless they are meta-analyses.). A total of 31 published studies were selected for review dealing with PAHs. These citations are collected in Appendix 4.

Among the 31 reviewed papers published between 2003 and 2008, we identified no research studies that examined directly the human health impact of PAHs produced during oil and gas exploration activities; this does not mean however that PAH exposure is not a human health risk.

Environmental exposures

Environmental exposure studies have revealed associations of chronic exposures to PAHs at different levels and alterations of immune responses by causing suppression of T-lymphocyte proliferation and augmentation of NK cell activity. Environmental exposure studies have also revealed that c-PAHs can alter the ability of blood lymphocytes to repair DNA damage and, as a result could potentially lead to effects that are hazardous to human health. (Karakaya, 2004, Cebulska-Wasilewska, 2007). One study measured prenatal exposure to airborne PAHs (low concentration) and birth weight, birth length, and birth head circumference, in two different populations, Krakow, Poland and New York City. The study suggested adverse reproductive effects of relatively low PAH concentrations in both populations. (Choi, 2006)

Occupational Exposures

No data on exposure to PAHs and occupational groups or adjacent populations in the process of exploration or production of oil and gas were recovered. The majority of PAH occupational exposure and effects on human health involve coke oven workers, exposed to PAHs at high concentration and DNA damage in the lymphocytes. Studies suggesting an increased risk of cancer (lung, bladder, skin, and gastrointestinal) in working populations exposed to PAHs are limited due to multiple exposures to carcinogens at work sites. (Wang, 2007, Siwinska, 2007, Chen, 2007, Pavanello, 2007)

Summary

There is very little data available on disease outcomes in non-occupationally exposed human populations. There is a significant gap of research in this area. As findings from this literature review demonstrate, the research in the past five years has been limited. There is some evidence of immune and lymphocyte damage in workers exposed to PAH at high concentrations and very limited evidence of reproductive effects of prenatal exposure to low concentrations of airborne PAHs. Findings from this literature review make it clear that future research is necessary to clarify our understanding of environmental and occupational exposure to PAHs.

Metals

Human activity may release environmental metals, or cause exposure to new metal containing compounds and are thus of concern. Metal exposure can occur through the air, water or soil and can enter the body through the skin, lungs or GI tract. Metals may be essential to life such as Copper(Cu), Iron(I) or Zinc(Zn) or toxic, such as Lead(Pb), Cadmium(Cd) or Arsenic(As). Toxic metals may influence human health by interactions with essential elements. The elderly and children are at a higher risk from metal exposure than the average adult due to developmental and immune factors. We examined the medical literature to identify published research on the human health impact of metals exposure a) specifically in relation to oil and gas exploration activities and b) generally in relation to populations with environmental exposure to toxic metal compounds.

Terms utilized in the search are summarized above. A total of 299 studies were found, including 35 studies related to Arsenic (As), 4 related to Barium(Ba), 23 related to Cadmium (Cd), 67 related to Chromium (Cr), 75 related to lead (Pb), 39 related to Mercury (Hg), 19 related to Selenium (Se) and 37 related to Zinc (Zn). Seventy-five studies were eliminated due to their reporting multiple exposures and thus being identified more than once. One hundred and forty-nine studies were eliminated from further review following our criteria for inclusion in this literature review (i.e. published within the past 5 years, English language, human; excluding basic mechanistic studies and excluding review articles unless they are meta-analyses.). Overall, a total of 75 papers were reviewed. The list of these citations appear in Appendix 5.

This section will initially examine those published studies that directly assess the human health impact of oil and gas exploration and the health risks associated with contact, inhaled or water based exposure to eight metals (As, Ba, Cd, Cr, Pb, Hg, Se and Zn) and those eight metals

in combination with one another. It will also offer an overview of the body of evidence regarding health effects related to metal exposure in the general population. The section will include a set of conclusions based on this literature review.

Among the 75 reviewed papers published between 2003 and 2008, we identified no research studies that directly examined the human health impact of metals exposure related to oil and gas exploration activities.

Notably, numerous epidemiologic and experimental studies have shown generally consistent relationships between metals exposure, either individually or in groups and adverse human health outcomes with individual metals showing distinct human health effects for instance exposure to lead and cognitive function. Much of the work in metals exposure involves industrial exposure to workers but there is a large body of literature involving population exposure to remnant industrial waste, for instance mine tailings and drinking water contamination. Many industrial sources do not create unique exposures to individual metals, rather several metals in combination may be an integral part of the industrial process, for instance tin smelting and exposure to As, Cd, Pb, antimony and polonium-210. The human health risks due to exposure to combined metals exposure versus each individual metal are difficult to assess though exposure to the combination is not likely to be protective. In some cases there is evidence that exposure causes damage to DNA but that that damage is subject to repair. The combination of exposure to more than one metal that causes DNA damage or increases oxidative stress (and thus reduces the body's ability to repair itself) can overwhelm inherent repair mechanisms. In other cases increased levels of a metal, such as Se, are found to be protective when examined in the context of a toxic exposure. For instance, Se may mediate ototoxicity caused by Pb exposure. (Chuang, 2007)

The majority of the studies reviewed are relevant in considering how potential metal exposure associated with oil and gas exploration activities may affect health outcomes. There are some examples of disagreement between investigators when specific exposures overwhelm the body's ability to repair itself, as when exposed to Cr and DNA damage (Paustenbach, 2003), Pb and cancer risk or stunting (Cocco, 2007), (Mahram, 2007), Hg and neurobehavioral changes or increased oxidative stress (Bast-Pettersen, 2005, Belanger, 2006) or Se and sperm motility. (Wirth, 2007) But, the consistent theme of metals exposure is there are known effects at the cellular or DNA level and some of these effects are consistent with neurologic, metabolic, immunologic and reproductive effects in individuals with specific exposures. The disagreement tends to occur when translating these known cellular and individual effects into population effects where the exposures are far more difficult to measure and correlate with health outcomes. This body of literature is sufficient to conclude that environmental exposures to metals are associated with the following;

- **Autoimmune disease:** Including Wegener's granulomatosis.
 - Cr (Albert, 2005)
- **Cancer:** Including all cancers; lung, stomach, oral and pharyngeal cancers.
 - **Pb, As, Cd, Zn;** (Dynerowicz 2005), (Lee, 2005 Apr), **Cd;** (Wang, 2004), (Satarug, 2003) **As** (Jones, 2007), (Lee,2006), (Vitayavirasak,2005), **As, Cd** (Obiri, 2006), **Cr** (Beaumont, 2008), **Se** (Gromadzinska, 2003), **Hg** (Zadnik, 2007)

- **Cardiovascular disease:** Including increased risk of atherosclerosis, hypertension and lipid abnormalities.
 - **Pb;** (Li, 2006), (Skoczynska, 2007), (Ademuyiwa, 2005), **Cd** (Satarug, 2003), **Hg** (Cortes-Maramaba, 2006)
- **Cognitive function:** Including neurobehavioral and cognitive effects, decreased IQ, cerebral white matter changes.
 - **Pb;** (Carta 2003), (Pusapukdepob, 2007), (Schwartz, 2005), (Bleecker, 2007) **As;** (Rosado, 2007), **Hg** (Carta, 2003)
- **Dermatologic toxicity:** Including occupational contact dermatitis
 - **Cr** (Athavale, 2007)
- **Genotoxicity** Damage to chromosomes and DNA
 - **As, Pb:** (Yanez, 2003), **As** (Jasso-Pineda, 2007), (Paiva, 2006), (Palus 2005), **Cr** (Kuo, 2003)
- **Hematology:** Including humeral and cell mediated immunity, altered levels of immunoglobulins and neutrophilic inflammation.
 - **Pb;** (Di Lorenzo 2007), (Heo, 2004), (Mishra, 2003), **Se** (Huang, 2003)
- **Metabolism:** Including reduced antioxidant capacity, increased oxidative stress, altered bone resorption, pancreatic dysfunction and bone fracture
 - **Pb,As;** (Chlebda 2004), **Pb** (Kasperczyk (2004), (Li 2004), (Li, 2006), (Potula, 2005), **Cd** (Lei, 2007), (Satarug, 2003), ↓Zn (Li, 2004)
- **Neurotoxicity:** Including altered heart rate variability, neurodegenerative disorders (multiple, sclerosis, transmissible spongiform encephalopathies and amyotrophic lateral sclerosis), neuromotor impairment, ototoxicity and visual impairment.
 - **Pb** (Gajek, 2004), (Blond, 2007), (Chuang, 2007), (Schwartz, 2005) **Ba** (Purdey, 2004), **Hg** (Despres, 2005), (Rodrigues, 2007), (Saint-Amour, 2006)
- **Renal dysfunction:**
 - **As, Pb** (Weaver, 2003), **Cd** (Lei, 2007), (Nogue, 2004), (Satarug, 2007), **Cr** (Saraswathy, 2007), **Hg** (Hodgson, 2007)
- **Reproduction, fetal health and development:** Including, growth stunting, reproductive impairment, stillbirth, low birth-weight, childhood under-weight and abnormal sperm morphology.
 - **Pb** (Ignasiak 2007), (Naha, 2006), (Shiau, 2004), (Tang, 2003), **Cd;** (Wang, 2004) **As** (Kwok, 2006), (Kumar, 2005)
- **Respiratory disease:** Including mucosal irritation, interstitial pneumonia, asthma.
 - **Pb, Cd** (Coelho 2007), **Cr** (Hisatomi, 2006), (Onizuka, 2006)

Conclusions

1. We identified no published studies in the past five years that directly examined the health impact of exposure to toxic metals in the population living and working in the vicinity of oil and gas exploration activities. This is a major gap and calls for additional research.
2. The absence of studies directly examining oil and gas exploration related exposure to metals in exposed does not mean an absence of risk. The peer reviewed body of scientific literature related to exposure to specific metals and metals in groups in this review indicates strong associations between metals exposure and specific human diseases.

3. There is disagreement in the literature as to specific human outcomes due to specific exposures though much of that disagreement is likely related to difficulties in measuring individual exposure over long time periods. The preponderance of evidence gleaned from well-controlled studies using clear end-points and measuring exposure precisely indicates an increased risk for individuals exposed. This risk is hard to detect on a population basis for the above mentioned reasons.
4. Based on the available evidence, it is likely that continued exposure to bioavailable metals will increase risk of associated adverse outcomes. Whether through inhaled or water based exposure, each of these metals can cause increased risk of many human diseases.
5. Specific populations are at increased risk for specific toxicities. These populations include children, the elderly and anyone already at increased risk due to other health problems.

Hydrogen Sulfide

Hydrogen sulfide (H₂S) gas release to the air occurs in oil and gas drilling and extraction and flaring as well as in many other settings such as industrial, sewage and water maintenance, and agriculture. H₂S also enters the air as off-gas naturally in geothermal areas and when organic matter decays such as in swamps. The health effects of hydrogen sulfide gas exposure in relation to oil and gas drilling has been studied infrequently, despite the fact oil and gas drilling near inhabited areas is common through out the world and hydrogen sulfide gas is frequently produced and released in exploration activities.

Terms utilized in the search are summarized above. A total of 85 studies were recovered. Sixty-five studies were eliminated from further review following our criteria for inclusion in this literature review (i.e. published within the past 5 years, English language, human; excluding basic mechanistic studies and excluding review articles unless they are meta-analyses.). A total of 20 studies were selected for review of hydrogen sulfide exposure, acute and chronic. These citations are collected in Appendix 6.

High Level Exposure

Hydrogen sulfide is known to be fatal at high exposure levels and can cause long term sequelae in those that survive acute high level exposure. Most fatal exposures to H₂S are occupational and occur in a confined space area or when the worker is near the opening of a confined space. There are several case reports describing fatal accidents for workers exposed to H₂S. Furthermore, fatalities in persons attempting to rescue downed workers have also been reported. Persons exposed to high levels of H₂S that did lose consciousness and persons exposed that did not lose consciousness both demonstrated neurobehavioral impairments when compared to controls. (Kilburn 2003; Hendrickson, Chang et al. 2004; Kage, Ikeda et al. 2004; Nam, Kim et al. 2004; Nikkanen and Burns 2004; Smith and Cummins 2004; Couch, Martin et al. 2005; Knight and Presnell 2005; Christia-Lotter, Bartoli et al. 2007; Gangopadhyay and Das 2007; Gerasimon, Bennett et al. 2007; Policastro and Otten 2007; Fiedler, Kipen et al. 2008; Yalamanchili and Smith 2008)

Low Level Exposure

There are very few current studies exploring chronic, low level H₂S exposure in individuals, although there are a few studies from earlier literature not addressed in this review. Current and earlier literature suggests neuropsychological effects in individuals with chronic low level H₂S exposure.

- Depression and hematological changes were reported in people living close to areas polluted by oil and gas drilling in Khozestan province, Iran. (Saadat and Bahaoddini 2004; Saadat, Zendehe-Boodi et al. 2006)
- Oil and gas extraction workers in Canada demonstrated a higher risk of transportation accidents if exposed to H₂S gas. (Lewis, Schnatter et al. 2003)
- Persons in Dakota City, Nebraska were exposed to chronic, low levels of H₂S from waste water lagoons, a beef slaughter/leather tanning factory and other point sources. Individuals reported a variety of symptoms, including loss of memory and loss of grip strength. (Inserra, Phifer et al. 2004)

Communities exposed to chronic low levels of H₂S may experience high hospital admittance for pulmonary disorders in both adults and children.

- Hospitals in Northeast Nebraska reported higher levels of admissions for pulmonary disease, COPD, asthma, pneumonia in both adults and children in days following high levels of Total Reduced Sulfur (TRS) and H₂S air pollution. (Campagna, Kathman et al. 2004)
- The city of Rotorua, New Zealand, lies over a geothermal area. Parts of the city lie directly over vents that off gas H₂S and parts of the City are downwind. Citizens living in these areas have a higher risk of being admitted to the hospital for pulmonary illness than those citizens not living in the high exposure areas of Rotorua. (Durand and Wilson 2006)

Summary

Studies of exposure to H₂S in relation to oil and gas drilling have not been done. The dangers of acute, high level H₂S exposure are well documented. Although there is a small body of literature suggesting adverse health effects due to chronic, low level exposure, significant gaps in this literature remain. Given the potential for increased exposure to H₂S from oil and gas drilling in proximity to human populations across the world, studies examining the health effects of H₂S due to drilling and extraction activities should be planned in the future.

Fossil Fuels

Oil and gas extraction is known to produce multiple toxic contaminants, which may be released to the air, soil or water. Workers involved in oil and gas drilling, extraction, as well as those involved in transportation and refining may be exposed to these chemicals at high levels. Persons living in close proximity to oil and gas extraction sites may also be exposed to toxic levels of chemicals and experience adverse health effects. Available literature regarding the

health effects to persons living and working in close proximity to oil and gas extraction sites demonstrates exposure to the oil and gas extraction process is detrimental to people's health.

Terms utilized in the search are summarized above. A total of 305 studies were recovered. Two-hundred and seventy-nine studies were eliminated from further review following our criteria for inclusion in this literature review (i.e. published within the past 5 years, English language, human; excluding basic mechanistic studies and excluding review articles unless they are meta-analyses.) A total of 26 studies were selected for review, including 3 studies prior to 2003. These citations are collected in Appendix 7.

Oil and Gas Extraction Exposures

- Residence near oil and gas extraction fields is associated with an increased risk of adult myeloid leukemia and all leukemias when compared to residence in a nearby county in Croatia. (Gazdek, Strnad et al. 2007)
- Residence near the Masjid-i-Sulaiman oilfields in southwest of Iran, where subsurface natural gas and hydrogen sulfide emissions are high is associated with abnormal blood cell indices, including increased red blood cells, and decreased white blood cells. (Saadat and Bahaoddini 2004)
- Residence near a Canadian oil sands community was associated with higher autoantibody titers when compared to residents in a distant community. (Schoenroth and Fritzler 2004)

Studies Prior to 2003

While our search was limited to publications of the last 5 years, some important studies done prior to this time and some studies not revealed by our search criteria deserve mention as they directly address the potential health effects of oil and gas extraction on local populations.

A series of studies reveal multiple elevated health risks associated with residence proximity to oil and gas extraction in the Amazon rainforest of Ecuador. Children living at close proximity to oilfields are at higher risk of childhood leukemia. Adults are at an increased risk of many types of cancers including stomach, rectum skin, soft tissue, kidney, cervix and lymph nodes. Residence at close proximity to these oil fields is associated with pregnancy ending in spontaneous abortion.

(San Sebastian, Armstrong et al. 2001; Hurtig and San Sebastian 2002; San Sebastian, Armstrong et al. 2002; Hurtig and San Sebastian 2004; San Sebastian and Hurtig 2004)

Other Fossil Fuel Exposures

Literature regarding the health effects of exposures associated with oil and gas extraction is limited. Petro-chemical complexes and refineries, work at coke ovens, and exposure to coal burning can share many of the same toxic exposures with oil and gas extraction sites. These exposures may include, but may not be limited to, benzene and other solvents, polyaromatic hydrocarbons (PAH), particulate matter, noise, air born sulfur oxides, arsenic, and hydrogen sulfide.

Community Exposures

- Pregnant women in the Labin district, Croatia residing near a power plant burning high sulfur coal are at increased risk of poor birth outcomes. High sulfur dioxide emissions during the first two months of pregnancy are associated with preterm delivery and birth of babies with low birth weight. (Mohorovic 2004)
- Prenatal exposure to toxic chemicals is associated with increased risk of fatal childhood cancers and leukemia. Children born to mothers living within 1 km of areas with high levels of carbon monoxide, PM10 particles, VOCs, nitrogen oxides, benzene, dioxins, 1,3-butadiene, and benz(a)pyrene. (Knox 2005)
- Residence in areas with high levels of outdoor air pollution from coal burning sources is associated with decreased height in children. This study controlled for socioeconomic factors, birth weight and respiratory illness. (Bobak, Richards et al. 2004)
- Incidence rates of wheezing in children living within 3 km of an iron, steel and coke factory in Calarasi, Romania, significantly decreased after the factory closed, from 41% to 24%. The list of known pollutants from the factory is long but contained several pollutants that are known to cause respiratory illness including SOX, NO₂, ozone, and particulates. (Cara, Buntinx et al. 2007)
- Residence in areas near a coke oven factory in Cornigliano district, Italy was associated with lung cancer in females and in both males and females in a part of the district where a foundry was operational. (Parodi, Stagnaro et al. 2005)

Occupational Exposures

- Workers at an oil refining plant in Australia have an increased risk of developing nonlymphocytic leukemia and chronic lymphocytic leukemia, due to benzene exposures. These increased risks are in association with their exposure to benzene at levels lower than previously identified as being hazardous. (Glass, Gray et al. 2003; Glass, Gray et al. 2005)
- Workers at petrochemical complexes have been shown to have high exposure to solvents and excess noise. There is an increased prevalence of hearing loss and standard threshold shift in these settings. (De Barba, Jurkiewicz et al. 2005)
- Acute hydrogen sulfide poisoning has been reported in a field operator at a petroleum refinery. (Nam, Kim et al. 2004)
- Workers at a petro-chemical complex have significant risk of respiratory symptoms (cough, phlegm, wheezing and shortness of breath) when exposed to dusts, vapors, metals and organic solvents. (Park, Lee et al. 2006)

Our literature search revealed some studies that do not find association of oil and gas extraction exposures and health effects. (Lewis, Schnatter et al. 2003; Neuberger, Ward-Smith et al. 2003; Buffler, Kelsh et al. 2004; Neuberger, Lynch et al. 2004; Dubnov, Barchana et al. 2007; Sorahan 2007) These negative studies suggest that potentially hazardous exposures related to oil and gas extraction have no health consequence. On the other hand, these negative results may be due to problematic issues such as lack of statistical power, misclassification of exposure, or other study design issues such as limited disease endpoints. Negative studies should not be taken

independently as proof of no ill effects to exposed populations but rather should be placed into context with all available literature regarding the particular chemical, exposure or the process and the health effects. Chemicals known to be toxic in other scenarios are likely to be toxic at similar exposure levels in different scenarios. When discrepancies exist in the literature, further study is warranted. Furthermore, the most conservative course of action with regard to pollution control measures should be undertaken to protect people's health.

Summary

Oil and gas extraction is increasing world wide. Oil and gas extraction is known to produce toxic contaminants. Oil and gas extraction sites are often near peoples' homes and children's schools, putting individuals and communities at risk of adverse health effects due to exposure to toxic contaminants. Studies documenting health effects of oil and gas extraction on individuals and communities are few and more studies should be done in the future.

Fracking Fluids

"Fracturing" "fracking" or frac'ing is a process used by the oil and gas industry to improve well production. Fracking involves the use of high-pressure injection of liquids and/ or solids into the ground, when a well is drilled and often again one or more times after a well is in production. Fracking fluids may be water or may be any combination of hazardous chemicals such as acids, diesel fuel, biocides, metals ethylene glycol, or other chemicals, but oil and gas companies are not required to reveal the chemical composition of fracking fluids. Fracturing of the subterranean land formations can introduce these unknown but possibly hazardous chemicals into underground drinking water sources, potentially exposing people to toxics and causing adverse health effects. Fracking fluids may also be left at the surface with drilling mud and toxics may dry out and be dispersed in the air or enter surface water via run off. Little is known about the potential and actual exposures local populations may have.

Since fracking chemicals are unknown, review of specific chemical literature could not be conducted. Terms utilized in the search are summarized above. A total of 243 studies were recovered. All studies were eliminated from further review following our criteria for inclusion in this literature review (i.e. published within the past 5 years, English language, human; excluding basic mechanistic studies and excluding review articles unless they are meta-analyses.)

Our literature search (expanded to include all literature regardless of publication date) did not find any studies addressing the health effects of fracturing or fracturing fluids on people, revealing a substantial gap in the medical and public health literature. This gap is especially troubling given the amount of oil and gas extraction occurring world wide in close proximity to human populations. This gap should be addressed. Studies examining the effect of fracturing subterranean land formations on nearby human populations should be conducted. Public disclosure of fracking fluid chemicals would permit studies examining human health effects of these chemicals to be undertaken.

Noise Pollution

We have examined the medical literature to identify published research on the human health impact of noise pollution on the communities surrounding oil and gas development. Specifically in relation to oil and gas exploration activities: drilling, well pumps, compressors, and vehicle traffic.

Terms utilized in the search are summarized above in the methods section of this document. A total of 881 studies were recovered. Eight-hundred and fifty-seven studies were eliminated from further review following our criteria for inclusion in this literature review (i.e. published within the past 5 years, English language, human; excluding basic mechanistic studies and excluding review articles unless they are meta-analyses.). A total of 24 studies were selected for review of noise pollution. These citations are collected in Appendix 8.

Our literature search, expanded to include all literature regardless of publication date, did not find any studies addressing the health effects of noise on communities surrounding oil and gas operations.

Low Frequency Noise

Low frequency noise, produced from oil and gas compressors, may be of concern in the surrounding communities. A small number of studies reported the following symptoms related to low frequency noise: annoyance, stress, irritation, unease, fatigue, headache, adverse visual functions and disturbed sleep. (Berglund, 1999, Pawlaczy-Luszczyniska, 2005)

Traffic related noise

Noise produced from oil and gas activity, also of concern to surrounding communities, has not been studied. Although many papers have been published in the last 5 years suggesting an association of cardiac health effects and noise related to traffic, these studies are restricted to urban settings. The majority of these studies reported annoyance and disturbance due to road traffic noise and associations with a higher incidence of myocardial infarctions, hypertension, ischemic heart disease, and sleep problems. (Babisch, 2003, 2005, Bluhm, 2004, 2007)

Occupational Related Health Effects

Research available on noise and health effects on oil and gas workers is limited. In the last 5 years, only one study has been published in the medical literature describing the health effects of noise among oil and gas workers. The study suggested an increased hearing threshold shift for high frequencies in workers who had chronic noise exposure from more than 15 years. (Chen, 2003) A small number of studies reported findings for workers exposed to noise and chemicals, such as toluene and other solvents (these studies were not specific to the oil and gas industry). Hearing loss was reported in 45.3% of workers from a petrochemical company, where workers had low exposure to solvents, and moderate exposure to noise. (De Barba, 2005) Another study found increased low frequency hearing loss in workers exposed to both noise and the chemical toluene. (Chang, 2006)

Summary

We identified no published studies in the past five years that directly examined the health impact of noise in the population living and working in the vicinity of oil and gas exploration activities. Noise produced from oil and gas operations and the health effects on the surrounding community as well as for workers calls for additional research.

Light Pollution

Light pollution is excess exposure to artificial light and occurs in occupational as well as community settings. Recent studies in the medical literature suggest that light pollution is an emerging public health issue indirectly linked to cancer incidence.

Terms utilized in the search are summarized above. A total of 297 studies were recovered. Two hundred and ninety-one studies were eliminated from further review following our criteria for inclusion in this literature review (i.e. published within the past 5 years, English language, human; excluding basic mechanistic studies and excluding review articles unless they are meta-analyses.). A total of 6 studies were selected for review of light pollution. These citations are collected in appendix 9.

In the last 5 years, no studies have been published in the medical literature describing the health effects of light pollution or light exposure at night among oil and gas workers or the communities surrounding oil and gas extraction activities. However, several studies suggest an increased risk of cancer among shift workers and exposure to light at night:

- The disruption of circadian rhythms caused by exposure to light at night is associated with an increased risk of breast and colon cancer in shift workers
- Light pollution interferes with the pineal gland and production of melatonin as well as hormone production
- Reduced levels of melatonin caused by light pollution are linked to tumor growth
- Exposure to magnetic fields while sleeping leads to decreased levels of melatonin and increased levels of reproductive hormones in women

(Anisimov, 2006, Davis, 2006, Pauley, 2004, Schernhammer, 2004, Schernhammer, 2004, Schernhammer, 2004)

Summary

Further investigation is needed to determine the health impacts of light pollution generated by oil and gas activities in workers and the surrounding communities.

Worker Health

Terms utilized in the search are summarized above. A total of 40 studies were recovered. Thirty-one studies were eliminated from further review following our criteria for inclusion in this

literature review (i.e. published within the past 5 years, English language, human; excluding basic mechanistic studies and excluding review articles unless they are meta-analyses.) A total of 9 studies were selected for review of occupational injuries. It is important to note that this final group of studies includes two articles published prior to 2003. These citations are collected in Appendix 10.

Occupational Fatalities

There are multiple safety and health risks associated with oil and gas extraction activities. In the U.S., fatal and nonfatal occupational injuries and illnesses among oil and gas workers are well documented through the Bureau of Labor Statistics (BLS) Census for Fatal Occupational Injuries (CFOI) and the BLS Survey of Occupational Injuries and Illnesses (SOII). However, only one study in the last 5 years has been published in the medical literature describing occupational fatalities among oil and gas workers in the U.S.: (CDC 2008)

- Oil and gas workers in the U.S. experience a disproportional rate of occupational fatalities compared to other high-risk industries and occupations.
- In the U.S., an increase in oil and gas extraction activities is significantly correlated with an increase in the rate of fatal occupational injuries among oil and gas extraction workers.
- The annual rate of fatal occupational injuries in the U.S. in the oil and gas industry from 2003 to 2006 was 30.5 per 100,000 workers.
- Fatal occupational injuries were attributable to transportation incidents and being stuck by equipment and heavy tools.

International Studies

Studies of international oil and gas workers in the last 5 years describe fatal and nonfatal injuries:

- In the Niger Delta, occupational fatalities in the oil and gas industry were attributable to falls, explosions and fires, transportation incidents, and falling objects. (Seleve-Fubara 2006)
- Venezuelan oil and gas workers were found to have chromosomal alterations due to continuous exposure to low levels of ionizing radiation. (Diaz-Valecillos 2004)

Studies Prior to 2003

We expanded our literature review to include studies conducted prior to 2003 providing evidence of fatal and nonfatal occupational injuries in oil and gas workers:

- About a third of minor injuries among oil and gas extraction workers in Venezuela were attributable to 'not paying attention when walking on or around labor areas'. Common injuries included being struck by equipment and tools, and contusions and crushing of upper and lower arms and legs. (Fernandez 2001)
- In Canada, workers involved in oil and gas drilling and extraction activities are at high risk for occupational injuries. (Guidotti 1995)

- Work-related injuries among international oil workers were higher and more severe than all industries in the US. The most common non-fatal injuries were getting arms ‘caught in’, ‘back strained’, ‘legs struck’, and ‘legs injured while slipping’ (McNabb 1994)
- Types of work-related injuries among international workers in the oil industry include burns, sprains, and hand injuries. (Sarma 2001)
- Workers in the oil and gas industry in the U.S. experienced a high rate of death related to asphyxiation and poisoning. (Suruda 1989)

Conclusion

Further research is needed to determine the health effects of oil and gas operations on workers.

Social and Psychological Health Effects

While some research has explored the physical health effects related to oil and gas exploration activities, less research has focused on the social and psychological impact of oil and gas development on individuals working or living in industrial communities. As such, we have examined the available literature to identify published research about a) the social and psychological impact of oil and gas development in neighboring communities. b) the social and psychological impact of industrial development in neighboring communities.

Terms utilized in the search are summarized above. An initial literature search recovered a total of 1,114 studies that were published within the last 5 years (between 2003 and 2008). Based on our established list of inclusion criteria, 1,093 studies were eliminated from further evaluation. Thus, only 21 studies were retained for this literature review. It is important to note that this final group of studies includes two articles published prior to 2003 and two relevant review articles. The full list of these references can be found in Appendix 11.

The body of literature reviewed provides some evidence that exposure to oil and gas activities can have serious negative social and psychological health implications. Conversely, there is some evidence that such industrial activities may be associated with positive social and psychological health outcomes.

Violence and Crime Rates

Communities near industrial development, including oil and gas development, often undergo swift changes in the existing social and cultural norms. These changes may be, at times, associated with high occurrences of violence and crime while at other times, industrial development has been credited with a perceived decrease in local crime. Additionally, when a new industry is brought into a community, there may be a high demand for new laborers. Often times, these workers are blamed for a rise in criminal deviance. In response to oil development in Louisiana, some local individuals blamed the increase in ‘unskilled laborers’ for the increase in criminal activities. One local individual claimed that, “during the 70s/80s [oil] boom we had lots of low life...police characters...criminals coming in as labor...they had little work history...when the [oil] bust hit they hung around and caused trouble...”. (Forsyth et al., 2007,

p.292) On the other hand, some individuals in these areas believe that oil and gas drilling has helped build and bring their communities closer together, which in turn, has led to a decline in criminal activity. This idea is supported by a resident in Louisiana who stated that “this [community] was all poor white trash until oil came...oil decreased crime...oil and the oil business have caused the cycle of crime to go down”. Rapid sociocultural change in Alaska has been associated with increasing rates of social pathology in native populations. Some of these populations have arrest rates for violent crimes 8 to 15 times higher than the overall national rate. (Wernham, 2007)

Sexual Promiscuity and Associated Diseases

Communities involved in oil and gas extraction activities have experienced high rates of sexually transmitted diseases. For example, oil and gas communities in British Columbia have witnessed a rise in the occurrence of Chlamydia, and several regions in Africa have had increasing rates of HIV/AIDS since the introduction of oil and gas drilling to their communities. (Frynas, 2004; Goldenberg et al., 2007; Jobin, 2003; Udoh et al., 2007) These effects can be mitigated to some degree through intensive environmental and health management planning on the part of the oil companies. In Chad and Cameroon, companies were able to achieve a reduction in the occurrence of some sexually transmitted diseases in their labor forces by requiring contractors to provide health care for workers.

Rates of Suicide

Communities involved in oil and gas exploration may also experience a rise in suicide rates. Whereas the U.S. general population has an average suicide rate of 11 out of every 100,000 individuals, communities on the northern slope in Alaska experience an average suicide rate of 45 out of every 100,000 individuals. This very high suicide rate is thought to be due to rapid sociocultural change in Inuit communities. High suicide rates are also found in communities associated with offshore oil drilling in Louisiana. (Kettl, 1998; Wernham, 2007; Seydlitz et al., 1993)

Mental Health Concerns

Individuals working or living in communities involved in oil and gas exploration often experience greater mental health concerns than individuals who live in areas not involved in these industrial activities. Some researchers report that individuals in these regions have a certain vulnerability to psychological or psychiatric problems. (Lester & Temple, 2006) For example, oil and gas development has been associated with high rates of mental and psychological stress. Furthermore, increasing mental health concerns such as anxiety and depression, have been linked to communities in Wales, India, and the Peruvian Amazon that are involved in oil and gas drilling activities. (Bhatia, 2007; Gallacher et al., 2007; Izquierdo, 2005; Lester & Temple, 2006; Murthy et al., 2005; Wernham, 2007)

Our literature search also revealed a few studies that did not find an association between oil and gas exploration and social and psychological health effects. In particular, two studies found no relationship between industrial activities and crime rates. (Luthra et al., 2007; Seydlitz et al., 1993) Some researchers believe that much of the research depicting a negative or positive relationship between oil and gas exploration and crime is speculative in nature. Because of methodological weaknesses in many studies in this research area, it seems necessary to conduct controlled, empirical research to verify whether a relationship between oil and gas exploration and social and psychological health does truly exist. Consequently, findings from existing research need to be interpreted with caution.

Summary

Overall, there is an apparent lack of research in this area. As findings from this literature review demonstrate, the research in the past five years has been inconsistent, making it difficult to draw definitive conclusions about the psychological and social implications of oil and gas exploration. However, based on the evidence provided, it is probable that oil and gas exploration activities can have serious effects on people's social and psychological health. Despite this possibility, the oil and gas industries have failed to take reasonable steps to protect these families and communities.

Findings from this literature review make it clear that future research is necessary to clarify our understanding of the social and psychological impact of oil and gas drilling on individuals living in and near industrial communities. By better understanding this relationship, we will be able to more effectively intervene and mitigate these potentially severe social and mental health problems.

Conclusions

As discussed in the medical and public health literature review (attached), few studies have been published on the health effects of oil and gas exploration and extraction on communities living and working in the vicinity of these activities. A lack of specific evidence, however, does not negate the fact that oil and gas operations use and produce toxic contaminants that adversely affect human health. Available studies show that exposure to air pollutants, toxic chemicals, metals, radiation, noise and light pollution cause a range of diseases, illnesses, and health problems, including psychological and social disruption. Neighborhoods, schools, and workers in close proximity to oil and gas activities may be at increased risk for cancer, cardiovascular disease, asthma, and other disorders due to uncontrolled or high exposures. Further research is needed to assess the health impact of oil and gas operations on surrounding communities.

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