Public Health Issues Related to Gas and Oil Hydrocarbon Exploration and Production

Environmental Health and Toxicology Branch

Biological Risks and Occupational Health Branch

March 2015

Institut national de santé publique Québec

Summary

On May 30, 2014, the Quebec Minister of Energy and Natural Resources and Minister responsible for the Northern Plan, as well as the Quebec Minister of Sustainable Development, Environment and the Fight Against Climate Change announced the Government Action Plan on Hydrocarbons. With the announcement of this plan, the Government of Quebec expressed its intention to carry out, starting in fall 2014, a comprehensive strategic environmental assessment (SEA) and another SEA specific to Anticosti Island.

The SEAs undertaken aims to provide a review of current knowledge and to determine what additional knowledge needs to be acquired regarding the potential repercussions of gas and oil hydrocarbon production on the environment, health and public safety, as well as community sustainable development. Specifically, the environmental, social, economic and public safety issues related to hydrocarbon exploration and production in the marine and terrestrial environments, as well as the issues related to transporting these resources, are considered.

As part of the work carried out under the *Human Health and Safety* component of the SEA working group on health and societal impacts (*Society* working group), the Institut national de santé publique du Québec (Quebec National Public Health Institute [INSPQ]) was given the mandate to document the issues and potential effects on public health related to the exploration and production of gas and oil hydrocarbons. A number of scientific teams from this organization helped carry out this mandate with the following objectives:

1. Draw up a knowledge profile on potential risks for human health (general population and workers) related to gas and oil hydrocarbon exploration and production in the marine and terrestrial environments.
2. Determine the additional knowledge required on public health and hydrocarbon exploration and production activities.
3. Propose prevention and management options regarding the health risks that the public might be exposed to in relation to hydrocarbon exploration and production in Quebec.

This report presents, in relation to oil hydrocarbons, the main issues with respect to population and workers' health. This analysis is based on the scientific knowledge obtained through a review of relevant scientific literature found using different documentary research strategies. In order to take into account public health issues related to exposure to gas hydrocarbons, the main findings from the INSPQ's publication called *État des connaissances sur la relation entre les activités liées au gaz de schiste et la santé publique – Mise à jour [state of knowledge on the relationship between shale gas activities and public health – update] (*Brisson et al., 2013) were invoked. The state of knowledge enabled us to determine the different types of knowledge that need to be acquired to support decision making. Furthermore, in the perspective of preventing and managing risks for public health, possible options are proposed.

Issues related to population health

The preliminary findings established based on the documentary analysis and the needs in terms of the knowledge that must be acquired are presented under the angle of ground and surface water (1), soil and sediments (2), ambient air (3) as well as under the angle of public health emergencies (4).

IMPACTS OF WATER CONTAMINATON (GROUND AND SURFACE) ON POPULATION HEALTH

1. Preliminary findings

The studies examined mainly described population exposure to crude oil as well as petroleum products following accidental events that have occurred particularly in the marine coastal environments. The nature of the contaminants that may represent a threat for human health (light and heavy hydrocarbons, metals and radionuclides) is variable and is specific to the context of each accidental event. Accidental events that are likely to cause contamination to the coastal and continental water, through crude oil and petroleum products, are, for example, vessel sinking or grounding, loading or unloading vessels at the wharf, oil pipelines rupturing or cracking, train derailments as well as spills and operational discharges following drilling operations.

Regular operations associated with hydrocarbon exploration and production, including drilling wells and oil extraction, can also be associated with potential exposure of the public to contaminants. More specifically with the fracturing technology, drilling fluids (sludge) as well as well stimulation liquids and flowback fluids (brine) may constitute a risk of exposure by members of the public if they come into contact with water destined for human consumption, including through extraction wells themselves or through migration pathways in geological media concerned. However, this finding is extrapolated from information on shale gas extraction, since this information is not currently available for shale oil extraction (or the equivalent) through fracturing or hydraulic stimulation.

Different exposure pathways to hydrocarbons and petroleum products were identified in the studies examined, including inhalation and skin contact. The studies consulted enabled experts to catalogue clinical manifestations that occurred following direct exposure to oil or hydrocarbon-contaminated water. The noted symptoms include mostly headaches, dizziness, nausea, vomiting, skin, eyes and mucous membranes (mostly of the nose and throat) irritation as well as respiratory problems (mainly difficulty breathing and coughing). Clinical manifestations identified are characterized as acute, since they are observed in the hours or days following exposure and they are generally reversible. The seriousness and duration of the health impacts seem to be related to the type and extent of exposure. Therefore, more significant clinical manifestations were noted among volunteers and workers who helped clean the shoreline after an oil spill at sea (sinking of an oil tanker) compared to less significant manifestations observed among people who live close to contaminated sites and who did not participate in such remediation activities.

It is important to point out that, none of the studies consulted looked at the long-term follow-up of people exposed to crude oil. Consequently, it is not possible to describe the possible chronic or sub-chronic health effects of crude oil exposure. However, it should be specified that a few studies conducted with biomarkers among people exposed to crude oil showed the presence of enzymatic and cellular abnormalities or chromosomal mutations, which shows possible long-term effects. However, these observations cannot be extrapolated since they were based only on one population located near a specific shipwreck.

2. Knowledge to be acquired

- The main aspect to be documented is the potential for the public to be exposed to crude oil through drinking water obtained from groundwater sources. In fact, the studied literature is silent on the presence of traces of crude oil in the groundwater and the effects on this oil on health.
- The public’s exposure to the fluids used or resulting from the application of well stimulation techniques or hydraulic fracturing is not specified in the literature in the context of oil production. It is the same for possible health effects among populations that are exposed to groundwater that could be contaminated by these fluids flowing from areas that are used for oil production, through well stimulation techniques or hydraulic fracturing techniques.

- Health effects as a result of exposure to dispersants used for clean-up after marine oil spills were briefly described in this document based on one literature review. A more comprehensive review of the literature on health risks associated with exposure to such products could be carried out at a later date.
- Finally, the health effects of ingesting seafood (specifically benthic marine organisms) contaminated by oil products have not been documented in this study, since this aspect was not part of the initial mandate. This issue could be the subject of a literature review at a later date.

IMPACTS OF SOIL AND SEDIMENT CONTAMINATION ON POPULATION HEALTH

1. Preliminary findings

The studies reviewed show that soil contamination may occur during regular hydrocarbon exploration and production operations (e.g., inadequate disposal of drilling waste and wastewater; deposit of contaminants emitted by the flaring procedure). However, soil contamination is mainly caused by major or minor accidental spills or by industrial activities after the facilities are abandoned.

Different scenarios should be considered regarding the population's exposure to soil contaminated by oil hydrocarbons. Contaminated soil dust and particles, carried by the wind outside of the contaminated sites, may be a source of exposure for neighbouring populations through inhalation of particles in the air, skin contact with particles or through ingesting these particles, particularly in young children. The underground migration of oil contaminants may contribute to exposure of the population to these contaminants. For example, volatile substances emitted by oil (e.g., BTEX, volatile organic compounds [VOCs], including benzene, toluene, ethylbenzene and xylenes) that have migrated to inhabited areas could infiltrate homes and be inhaled by their occupants. This migration to inhabited sites where gardening activities are carried out could lead to an accumulation of contaminants in the vegetable garden plants that are subsequently consumed by inhabitants.

In a marine environment, sediment in the perimeter of drilling sites may be contaminated with the same products as those used during drilling activities on land either due to leaks from the drilling wells themselves or due to dumping at sea, by oil rigs, of sludge used as lubricant during drilling activities. In this case, dumped sludge can disperse and contaminate the marine sediment over areas that are likely to be much greater than the immediate area of influence of drilling sites. Contamination of the food chain (the fauna in the seabed or in surface aquatic environments in areas where intense oil activities on land are carried out) could also be a source of exposure of the population to oil contaminants. This would naturally occur where these marine organisms are for human consumption.

With regard to health impacts associated with soil contamination, it is important to point out that the data in the consulted studies does not allow for the health impacts resulting from oil exploration and production to be distinguished from those resulting from soil contamination as a result of other oil-related industrial activities (e.g., petrochemical transformation). In this context, the health impacts correspond to those generally related to the substances in question in these activities (mainly BTEX, polycyclic aromatic hydrocarbons [PAHs] and certain metals, particularly cadmium) and are not specific to types of activities or events (in this case exploration and production) that led to soil contamination. It should also be specified that the oil extraction activity, particularly on land, may result in increased radionuclide concentration in surface soil in the drilling area. Moreover, the literature reports an increase in radon emissions (^{222}Rn) in the air near drilling sites.

2. Knowledge to be acquired

The production of rigorous risk assessments requires a characterization of background concentrations of relevant contaminants in soil and sediment in the Quebec environments where industrial exploration and

production activities take place.

A comprehensive assessment of the impact on human health following development of the oil exploration and production sector in Quebec would require:

- documenting and characterizing sources of soil and sediment pollution in local or regional environments used for these activities in accordance with the oil exploration and production development scenarios planned for Quebec; and
- obtaining an exhaustive (full) list of chemicals, and their respective quantities that are planned to be used during the activities carried out in Quebec that are related to gas and oil hydrocarbon exploration and production.

The quantitative risk assessment requires using data that describes the environmental concentrations in areas where the population lives. Therefore, it will be necessary to obtain such data that is applicable to the Quebec context. The data taken in the field (e.g., Anticosti, Gaspésie) or modelled data should be used.

IMPACTS OF CONTAMINATION IN THE AMBIANT AIR ON POPULATION HEALTH

1. Preliminary findings

The main pollutants emitted through hydrocarbon exploration and production activities are fine particles ($PM_{2.5}$, whose median diameter is < 2.5 µm), Nitrogen Oxides (NO_x) and Sulphur Oxides (SO_x) and VOCs such as benzene, toluene, xylenes, ethylbenzene and aldehydes.

Fuel combustion when equipment (pumps and compressors) is used for drilling and transporting gas and oil via pipelines contributes to NO_x, $PM_{2.5}$ and VOC emissions. Truck and vessel traffic is associated with NO_x, SO_x, $PM_{2.5}$ and VOC emissions. Motor vehicles generate road dust when the roads are not paved. Gas flaring contributes to VOC and NO_x emissions.

Emissions vary according to the type of extraction (oil or gas, conventional extraction or not), but very little information exists on this topic. Non-conventional extraction would emit more contaminants to produce the same amount of hydrocarbons, given the use and dumping of greater amounts of water and the drilling of a greater number of wells.

Emissions from hydrocarbon exploration and production activities may therefore contribute to increased pollutant concentrations in ambient air (NO_x, SO_x, $PM_{2.5}$ and VOCs), particularly close to exploration and production sites, and contribute to increasing exposure of local populations to these pollutants. However, there is very little information on population exposure related to hydrocarbon exploration and production. Generally speaking, exposure varies based on the distance between the populations and the sites, the activity intensity and other specific conditions (e.g., topography). A study would report, near the unconventional hydrocarbon exploration and production sites, that the levels of benzene, formaldehyde and hydrogen sulphide often exceed reference values.

Pollutants produced during hydrocarbon exploration and production activities are associated with cardio-respiratory effects and cancers. Very few studies on people who live near hydrocarbon exploration and production sites have been published and those that have been carried out have limitations. Recently, two studies were carried out among populations that live near these sites. The first one suggests a link between congenital heart defects and well density/proximity and the second does not present any differences in cancer rates among children before and after hydraulic fracturing.

In conclusion, there is very little information on the levels of exposure of populations to NO_x, SO_x, $PM_{2,5}$ and VOCs before, during and after drilling activities. Studies on the health effects associated with

exposure to pollutants in the air near hydrocarbon exploration and production sites are also practically non-existent.

Despite the low number of studies, the health risks associated with exposure to air pollutants emitted during hydrocarbon exploration and production in Quebec may be assessed using epidemiological studies published regarding the effects of air pollutants on health that are carried out in urban environments. However, exposure estimates must be obtained during exploration and production periods in Quebec in order to be able to carry out such a risk assessment.

2. Knowledge to be acquired

The data required to estimate population exposure and health risks associated with hydrocarbon exploration and production in Quebec is not available.

Given the simultaneous presence of a number of compounds during hydrocarbon exploration and production activities, approaches to take into account the cumulative effect of all of the compounds emitted in the air will need to be developed to estimate the cumulative health risks (or health impacts) from this mixture of pollutants.

EFFECTS ON POPULATION HEALTH OF EMERGENCIES RELATED TO OIL HYDROCARBON EXPLORATION AND PRODUCTION

1. Preliminary findings

Analysis of different papers selected to document accidents that may occur as well as their potential effects on population health helped identify the populations that are most at risk of exposure, potential accidental incidents and their main characteristics, as well as the potential or real acute effects of these accidents on the health of the affected population.

In the consulted documents, it is mentioned that in the case of accidental spills and oil hydrocarbon and chemical spills, workers, the shoreline population and first responders are the people who are most at risk of suffering potential serious repercussions of exposure of which the health effects are not well documented.

Moreover, different accidental incidents may occur during oil hydrocarbon exploration and production activities: explosions, fires, leaks and spills. These events lead to environmental contamination (water, ambient air, soil and sediment) by crude oil and other chemicals (e.g., chemicals used and dumped during hydraulic fracturing, emitted during a fire).

At fixed sites, most of the spills identified occurred in port facilities. Others, generally smaller spills, occurred during switching activities in rail facilities.

Major spills occurred on offshore rigs where the risks of fire and explosions as well as structure breakdown are relatively high (both from the point of view of frequency and significance of repercussions) and where safety management is made more complicated because of the involvement of a large number of specialized subcontractors. Major spills may also involve oil tankers, bulk carriers and barges during groundings and collisions as well as train derailments.

Regardless of the mode of transportation used (roads, rail, marine, pipeline), accidents related to hazardous materials, including oil, occur two times more often during loading and unloading activities at transportation facilities than during transportation itself.

Finally, the contributing factors identified during accident investigations frequently includes an

inadequate culture of safety in the company, ineffective risk management, inadequate worker training, poor equipment maintenance and inefficient monitoring by the agencies responsible for the different regulations.

In terms of the acute effects of these accidents on population health, it appears that in addition to deaths during fires and explosions involving hydrocarbons, the population in proximity would be exposed to emissions from toxic products from not only the oil itself (oil hydrocarbons, benzene, toluene, ethylbenzene, xylenes and hydrogen sulphide), but also dispersants used during and contaminants resulting from fires (PAHs, dioxins and furanes). Few studies have been conducted on the acute effects of these contaminants on the population, because relatively few spills have occurred near densely populated areas.

The three possible means of exposure to toxic products during an accident (fire, explosion, leak and spill) are inhalation, ingestion and skin absorption. The effects depend on the type of product spilled and the duration of exposure. The possible symptoms, studied mainly among riverside populations, include headaches; eye, throat, skin and respiratory tract irritation; irritability, fever, fatigue, nausea and vomiting. It seems that most of these symptoms disappear in less than a week in people who do not take part in clean-up work. Recently, hematological, liver, renal, respiratory abnormalities as well as certain neurological abnormalities were also noted among exposed populations and workers. Psychosocial effects predominate and last for a long period among people exposed to these types of toxic products and within the affected communities.

Finally, although some petroleum product compounds are recognized carcinogens, since the duration of exposure is generally short, the probability of such effects remains low in the context of accidents and acute exposure.

2. Knowledge to be acquired

The assessment and management of potential health impacts related to oil exploration and production must take into account potential exposure of the population to hazardous material that is stored and transported as part of oil industry operations. In this regard, a number of aspects concerning risks for health during emergencies related to oil exploration and production still need to be documented through or by the businesses (dealing with handling, storage and transportation of hazardous material) and the responsible government authorities, including:

1. In terms of the presence and nature of hazardous material in a given area and population exposure to hazardous material handled, stored and transported in this area:
    - obtain a comprehensive list of hazardous material and the quantities that will be handled (particularly during loading and unloading activities at transshipment sites), stored and transported;
    - find out the volume and duration of activities;
    - locate the main storage facilities (fixed sites) and transportation facilities (road, rail, port, pipeline);
    - characterize human populations likely to be exposed;
    - document the distance between the populations likely to be exposed and the exploration and production sites, the hazardous material storage sites and the transportation facilities (including roads);
    - collect information from carriers on the routes used; and
    - obtain contingency plans and find out the actual capacity of small municipalities to implement them.

2. With regard to accidental events and their potential impacts on human health:

- document the probability of the occurrence of accidental events;
- gather descriptive data or investigation reports on past accidental events (frequency, types, exposure circumstances, main health effects to be assessed, etc.);
- obtain data on the main accident scenarios (modelling, etc.); and
- document the main potential impacts of accidental events involving hazardous material on the environment and human health, specifically through a literature review.

3. With regard to the management of risks related to accidental events:

- conduct an analysis of current statutes, regulations and standards related to emergencies and disasters;
- conduct a literature review on the assessment of the application of different risk management options and on their capacity to reduce risks; and
- conduct a literature review on the communication and perception of risks of accidents and risks for health.

Issues related to workers' health

PRELIMINARY FINDINGS

The literature consulted brings to light a number of risk factors related to the health of oil industry workers in the marine production environment and in the terrestrial production environment.

The risks to which workers in this industry may be exposed include chemical risks (e.g., VOCs, chemical compounds of drilling fluids and sludge, crystalline silica, hydrogen sulphide, diesel particulate matter), physical risks (e.g., intense noise, vibrations, radiation, extreme temperatures) biological (e.g., Legionnaires' disease), ergonomic risks (e.g., handling, work postures), psychosocial risks (e.g., variable work schedules, night work, remoteness) as well as safety risks (e.g., vehicle accidents, explosions, fires, falls from heights, contact injuries, insufficient lighting, confined spaces). These risk factors have been associated with various health effects (even irreversible effects) whose nature and seriousness depend on the source of exposure and work conditions.

In a marine environment, more than 90% of chemicals found on oil rigs in high sea are used as drilling fluids. These fluids, complex mixes that vary depending on the drilling conditions, are associated with various health effects such as irritation, inflammation and dermatitis. Moreover, some studies consulted show chronic effects on the health of marine oil industry workers, specifically excess cases of cancer.

On land, the hydrocarbon extraction procedure through hydraulic fracturing is relatively new. There is therefore very little data on the characterization of toxicological risks associated with this procedure, and no epidemiological study has been published regarding the long-term effects on the health of workers in this sector. However, according to the results of studies carried out by the National Institute for Occupational Safety and Health (NIOSH), exposure to crystalline silica, used as a proppant in fracturing fluids, is a major risk for workers' health, since the exposure levels observed during these extraction activities are often higher than the regulated or recommended exposure limits in the United States. Moreover, studies have identified other potential risks associated with hydraulic fracturing processes, including the risk of exposure to different chemical compounds of fracturing and flowback fluids.

Finally, it should be specified that workers in the oil industry in general have a high mortality rate. In this

regard, the literature reports that, for the period between 2005 and 2009, the mortality rate of oil industry workers in the United States was two and a half times higher than that of construction industry workers, and seven times higher than that of all industrial sector workers combined. Vehicle accidents during the transportation of hydrocarbons and being hit by objects are the main causes of death. Paradoxically, the rate of injury or trauma in the oil industry is lower than that of the construction industry, which could be attributed to underreporting.

KNOWLEDGE TO BE ACQUIRED

As the occupational health and safety approach used on rigs in marine environments is focused mainly on risks to safety and emergency response, there is little published data on the potential long-term health risks for workers in the oil extraction industry in the marine environment. It is also necessary to:

- draw up a comprehensive inventory of products used in the drilling fluids in Quebec and to better characterize and monitor occupational exposure to these products.

With respect to unconventional oil production on land, it is necessary to:

- characterize occupational exposure during hydrocarbon extraction through horizontal hydraulic fracturing; and
- further document the long-term effects observed among this sector's workers through an approach based on monitoring health risks and the resulting occupational illnesses.

Findings related to population health and activities associated with gas hydrocarbon exploration and production

The profile of the main issues related to general population health (excluding gas industry workers), in relation to gas hydrocarbons, was illustrated based on the summary of the most recent INSPQ publication on the topic entitled *État des connaissances sur la relation entre les activités liées au gaz de schiste et la santé publique – Mise à jour [state of knowledge on the relationship between shale gas activities and public health – update]* (Brisson et al., 2013). The main findings laid out in this publication are described in this report at the request of the coordinators of the *Society* working group of the comprehensive SEA on hydrocarbons.

TECHNOLOGICAL RISKS

- Explosions, fires, leaks and hazardous material spills are the main types of accidental events related to shale gas exploration and production activities that are likely to threaten population health. Such events were reported in the United States and Canada.
- Accidental events can occur throughout the exploration and production process of this resource:
    - at the production site (e.g., during drilling, well construction and maintenance; hydraulic fracturing and collection and processing of captured natural gas);
    - during the transportation of hazardous material (e.g., to drilling, processing or storage sites; transportation by pipeline); and
    - during natural gas storage.
- Most accidents throughout the gas exploration and production process are associated with human error, negligence, equipment failure and unfinished drilling wells. Natural risks (e.g., tornados, lightning, storms, flooding and forest fires) may cause or aggravate accidental events resulting from shale gas production activities.
- During chemical spills and leaks, workers, neighbouring population (of the production site or

transportation systems) and the first responders are the most at risk for suffering serious consequences. The repercussions on people's health vary depending on the context and the seriousness of the accidental event in question.

- The transportation of hazardous materials involves risks specific to the different transportation steps (loading, transport and unloading).

The documents reviewed showed findings regarding the management of these risks:

- Strengthened guidance of the industry and stricter legislation seem to be effective ways of reducing the frequency of environmental events.
- Emergency measures and monitoring are aspects of risk management to be considered closely; one of the challenges is fostering cooperation between the gas industry and the main public agencies involved.

The findings from the literature consulted show that knowledge of the nature, quantities and procedures for handling and transporting chemicals used by the gas industry is still incomplete. Because of this lack of knowledge, it is not possible to assess the potential level of exposure to these substances of workers or for the neighbouring population and to do the risk assessment.

RISKS RELATED TO AIR POLLUTION

Exposure to air pollutants is associated with a number of health effects, specifically cardio-respiratory effects. The documentation consulted showed the following:

- A number of models and measures implemented since 2010, near sites where shale gas-related activities take place, have indicated local increases in concentrations of certain air pollutants, particularly increases in fine particles of ozone and gases that are precursors to the formation of ozone (namely VOCs).
- Very few studies have looked at the health risks associated with exposure to air pollutants emitted during shale gas exploration and production activities. A few assessments estimate that the risks are greater for people living near wells (e.g., < 1 km) or in the US counties where the activities are the most concentrated.

From the perspective of risk management, the scientific literature reviewed and standard practices related to health risk assessment suggest that approaches to estimate the health risks, specifically with regard to the cumulative effect of compounds emitted in the air and air pollutant measurements taken prior to any exploration activities. Moreover, the risk management principles applied to public health (Ricard, 2003) lead us to believe that the risk would be better managed by taking account of separation distances between the shale gas exploration and production sites and inhabited areas.

Finally, the findings from the documentation consulted show that the indirect health effects associated with greenhouse gases emitted during shale gas exploration and production activities need to taken into account to document the risks in a consistent manner based on the public health practices.

RISKS RELATED TO WATER CONTAMINATION

The documentation consulted shows that the possibilities of groundwater contamination are real, such as:

- Contamination occurs after an accident, for example, during a technical failure during fracturing, which leads to sludge and fracturing products to be dumped; during a gas leak due to a failure in the avenues of extraction and during regular shale gas extraction operations.
- It was shown that gas wells with compromised tightness and structural integrity (e.g., faulty casing and cementing of the well) were the cause of contamination cases which occurred in normal operating

conditions.

- A controversial hypothesis suggests that the accelerated migration of contaminants in the bedrock to the surface through faults or cracks was caused or accentuated through hydraulic fracturing. However, this hypothesis remains to be confirmed or disproved by new research. If it is confirmed, the risk of water table contamination would remain, even if permanent technical solutions were to be applied to the leakage problems.

Finally, the INSPQ literature review (as well as that of 2010 and that of 2013) shows that there are still areas where knowledge needs to be acquired (Brisson et al., 2010, 2013).

RISKS OF EFFECTS ON QUALITY OF LIFE

Activities related to shale gas exploration and production are likely to have impacts on quality of life and on social and psychological health, specifically on:

- Increased traffic, noise, intense light and vibrations caused by these industrial activities create nuisances for the neighbouring population, particularly among residents who live near the drilling site or one of the roads used by workers.
- The boomtown phenomenon (rapid increase in the population and arrival of newcomers to a community or region) has been observed many times in shale gas-producing communities in the United States. This phenomenon brings with it socio-economic, cultural and psychological effects. These impacts vary according to the profile of the host community, the existing infrastructure and services, and the preparedness of the authorities.
- A housing shortage, increased price of goods and services and increased tension and conflict have been observed in a number of cases studied.
- Among some people, the nuisances and social effects have caused, in turn, stress, anxiety and anguish and have raised feelings of loss of trust and loss of control.

The results of the literature consulted lead us to reflect, specifically when it is appropriate to investigate and characterize each population concerned. Based on standard practices in impact assessment, carrying out these activities before an industry arrives in a region usually allows for some of these social and psychological effects to be prevented.

Options for managing the risks for the health of the population and workers related to hydrocarbon exploration and production activities

The documentation consulted as part of this mandate suggests that regular hydrocarbon exploration or production activities, especially accidents may present potential risks for human health. In this context, it is important that the responsible stakeholders, specifically government authorities and businesses, ensure that different risk management options are implemented to protect population health. In this regard, in each of the thematic sections, some more specific potential solutions are presented in order to contribute to preventing and managing risks for population health, including the health of workers. Readers are encouraged to refer to this for more detailed descriptions.

The possible solutions are based, among other things, on the guiding principles of the public health risk management approach (Ricard, 2003), namely: appropriation of powers by individuals and the community, equity in the communities and openness allow for interested and affected parties to participate, the predominance of protecting human health, prudency, scientific rigour as well as transparency with interested and affected parties. Based on evolving knowledge, over time, these risk management options could be tailored or updated.

Finally, among the different risk management options proposed in the different chapters of this report, some are common to environmental health and occupational health. They can be grouped as follows:

- Document and measure the parameters before any operations begin (e.g., characterization of background concentrations of the relevant contaminants).
- Document in detail the risks related to procedures, work methods and products used during hydrocarbon extraction activities and take the cumulative effects of these risks into account.
- Look for existing supporting legislation, and if applicable, introduce new regulations to guide activities related to this industry.
- Look for supporting reference frameworks on prevention and response to accidental spills.
- Establish prevention and protection measures to limit the risks to the health of the population and workers during regular activities and during accidents.
- Facilitate collaboration, specifically through an integrated approach and management of the land.
- Promote collaboration between the industry and the university communities to find solutions.
- Provide for a system to monitor accidents and health effects (including occupational illnesses) to improve prevention and follow-up.
- Monitor developments in scientific research and new knowledge, specifically in relation to public health issues related to gas and oil exploration and production activities.

9 Conclusion

The development of the gas and oil hydrocarbon industry in Quebec is raising some concern regarding the impacts related to the exploration and production of these resources on the environment, health and public safety as well as on the sustainable development of the affected communities. The mandate on population health and safety given to the INSPQ is part of the field work of the *Society* component of the comprehensive SEA on hydrocarbons.

It should be noted that by soliciting the expertise of the INSPQ, the people responsible for SEAs are ensuring that public health issues are taken into account in the acquisition of knowledge on the hydrocarbon exploration and production activities. This mandate is consistent with the INSPQ mission, which is to advance knowledge and propose strategies and intersectoral action to protect and improve population health and well-being.

The main purpose of the scientific approach used by the INSPQ was to document the public health issues related to hydrocarbon exploration and production. The knowledge profile produced helped identify potential impacts on the health of the population and workers, and to establish a list of different types of knowledge that need to be acquired to support effective decision-making. Also, in a perspective of preventing and managing risks for public health, potential solutions are suggested.

9.1 Issues related to population health

9.1.1 IMPACTS OF WATER CONTAMINATION (GROUNDWATER AND SURFACE) ON POPULATION HEALTH

9.1.1.1 Preliminary findings

- Events that are most likely to lead to population exposure to crude oil through water are mainly associated with accidental events, such as a pipeline bursting or cracking, oil spilling from a ship or loading dock, rail cars derailing, or contaminants being dispersed after drilling operations.
- Exposure to crude oil through contaminated water leads to a certain number of clinical manifestations that are discussed in the scientific literature consulted: headaches; skin, eyes and mucous membranes (mainly of the nose and throat) irritation; as well as a variety of respiratory problems (mainly breathing problems and coughing). These effects are characterized as acute, because they are observed in the hours or days following exposure and are generally reversible.
- The drilling fluids (sludge) as well as the well stimulation fluids and flowback fluids (brine) may constitute a risk of population exposure if the public comes into contact with water for human consumption, specifically through the extraction wells themselves or through the avenues of migration within the geological media in question. However, this finding is based on the information on hydraulic fracturing operations that extract gas from shale, since this type of information is not currently available or published for extracting oil from shale (or the equivalent) through fracturing.

- In fact, since the population studies consulted do not look at long-term follow-up of exposed people, it is currently not possible to draw a profile of the potential chronic effects associated with exposure to oil. However, it is important to specify that a few studies conducted based on biomarkers among people exposed to crude oil have shown the presence of enzymatic and cellular abnormalities or chromosomal mutations, which show the potential long-term health effects. Although crude oil, as a whole, is not considered carcinogenic, some compounds emitted during refining or fracturing are recognized as being carcinogenic in animals or humans. However, this effect manifests itself when the people are exposed to certain concentrations of these substances (especially if they are in their pure state), but this cannot be transposed as is to crude oil because the concentration of these substances remains variable. Consequently, such effects cannot be excluded, even though it is impossible to quantify them without gathering precise data on exposure and concentration of these substances in a

context of population exposure.

9.1.1.2 Knowledge to be acquired

- The main aspect to be documented is the potential for the public to be exposed to crude oil through drinking water obtained groundwater sources. In fact, the studied literature is silent on the presence of traces of crude oil in the groundwater and the effects of this oil on health.
- The public's exposure to the fluids used or resulting from the application of well stimulation techniques or hydraulic fracturing is not specified in the literature in the context of oil production. It is the same for possible health effects among populations that are exposed to groundwater that could be contaminated by these fluids flowing from areas that are used for oil production, through well stimulation techniques or hydraulic fracturing techniques.
- Health effects as a result of exposure to dispersants used for clean-up after marine oil spills were briefly described in this document based on one literature review. A more comprehensive review of the literature on health risks associated with exposure to such products could be carried out at a later date.
- Finally, the health effects of ingesting seafood (specifically benthic marine organisms) contaminated by oil products have not been documented in this study, since this aspect was not part of the initial mandate. This issue could be the subject of a literature review at a later date.

9.1.2 IMPACTS OF SOIL AND SEDIMENT CONTAMINATION ON POPULATION HEALTH

9.1.2.1 Preliminary findings

- No full assessment of population exposure and the resulting health risks has been carried out in a context similar to that of Quebec in relation to the implementation of oil and gas exploration and production activities in marine or terrestrial environments.
- The data available in the literature does not allow for the impacts on health related to soil contamination resulting from oil exploration and production to be distinguished from the impacts related to soil contamination resulting from other industrial activities, such as petrochemical transformation, or after contaminated sites are abandoned.
- Soil contamination during these activities is mainly caused by accidental spills, major or minor, or by industrial activities after facilities are abandoned.
- In a marine environment, sediment at the perimeter of drilling sites may be contaminated by the same products as those used for drilling on land, regardless of why the drilling wells leak or because of dumping in the sea, by oil rigs, sludge used as lubricant during drilling activities.
- Contamination of the food chain through benthic fauna living in sediment and in the seabed is mentioned in the literature as a vector of contamination to the extent where marine organisms are consumed by humans.
- Contaminated soil dust and particles carried by the wind outside of contaminated sites may be a source of exposure for neighbouring populations through inhalation of carried particles, skin contact or ingestion, particularly in young children.
- Oil extraction, particularly on land, may lead to an increased concentration of radionuclides in surface soil.

9.1.2.2 Knowledge to be acquired

The production of rigorous risk assessments requires a characterization of background concentrations of relevant contaminants in soil and sediment in the Quebec environments where industrial exploration and production activities take place.

A comprehensive assessment of the impact on human health following development of the oil exploration and production sector in Quebec would require:

- Documenting and characterizing sources of soil and sediment pollution in local or regional environments used for these activities in accordance with the oil exploration and production development scenarios planned for Quebec.
- Obtaining an exhaustive (full) list of chemicals, and their respective quantities, that are planned to be used during the activities carried out in Quebec that are related to gas and oil hydrocarbon exploration and production.

The quantitative risk assessment requires using data that describes the environmental concentrations in areas where the population lives. Therefore, it will be necessary to obtain such data that is applicable to the Quebec context. The data taken in the field (e.g., Anticosti, Gaspésie) or modelled data should be used.

9.1.3 IMPACTS OF AMBIENT AIR CONTAMINATION ON POPULATION HEALTH

9.1.3.1 Preliminary findings

- Hydrocarbon exploration and production activities emit air pollutants such as fine particles ($PM_{2.5}$, with a median diameter is < 2.5 µm), NOx, SOx and VOCs (such as benzene, toluene, xylenes and ethylbenzenes).
- Emissions vary depending on the type of extraction (oil or gas, conventional or unconventional) but very little information exists on this topic.
- Other contaminants may also be emitted near hydrocarbon exploration and production sites, such as hydrogen sulphide, if it is present in the gas burned in the flares.
- There is little information on population exposure related to hydrocarbon exploration and production. However, exposure varies based on the distance between the populations and the sites, the intensity of activities and other specific conditions (topography for example).
- Pollutants emitted during hydrocarbon exploration and production are associated with cardiorespiratory effects and cancers. Very few studies on people who live near hydrocarbon exploration and production sites have been published and they have limitations.

9.1.3.2 Knowledge to be acquired

The data needed to estimate population exposure and health risks associated with exposure to hydrocarbons in Quebec is not available.

Given the simultaneous presence of a number of compounds during hydrocarbon exploration and production activities, approaches to take into account the cumulative effect of all of the compounds emitted in the air will need to be developed to estimate the cumulative health risks (or health impacts) from this mixture of pollutants.

9.1.4 EFFECTS ON POPULATION HEALTH OF EMERGENCIES ASSOCIATED WITH OIL HYDROCARBON EXPLORATION AND PRODUCTION

9.1.4.1 Preliminary findings

- In case of accidental spills as well as oil hydrocarbon and other chemical leaks, workers, neighbouring population and first responders are the people who are most at risk of suffering potential serious repercussions of exposure of which health effects are not very well documented.

- Various accidental events may occur during oil hydrocarbon exploration and production activities: explosions, fires, leaks and spills. These events lead to environmental contamination (water, ambient air, soil and sediment) by crude oil and other chemicals (e.g., products used and dumped during hydraulic fracturing, emitted during a fire).
- The contributing factors identified during accident investigations include: a weak safety culture in the company, ineffective risk management, inadequate worker training, poor equipment maintenance and ineffective monitoring by the different regulatory agencies.
- Most of the spills identified in fixed sites occur in port facilities. Others, generally smaller, occur during switching activities in rail facilities.
- Major spills occurred on offshore rigs where the risks of fire and explosions as well as structure breakdown are relatively high and where safety management is made more complicated because of the involvement of a large number of specialized subcontractors. Major spills may also involve oil tankers, bulk carriers and barges during groundings and collisions as well as train derailments.
- Regardless of the mode of transportation used (roads, rail, marine, pipeline), accidents related to hazardous materials, including oil, occur two times more often during loading and unloading activities at transportation facilities than during transportation itself.
- It appears that in addition to deaths during fires and explosions involving hydrocarbons, the population in proximity would be exposed to emissions from toxic products from not only the oil itself (oil hydrocarbons, benzene, toluene, ethylbenzene, xylenes and hydrogen sulphide), but also dispersants used during and contaminants resulting from fires (PAHs, dioxins and furanes). Few studies have been conducted on the acute effects of these contaminants on the population, as relatively few spills have occurred near densely populated areas.
- The three possible means of exposure to toxic products during an accident (fire, explosion, leak and spill) are inhalation, ingestion and skin absorption. The effects depend on the type of product spilled and the duration of exposure. The possible symptoms, studied mainly among riverside populations, include headaches; eye, throat, skin and respiratory tract irritation; irritability, fever, fatigue, nausea and vomiting. It seems that most of these symptoms disappear in less than a week in people who do not take part in clean-up work. Recently, hematological, liver, renal, respiratory abnormalities as well as certain neurological abnormalities were also noted among exposed populations and workers. Psychosocial effects predominate and last for a long period among people exposed to these types of toxic products and within the affected communities.
- Finally, although some petroleum product compounds are recognized carcinogens, since the duration of exposure is generally short, the probability of such effects remains low in the context of accidents and acute exposure.

9.1.4.2 Knowledge to be acquired

The evaluation and management of potential health risks related to oil exploration and production must necessarily take into account the potential exposure of the population to hazardous material that is stored and transported as part of oil industry operations. In this regard, a number of aspects concerning the health risks during emergencies in relation to oil exploration and production still need to be documented by the businesses (dealing with handling, storage and transportation of hazardous material) and or by the responsible government authorities, such as:

1. In terms of the presence and nature of hazardous material in a given area and population exposure to hazardous material handled, stored and transported in this area:
    - obtain a comprehensive list of hazardous material and the quantities that will be handled

(particularly during loading and unloading activities at transshipment sites), stored and transported;

- find out the volume and duration of activities;
- locate the main storage facilities (fixed sites) and transportation facilities (road, rail, port, pipeline);
- characterize human populations likely to be exposed;
- document the distance between the populations likely to be exposed and the exploration and production sites, the hazardous material storage sites and the transportation facilities (including roads);
- collect information from carriers on the routes used; and
- obtain contingency plans and find out the actual capacity of small municipalities to implement them.

2. With regard to accidental events and their potential impacts on human health:

- document the probability of the occurrence of accidental events;
- gather descriptive data or investigation reports on past accidental events (frequency, types, exposure circumstances, main health effects to be assessed, etc.);
- obtain data on the main accident scenarios (modelling, etc.); and
- document the main potential impacts of accidental events involving hazardous material on the environment and human health, specifically through a literature review.

3. With regard to the management of risks related to accidental events:

- conduct an analysis of current statutes, regulations and standards related to emergencies and disasters;
- conduct a literature review on the assessment of the application of different risk management options and on their capacity to reduce risks; and
- conduct a literature review on the communication and perception of risks of accidents and risks for health.

9.2 Issues related to workers' health

9.2.1 Preliminary findings

Oil industry workers in marine or terrestrial environments face a high mortality rate attributable, mainly, to vehicle accidents and contact with objects. The literature reviewed also identified a number of risk factors affecting the health of workers in this industry, such as:

- chemical risks (toxic and corrosive products, irritants, sensitizers, asphyxiants, nerve agents and carcinogens);
- physical risks (noise, vibrations, radiation and extreme temperatures);
- ergonomic risks (handling, repetitive work and work postures, vibrating tools); and
- psychosocial risks (overwork, work hours, work in remote areas).

In the perspective of the installation of the oil industry in Quebec, all the occupational hazards mentioned below are likely to be found in Quebec workplaces (terrestrial and marine).

- Some chemical and physical risks that can cause irreversible effects must be prioritized in the short

term, especially exposure to carcinogens such as benzene, to BTEX mixture (neurotoxic), to diesel particulate matter (irritations and pulmonary inflammation), to crystalline silica (fibrogenous and carcinogenic), to ionizing radiation (mutagenic) and to intense noise (hearing loss).

- Musculoskeletal disorders (MSDs) are also seen in workers in this sector, mainly those caused by excessive effort and vibrating tools, regardless of the production environment (terrestrial and marine environments).

More specifically, in a marine environment, over 90% of chemicals found on offshore oil rigs are used as drilling fluids.

- These fluids, complex mixes that vary depending on the drilling conditions, are associated with a variety of health effects such as irritations, inflammation and dermatitis.

- In addition, workers would also be exposed to a variety of contaminants from drilling sludge.

On land, the hydrocarbon extraction procedure via hydraulic fracturing (unconventional extraction) is relatively recent. Therefore, the development and application of effective control measures are necessary to limit occupational exposure to:

- Silica used as a proppant in fracturing fluids;
- Different chemical compounds of fracturing fluids; and
- Contaminants emitted during flowback fluids recovery, storage and handling.

9.2.2 KNOWLEDGE TO BE ACQUIRED

To better protect the health of Quebec workers during future oil hydrocarbon extraction and production activities, it would be necessary to:

- draw up a comprehensive inventory of products used in the drilling fluids and sludge in the marine environment in Quebec and better characterize and monitor occupational exposure to these products;
- characterize occupational exposure during hydrocarbon extraction through horizontal hydraulic fracturing; and
- further monitor the long-term effects observed among oil industry workers by adopting an approach focused on monitoring health risks and the resulting occupational illnesses.

9.3 Options for managing the risks for the health of the population and workers related to hydrocarbon exploration and production activities

The documentation consulted as part of this mandate suggests that regular hydrocarbon exploration or production activities, especially accidents, may present potential risks for human health. In this context, it is important that the responsible stakeholders, specifically government authorities and businesses, ensure that different risk management options are implemented to protect population health. In this regard, in each of the thematic sections, some more specific potential solutions are presented in order to contribute to preventing and managing risks for population health, including the health of workers. Readers are encouraged to refer to this for more detailed descriptions.

The possible solutions are based, among other things, on the guiding principles of the public health risk management approach (Ricard, 2003), namely: appropriation of powers by individuals and the community, equity in the communities, openness allowing for interested and affected parties to participate, the predominance of protecting human health, prudency, scientific rigour as well as transparency with interested and affected parties. Based on evolving knowledge, over time, these risk management options could be tailored or updated.

Finally, among the different risk management options proposed in the different chapters of this report, some are common to environmental health and occupational health. They can therefore be grouped as follows:

- Document and measure the parameters before any operations begin (e.g., characterization of background concentrations of the relevant contaminants).
- Document in detail the risks related to procedures, work methods and products used during hydrocarbon extraction activities and take the cumulative effects of these risks into account.
- Look for existing supporting legislation, and if applicable, introduce new regulations to guide activities related to this industry.
- Look for supporting reference frameworks on prevention and response to accidental spills.
- Establish prevention and protection measures to limit the risks to the health of the population and workers during regular activities and during accidents.
- Facilitate collaboration, specifically through an integrated approach and management of the land.
- Promote collaboration between the industry and the university communities to find solutions.
- Provide for a system to monitor accidents and health effects (including occupational illnesses) to improve prevention and follow-up.
- Monitor developments in scientific research and new knowledge, specifically in relation to public health issues related to gas and oil exploration and production activities.