APPENDIX L
Review of Public Safety Risks of Hydraulic Fracturing Operations

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Report submitted to:
Newfoundland and Labrador Hydraulic Fracturing Review Panel

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1 INTRODUCTION

The past decade has seen significant advances in unconventional oil and gas production technologies, which have resulted in a huge increase in development and extraction in North America (Council of Canadian Academies, 2014). Hydraulic fracturing is a well stimulation technique by which pressurized fluid is pumped under high pressure causing fractures in the geological formation to help extract oil or gas. Public concerns about safety and environmental impacts of hydraulic fracturing have accompanied the rapid growth in oil and gas production. The objectives of this report are:

- To identify public health and environmental impacts of hydraulic fracturing;
- To identify the main risk factors of hydraulic fracturing operations;
- To review best industry practices to mitigate risks of hydraulic fracturing;
- To discuss precautionary principles and ALARP (As Low As Reasonably Practicable) with respect to risk management of hydraulic fracturing; and
- To propose the application of public participatory approaches to hydraulic fracturing policy development in Newfoundland.

2 PUBLIC HEALTH AND ENVIRONMENTAL IMPACTS

From a human health perspective, the two main direct exposure pathways are through contamination of drinking water and air pollution. This section will identify the potential health impacts associated with these two pathways.

2.1 Contamination of Drinking Water Sources

Colborn et al. (2011) reported potential health impacts caused by exposure to chemicals used in hydraulic fracturing. Carrier (2012) presented a report for Health Canada, which provided a list of the 750 chemical components of hydraulic fracturing fluids used by fourteen oil and gas companies in the U.S. and classified them according to their toxicity. However, Colborn et al. (2011) claimed that further research is needed to determine the relationship between the quantitative exposure of the chemicals and illness. It is difficult to obtain direct evidence of adverse impacts from any specific fracturing fluid mixture because:

- The fracturing fluid mixture has not been standardized.
- Oil and gas companies do not always release information on the compositions of their fracturing fluids.
- The vast majority of the chemicals on the exhaustive composition list provided by companies is seldom or extremely rarely used in practice, or has been discontinued.

Surface fracturing fluid spills and migration to surface ground water are two main routes by which toxic chemicals may affect human health either through ingestion or contact. During fracturing and flow-back processes, methane gas and toxic chemicals leach out from the system and contaminate nearby groundwater. There are concerns about constituents of flow-back water returning to the surface. This flow-back water may include any dissolved gases, liquids, and solids in oil and gas deposits, naturally occurring radioactive materials (NORMs), technologically enhanced naturally occurring nuclear radioactive materials (TENORM), hydrogen sulfide, heavy metals and others (Finkel and Hays, 2013).

2.2 Air Pollution

Air quality studies around fracturing wells show the presence of chemical contaminants (Wolf Eagle Environmental, 2009). Colborn et al. (2011) reported that airborne chemicals from hydraulic fracturing operations might potentially affect human health through direct contact or inhalation. The associated traffic may also produce emissions of particulate matter, carbon monoxide, NOx, and other air pollutants. There is also concern about additional impacts caused when air pollutants from hydraulic fracturing contact other pollutants and consequently form ozone that will affect respiratory health (Medina-Ramon and Schwartz, 2008). McKenzie et al. (2014) reported a potential association between atmospheric exposures and birth outcomes. However, Kibble et al. (2014) claimed that this association is relatively weak and can be a chance finding.

3 IMPACTS ON WATER

Impact on water quality and quantity is the top public concern associated with hydraulic fracturing operations. This section will discuss the impacts from both the perspectives of water quality and quantity.

3.1 Water Quality

The depth of a drilled drinking water well is typically about 45 m in Newfoundland (Department of Environment and Conservation, 2013). Since the fractures produced by hydraulic fracturing extend approximately 100 m vertically and approximately 200-300 m horizontally (King, 2012), the induced fractures are hundreds to thousands meters below drilled water wells or the groundwater aquifer. This indicates that the chance of direct contamination of hydraulic fracturing fluids is low. Based on current knowledge and information, the risk to water quality is more associated with operational practice (e.g., chemical handling at the surface), rather than the fracturing process. To safely manage the chemical agents used for hydraulic fracturing and prevent the contamination of drinking water supplies, a strong regulatory framework needs to be established.

3.2 Water Quantity

The U.S. Environmental Protection Agency estimated that 70 to 140 billion gallons of water are used to fracture 35,000 wells in the U.S. each year. This is approximately the annual water consumption of 4 cities, each with a population of 1 million. However, the Council of Canadian Academies (2014) pointed out that the amount of water needed for unconventional oil and gas development is relatively small compared to the annual total surface flow in Canada. It can be anticipated that Newfoundland would have sufficient water capacity to maintain its current water use in the event that hydraulic fracturing were implemented.

4 THE MAIN SAFETY ISSUES IN HYDRAULIC FRACTURING OPERATIONS

Nine main risk factors that may contribute to the above-mentioned impacts were identified and listed as follows.

- Accidental spills of chemicals and hydraulic fracturing fluids during transportation, storage, or use.
- Spills of flow-back water (i.e., the return of part of the aqueous fluid used in the hydraulic fracturing operation).
- Uncontrolled releases of hazardous chemicals due to piping separation at connection points, leaks and equipment failures due to high-pressure activity.
- Inadequate storage, treatment, and disposal of flow-back water including both fracturing fluids and saline formation water.
- Disposal of fracturing wastes that contain TENORMs and other toxic chemicals.
- Release of methane and hydrogen sulfide during well operation, which may pose explosive risk.
- Substantial requirement of water.
- Heavy demand for public service (e.g., transportation of massive amounts of water, sand and fracturing chemicals).
- Deep-injection disposal of hydraulic fracturing flow-back and produced formation brine (which may have the potential to induce earthquakes).

5 BEST INDUSTRY OR GOVERNMENT PRACTICES

This section aims to summarize the best practices or recommendations that can be adopted to mitigate the risk related to hydraulic fracturing operations. The recommendations are:

- To conduct a health impact assessment to consider what changes are needed to maximize health benefits and reduce health risks;
- To develop and apply emergency preparedness procedures in the context of hydraulic fracturing;
- To evaluate wastewater treatment technologies and approaches to mitigate risks to the receiving body;
- To develop clear design standards for wastewater disposal and/or treatment, well installation, and decommissioning;
- To develop detailed analysis of water demand and water balance of the area where hydraulic fracturing operations will likely occur; and
- To develop water safety plans to ensure safe drinking water.

6 PRECAUTIONARY PRINCIPLE AND ALARP APPLIED TO RISK MANAGEMENT OF HYDRAULIC FRACTURING

6.1 Precautionary Principle (PP)

PP applied to risk management denotes a duty to properly manage risk, when it is within our capability to do so, even when there is a lack of scientific certainty. The PP was brought to international prominence and accepted as a principle after it was described as "Principle 15" in the Rio Declaration (UNCED, 1992). The following presents some broadly shared insights on the PP in the scientific and policy-making communities.

- The PP applies when there are considerable scientific uncertainties about causality, magnitude, probability, and nature of harm.
- Since the PP deals with risks that are poorly known and understood, the unquantified possibility is sufficient to trigger the consideration of the PP. This distinguishes the PP from the as low as reasonably practicable (ALARP) principle. If one does have a credible ground for quantifying probabilities, the ALARP principle applies instead.
- Application of the PP is mainly limited to those events that potentially have severe consequences when knowledge of their occurrence is unknown or unpredictable.
- Interventions are required before possible harm occurs, or before certainty about the consequence of such harm can be achieved. This does not suggest stopping or doing nothing. However, application of the PP may indirectly suggest a wait-and-see-strategy, i.e., wait until we are more certain about the harm or/and how to minimize its impact.

The PP is a guiding principle for risk management that has been developed in circumstances of scientific uncertainty, reflecting the need to take prudent action in the face of potentially serious risk without having to await the completion of further scientific research.

6.2 ALARP (As Low as Reasonably Practicable)

Conceptually, the ALARP principle requires that risks be reduced to a level between the upper limit of risk that can be tolerated in any circumstances and the lower limit where risk is of no practical interest (i.e. there is a gross disproportion between the risk and the sacrifice necessary for averting the risk). Therefore, this principle stipulates that those responsible should reduce risk to an appropriate level. A real concern from an engineering point of view over the subjective nature of the ALARP's working principle (i.e., "low", "reasonable", and "practicable") leaves the door open for arguments in the engineering community about what are the quantitative bases that make risk be considered low, reasonable and practicable. The term "reasonable practicability" has been interpreted in legal cases as the degree of risk that can be balanced against time, trouble, cost and physical difficulty of its risk reduction measures. Risk tolerability in the ALARP principle is subject to social participation of people exposed to risks that may be imposed by projects undertaken by industry, government, or other agencies that are not under the direct control of the community. Public participation is a proper approach that can be used to determine risk tolerability with ALARP.

Almost all engineering developments adopt the ALARP principle. This principle is now widely applied in safety decision-making in oil and gas, mining, and marine industries (Aven, 2008). In the context of uncertainties, the ALARP provides a reasonable and cautious approach to proceed with engineering projects without delaying their expected benefits. Having acquired more knowledge and addressed uncertainties, the ALARP criteria can be better defined. Jones-Lee and Aven (2011) claimed that there is little doubt that the social cost-benefit analysis provides a specified framework within which the cost and benefit of a proposed engineering project can be appropriately defined and estimated.

One of the potential confusion points in ALARP is who defines the reasonableness and also the practicability. It is generally believed that industry defines what is reasonable and practicable. To a certain extent, this is true because industry best knows the technology, operating conditions, and limitations in given conditions. However, industry only defines, rather than decides. It is the third-party verification/certification along with the regulatory body that decides whether the defined case of ALARP is acceptable or not. A classical example of this is post-Piper Alpha platform development in the North Sea. Each oil and gas operator in the North Sea is expected to develop safety cases based on the principle of ALARP. Operators develop the safety case, which is reviewed and approved by the third party. Assuring that the given solution leads to risks that are as low as reasonably practicable, thereafter the Health Safety Executive (UK regulatory organization) makes an independent review and renders the decision. In summary, there are two additional levels of checks beyond industry defining the risk or making an ALARP case.

6.3 ALARP and PP Applicability to Hydraulic Fracturing

For a project or an activity that could have serious and harmful consequences and when there is significant scientific uncertainty about the nature and magnitude of the consequences and/or likelihood of occurrence of these consequences, perhaps the PP is the appropriate approach to be applied. Since there is sufficient experience in hydraulic fracturing operations and consequently known uncertainty, it is more appropriate to apply the ALARP approach. Additionally, it is not clear how the application of PP (being more protective and conservative) to risk management of hydraulic fracturing operations would and could minimize the consequences while waiting for more scientific proofs to be tabled. The knowledge and scientific proofs would be developed only if one proceeded with project activity with caution and interest to learn more and better define risk management strategies. The ALARP approach provides the framework for us to know the current state, and move forward cautiously to monitor and update knowledge as it is being developed. Application of the ALARP approach would help to better understand and minimize the likelihood of occurrence and/or consequences of potential risks through both cautious and preventive operations.

Considering the current state of the knowledge of hydraulic fracturing and its impacts, the application of ALARP to risk management of hydraulic fracturing operations is more appropriate.

6.4 Dynamic Risk Management of Hydraulic Fracturing: Integration of Adaptive Risk Management and ALARP

Contemporary challenges faced in risk management are those of systems and activities characterized by high uncertainty, particularly the uncertainty regarding potential future events and consequences. This is due to constraints on knowledge, and the crucial feature caused by these constraints is the lack of fully justifiable prediction models (Aven, 2011 and 2013). In response to situations of high uncertainties in risk assessment, adaptive risk management strategies are often recommended (Lempert et al., 2004; Kasperson, 2008; Walker et al., 2010). Adaptive management, which is often credited to Holling (1978), is defined as an iterative, structured and systematic process, aimed to reduce uncertainty over time through system monitoring that is used when decision makers confront uncertainty.

Adaptive management is a learning-based approach that involves the application of management in the spirit of experimental science to investigate how to manage more effectively. The basic mechanism is to feed new information of management outcomes back into the decision-making process so that engineering and environmental resources can be properly reallocated. Adaptive management is based on recognition that there is a known high uncertainty about the system of interest and the necessity of using what is learnt from current management of resources to plan for future management. Conventional risk models are not applicable to handle such cases of high uncertainty because of their static character, insufficient knowledge base, and inadequate database. Meanwhile, the implementation of ALARP to risk management also requires the continuous analysis of the benefits gained from risk reduction versus the resource to be consumed to ensure that risk is lessened to the lowest level at reasonable cost. The integration of adaptive management and the ALARP principle produces a new generation of approaches called "Dynamic Risk Management."

Dynamic risk assessment and management is recognized as one of the future research trends of process safety and risk management development (Khan et al., 2014). Integration of Bayesian Network methods with many qualitative and quantitative risk assessment methodologies provides the capability to update and predict accident probabilities using new information or data collected during ongoing operation. Dynamic risk assessment methods are capable of modeling the dynamic changes of hazardous conditions on highly complex technical and social systems, such as offshore drilling operations (Abimbola et al., 2014), and refinery systems (Kalartania et al., 2009). The outcome of the assessment - the real-time updated risk - provides better overall management of risk through time. The use of dynamic risk assessment and management approaches helps to predict abnormal situations and thus notify decision-makers to take early actions to prevent accidents during hydraulic fracturing operations. This way, abnormal events can be anticipated and prevented rather than relying on "end-of-the-pipe" safety measures.

The feasibility and application of dynamic risk management to hydraulic fracturing are supported by the availability of a new generation of monitoring and diagnostic technologies that help to assess and track the fracturing progress, e.g., fracture diagnostic techniques (direct far-field methods, fracture-mapping and offset microseismic fracture mapping techniques), post-fracture well-test analyses (used to compute estimates of the propped fracture length, fracture conductivity, and drainage area of the formation), fracture propagation models, well logging, and leak-off tests.

In summary, dynamic risk management methods provide a reasonably practicable approach that would help to enhance the inherent safety of hydraulic fracturing operations.

7 HYDRAULIC FRACTURING AND PUBLIC POLICY DEVELOPMENT

Turnpenny et al. (2009) describe how policy making for unconventional oil and gas development is exceedingly intricate. They advocate that this may be addressed through participatory policy-making processes encompassing all involved parties as a part of the solution. Unfortunately, it is important to observe that sometimes the government is bound to make resolutions that do not necessarily address citizens' concerns in the absence of public participatory laws. This is obvious when governments' main concern is to obtain "community permission" in order to continue trading oil and gas in the areas regardless of the importance of considering policy making regarding any potential technological risks. Eventually, the development of oil and gas in any province will result in environmental and human health risks where the government inescapably should rethink its policies and consider the public participation in formulating risk policy as one of the solutions to mitigate technological risk arising in the oil and gas industry.

Public participatory approaches to public policy development have been applied in renewable energy strategies (Adams et al., 2011) and environmental assessment (Gauthier et al., 2011). Wheeler et al. (2015) proposed a fully independent public participation and review process on the economic, environmental, health, community risks and benefits of hydraulic fracturing. This type of review will help to enhance the public understanding of risk through a high level transparent participatory process that can lay down a solid basis for policy development and prepare the province for more informed risk-based decision-making. It is anticipated that a similar approach can be adopted by the Newfoundland government to review the risks and benefits to assist in the development of public policy related to hydraulic fracturing.

Successful, methodical and proficient public participation in risk policy-making commences from the inception of a voluntary public commentary system that comprises academic and technical experts from public nominations, without any governmental interposition. The government shall allow anybody to honestly and faithfully participate in that process if they wish as an act of democracy without any restrictions. The public community panel then proceeds to appoint a technical consultant to facilitate the panel's work and a project administrator to coordinate the panel's review. The panel's sole activities are to conduct public consultations on potential risks associated with hydraulic fracturing operations and conduct a literature review on the health, safety and socio-economic impacts to the public. The final findings and recommendations from the community panel on the potential risks versus benefits of oil and gas development and production through hydraulic fracturing must be shared, discussed and approved by the public or their nominated representatives. Final outcomes and recommendations from the public are to be raised with the government. Finally, both the public and government must agree on the plan to go forward with legislative regulations and laws that are capable of chaperoning the nation, respecting future generations' rights and environment needs, yet considering the optimal utilization of oil and gas resources without sacrificing or jeopardizing health, safety and environmental principles.

Establishing public policy related to hydraulic fracturing or any unconventional energy source would require better understanding of scientific and engineering challenges, public perception of risks, quantification of real (technical, social and environmental) risks, and delineation of societal and economic benefits. It is prudent to invest early to investigate such topics. The information developed through this early investment will help to better define policy and ensure risk-based decision-making.

8 CONCLUSIONS

This report provides a brief review of public safety risks associated with hydraulic fracturing operations in a general context. Contamination of drinking water supplies and air pollution are considered two main threats to public health and safety. Impacts on both water quality and quantity are identified as the most significant environmental impacts. The identified risk factors are well understood and common to general hydraulic fracturing operations. The ALARP principle is an applicable risk management mechanism for hydraulic fracturing operations that are characterized by uncertainty. A dynamic risk management framework needs to be developed to better manage the risks associated with hydraulic fracturing. This brief review can be expanded into a detailed and specific review of risks and benefits related to hydraulic fracturing operations in western Newfoundland, after more detailed information is disclosed or provided, e.g., the geographical location where hydraulic fracturing is to be applied to develop the unconventional gas and oil potential in western Newfoundland.

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