Mapping the Use of Engineered NM in Quebec’s Industries and Research Laboratories

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Abstract. Engineered NanoMaterials (NM) offer an opportunity to develop a wide variety of new products with unique properties but many studies have shown potential OHS risks specific to NM. Addressing these risks requires knowledge about release of NM into the workplaces. This research aimed to map the state of nanotechnology OHS practices in Quebec through a questionnaire following a first contact by telephone when possible and by compiling the type and volumes of NM used as well as gathering information related to the working conditions and OHS aspects. This survey was conducted among 1310 Quebec industries and 653 researchers working in different specialties potentially involved in the development/production/distribution/integration of NM and use of NM containing products. Overall, 90 questionnaires, including 51 from the industries, were completed. These showed that NM are mainly used into the powder form, in many different sectors and deserve a wide range of markets. The prevention measures implemented vary widely from a workplace to another but about one third of the participants report that they have implemented NP adapted prevention measures but they remain worried on some specific operations. More than 50% of the participants request more information about the safe laboratory/plant design, toxicity, regulation, good work practices and prevention measures, efficiency of personal protective equipment and environmental impacts.

1. Introduction
Nanotechnology (NT) is developing rapidly and new products containing nanomaterials (NM) are being marketed every week. Extrapolating the existing data, it can be estimated that around 1800 products containing NM are currently commercially available \cite{1}. In 2009, these products were worth 224 billion US dollars and contained for one billion dollars of NM \cite{2}. The development of these NM, their industrial large-scale production, distribution, and their integration into different products followed by machining of some NM containing products already results in a potential occupational exposure to NM of hundreds of thousands of workers worldwide. It is estimated that by 2015, up to 10% of workers into the manufacturing sector could be involved in nanotechnologies (NT) \cite{3}. Research in NT is very active in Québec and NanoQuébec \cite{4} promotes the industrial implementation
of new applications. Consequently, for the last 5-10 years, many new companies are entering this field. This trend should continue for several years. One direct impact from this displacement from research laboratories to industrial production is that the number of potentially exposed workers as well as the volume of NM handled substantially increases. Another impact is that the level of knowledge about the specific potential risks and the prevention measures to implement with NM can be lower in the industry, especially in small and medium size companies, compared to research laboratories or large companies.

The toxicity of NM has been widely studied and several literature reviews are now available [5-9]. Many toxicological studies on different substances have demonstrated toxic pulmonary effects including inflammation, fibrosis and granuloma. Health effects have also been reported on various organs and biological systems including the circulatory, cellular, cutaneous, renal and reproductive systems. It is found that in general, a NM will usually be more toxic than the same chemical substance with a larger dimension. The literature gives us very little information specific to NM relating to their physical hazards such as fires or explosions but NM can be much more reactive than larger particles [10, 11]. Overall, it is recognized that NM remains an important source of concern in OHS. In fact, not only does the diversity of commercially available chemical products of nanometric dimensions continues to increase, but also, the information available about the hazards specific to each of these substances is still very fragmentary.

Addressing the risks of NM requires knowledge about the occupational exposure. However, in Québec, this information is not currently available and risk assessment lacks of quantitative data. Consequently, the essential first step is to identify the different workplaces where workers could potentially be exposed to NM. These include the development (research laboratories), the industrial production, distribution, and integration of NM into final products and the use of these products into production or assembly lines (Ex. CNT containing composites used in the production of transportation vehicles). The project aims to 1)-_ identify and document different workplaces using NM and, 2)-map the state of nanotechnology OHS practices in Quebec as well as gather specific information related to the working conditions and needs for additional information.

2. Methods

2.1. Nanoparticle Definition
Engineered NM are designed with specific properties. Engineered NM encompasses nano-objects and nanostructured materials. The former are defined as materials with one (nanoplate), two (nanofibre), or three external dimensions (nanoparticle) at nanoscale level (i.e., between approximately 1 and 100 nm). Examples of nanostructured materials are nanocomposites composed of nano-objects embedded in a solid matrix or nano-objects bonded together in simple random assemblies as in aggregates and agglomerates or ordered as in crystals of fullerenes or carbon nanotubes (CNT) based on ISO/TS 80004-137 [12, 13]. In this paper, NM definition excludes undesired pollutants of nanometric dimensions (ultrafine dusts) which originate from natural (fire fumes, pollens…) or anthropomorphic (diesel or welding fumes…) sources of Nanoparticles.

2.2. Questionnaire.
A questionnaire adapted to the specific objectives of the study has been elaborated from a literature review covering previous international or local surveys [14-24]. The questionnaire was validated by a small group of 3 researchers and 3 representatives from the industries directly involved in NT. The questionnaire was available in French and in English.
The 17 questions aimed to document potential exposures to NM in different workplaces. It targeted the size of the total workforce and the number of people directly involved in NT, their education level, the NM involved, and their potential release into the work environment, their quantities, origins and physical states, the already developed or targeted markets, the OHS procedures and prevention measures already implemented and the additional information/knowledge and support deemed useful to improve OHS aspects regarding NM.

2.3. Study population.
Previous international surveys have been used as a starting point to identify the economic sectors where NM has been documented [14-24]. A total number of 1310 companies have been identified and cover the activity sectors previously identified among which chemistry, aeronautics, rubber, plastic manufacturing, pharmaceutics and neutraceuticals, photonics, foundries and metal transformation, composites, textiles, inks and pigments, paints, cosmetics, and electronics. The proportion of companies in each sector is not representative of the Quebec industry.

Researchers in universities (n=653) and research centers were identified through publicly available information (NanoQuébec web site, lists of research granting agencies, etc.). Research is performed on a very wide diversity of topics including physics, chemistry, mechanics, industrial engineering, agro-foods, mines, metallurgy, materials, software and information technologies, biology, biochemistry, biotechnology, bio-products, wood and forest sciences, construction, environment, pharmaceutics and pharmacology, telecommunications, etc…

2.4. Survey design and sampling
Two different approaches were used. The companies were contacted (once or twice if no answer) by phone to explain the project, document if they work with NM and, if so, invite them to fill up the secured questionnaire available on the web (Survey Monkey™). The academic researchers were not contacted by phone. The companies which confirmed their use of NM and agreed to fill-up the questionnaire, the companies which did not return our phone calls and the academic researchers received, by email, an invitation to fill-up the questionnaire. The email contained all the required information about the objectives of the project, the research team, the ethical aspects and a personal confidential identification code. Two recall emails were sent to the participants who did not complete the survey.

2.5. Data Analysis
The data collected from the English and the French versions of the questionnaire filled on Survey Monkey™ have been integrated in the same file. The data have been analysed using the SPSS® version 17, and Microsoft Excel®, version 2010. Using the SPSS® software, tables were produced to group participants by sectors for specific questions. Microsoft Excel® was used to produce Graphs.

3. Results

3.1. Description of the participants
A total of 2001 participants were selected including 1310 from the industries, 38 from CEGEPs (technical schools programs) and 653 from universities and research centers. Globally, 90 participants completed the questionnaire (Table 1). In the industrial sector, 64% employ less than 50 workers and 6% more than 500. Nanotechnology represents less than 10% of the activities in 75% of the industrial plants, suggesting that the NM are used mainly in already established industries. The industrial sector covers the production of NM and the required equipment, importation, exportation, distribution, and use/integration of NM as well as suppliers of raw materials already integrating NM and consultants. Among the participants involved in NT, the level of education is higher than in the other industries as 30% of the industries have at least one employee with a master degree or higher. Only 8% of the
industries (mainly producers of NM) report that NM involves more than 60% of their activities. Very few researchers are involved only in nanotechnology. In fact, NT accounts for less than 10% of the activities for 53% of the researchers and more than 60% for only 13% of them.

The industrial sector has developed its market in several sectors including health, biotechnology, pharmaceutics, chemicals and chemical processes, equipment, composite materials, sport goods, transportation, aeronautics, electronics, construction, consumer products, military, energy, safety, mines and the environment, agriculture and food, and information and communication technologies. Research is very active in the fields of nanochemistry, bionanotechnology, medical diagnostic, nanophotonics, nanoelectronics and nanocellulose. Some academic researchers are also involved in OHS, and environment.

In the province of Québec, the results clearly suggest that NM are currently used mainly into powder form in the industries as well as in the academic research sector. Carbon black, nanoclays, nanocellulose, and carbon nanotubes are the most frequently used NM. Most laboratories use less than one kilogram per year and only seven industries reported that they use more than 100 kgs per year.

3.2. Occupational health and safety practices
Many operations and work practices can release some NM in the work environment. Among these, the employers are mainly concerned by weighing, dry transfer, and waste management. Processing, dry packaging, reactors and mixers operations, and dismantling and cleaning of equipment are also of concern to many industrials. Many employers report they have implemented satisfactory control measures but some are still looking for improved control measures, especially for dismantling and cleaning operations, and waste management.

Surprisingly, more academic researchers seem concerned by the potential release of NM in their labs environment despite the fact that more industrials completed the survey. Many academic researchers have implemented satisfactory control measures but some are still concerned and are seeking for new or improved methods for all the operations proposed in the survey.

About 50% of the industries and 60 % of the academic researchers have implemented some specific OHS practices to handle NM in the workplace. The most frequently reported actions by the industry are OHS directives given to their employees, information on risks, training of workers, prevention/information on safe practices, and availability of a health professional. The academic researchers report, in decreasing frequency information on risks, training of workers, OHS directives, information/prevention programs on safe practices, and availability of a health professional. Figure 1 illustrates the prevention measures implemented in the industry and in the academic research laboratories. Ventilation, personal protective equipment and detailed work procedures are the most frequently reported specific prevention measures reported. About one third of the participants reported that prevention measures are not applicable.

The last question of the survey covered the additional information and knowledge deemed useful to improve OHS regarding NM. Figure 2 clearly shows that more information/knowledge is considered valuable on all aspects of OHS. In general, a larger proportion of researchers would like to get more information than the industry.

4. Discussion
The aim of this survey was 1) to develop a questionnaire specific to NM and to establish the mapping of NM in Québec based on public and private industry lists available.as well as 2) to gather information about workplaces ,work practices and prevention measures related to NP. Based on an
initial literature review, the survey questionnaire has been developed and adapted to reflect Québec’s reality. Two experimental approaches have been used in the survey. Some companies (n=650) have been directly contacted by phone and 29% of those who confirmed their use of NM have answered, on a voluntary basis, to the questionnaire sent by email. This proportion is higher than the 19% of the international ICON study published in 2006 [18, 19] using a similar approach but lower than the 58% of the Swiss study [23] where the participation to such study is mandatory. The other companies and the researchers have received an invitation by email only. Respectively 6.40% and 6.33% of the industries and the researchers completed the survey without being previously contacted. This result suggests that a preliminary contact promotes the level of response but some people not involved in NT possibly concluded that it was not useful to complete the survey. Considering that 51 industries involved in NT completed the survey and assuming a response ratio of 29%, this preliminary survey would suggest that, at least, 175 industries are involved in NT in Québec. Far more than 200 research teams are currently running research projects on NT according to NanoQuébec. The minimal current workforce potentially exposed to NM in Québec is estimated to be more than 2 000 people.

The methodology of this study could be improved in some ways. First, the industries could be selected on a totally random basis, covering all the activity sectors and be proportional to the importance of each economic sector. Every participant should first be contacted by phone and it could be offered to complete the survey by phone or in their workplace. The participant should be contacted again for quality-control when some answers are incomplete or seem inadequate. For example, a few industries mentioned that they already have products on the markets, gave complete indications on the NM they use but report that no employee are involved in NT or handling NM. Finally, working in collaboration with associations (Ex. industry associations) could increase the participation to this voluntary survey. It is not surprising to see that most of the industries involved in NT are small or medium size industries. This reflects the Québec industrial profile [25]. NT represents more than 10% of the activities for 53% of the companies involved in this survey. Many companies developed their own applications, have a research laboratory and have already marketed some products. Also, some factories have the capacity of large size production of carbon nanotubes, nanometric size metals, metal oxides, ceramics, and nanocellulose. Considering the industry and research in universities and research centers, the total manpower involved in NT is estimated to be larger than 2000 spread in 175 industries and more than 200 research teams.

The survey suggests that NM are used mostly into the powder form, not only in the industry but also in most research laboratories. Considering OHS, the industries use much larger quantities of NM but seem generally less concerned about the potential release of NM in their workplace or have implemented adequate prevention measures. A detailed study of the results suggests that the most concerned industries about the safety of their employees are the industries which have their own research laboratories. In academic research laboratories as well as in the industries which produce NM, some participants are concerned and are looking for efficient prevention measures especially for dismantling and cleaning of equipment and NM waste management. OHS practices in industry and research are quite similar but follow-ups seem more regular for the industries. Some prevention measures are already implemented in most workplaces but surprisingly many people report that this is not applicable in their workplace. Globally, most participants would appreciate to have additional information on the OHS and environmental aspects.
5. Conclusion

Despite the limitations of such a targeted survey, it appears clearly that Québec is deeply involved in research in NT, has an important NM production capacity (nanocellulose, carbon nanotubes, nanometric metals, metal oxide and ceramics) and many workplaces have already implemented good work practices. New products are being continuously developed, shifting from the laboratory to the industry. Consequently, an increasing number of workers are potentially exposed to NM and handle much larger quantities. Some industries and laboratories are still concerned about the safety of some specific operations (dismantling and cleaning of reactors, waste management) but most participants request more information about all OHS aspects (design, engineering, administrative measures and personal protective equipment).

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1) **Table 1: Survey population and level of participation.**

| Category of participants | Features | Number of participants |
|--------------------------|----------|------------------------|
| Industry                 |          |                        |
| Participants targeted    |          | 1310                   |
| Closed or non functional phone number |          | 129                    |
| Reached by phone         |          | 650/1181 (55.0 %)      |
| Confirmed the use of NM and agreed to answer the survey |          | 48/650 (7.5 %)         |
| Number of invitations sent by email |          | 607/1181 (51.8 %)      |
| Participants who filled the questionnaire |          | 51 (8.4 % of 607). Only 29.16% (14/48) of the participants who confirmed the use of NM and agreed to fill the questionnaire |
| Universities and research centers |          | 653                    |
| Emails who did not reach their recipient |          | 37                     |
| Participants who filled the questionnaire |          | 39/616 (6.3 %)         |
| Researchers in CEGEPs    |          | 0/38                   |
Figure 1: Protection methods used by the participants during the manipulation of nanoparticles or their aggregates. A comparison between Industry and Public research organizations.

Figure 2. Information/knowledge deemed useful to improve OHS regarding NM. A comparison between Industry and Public research organizations.