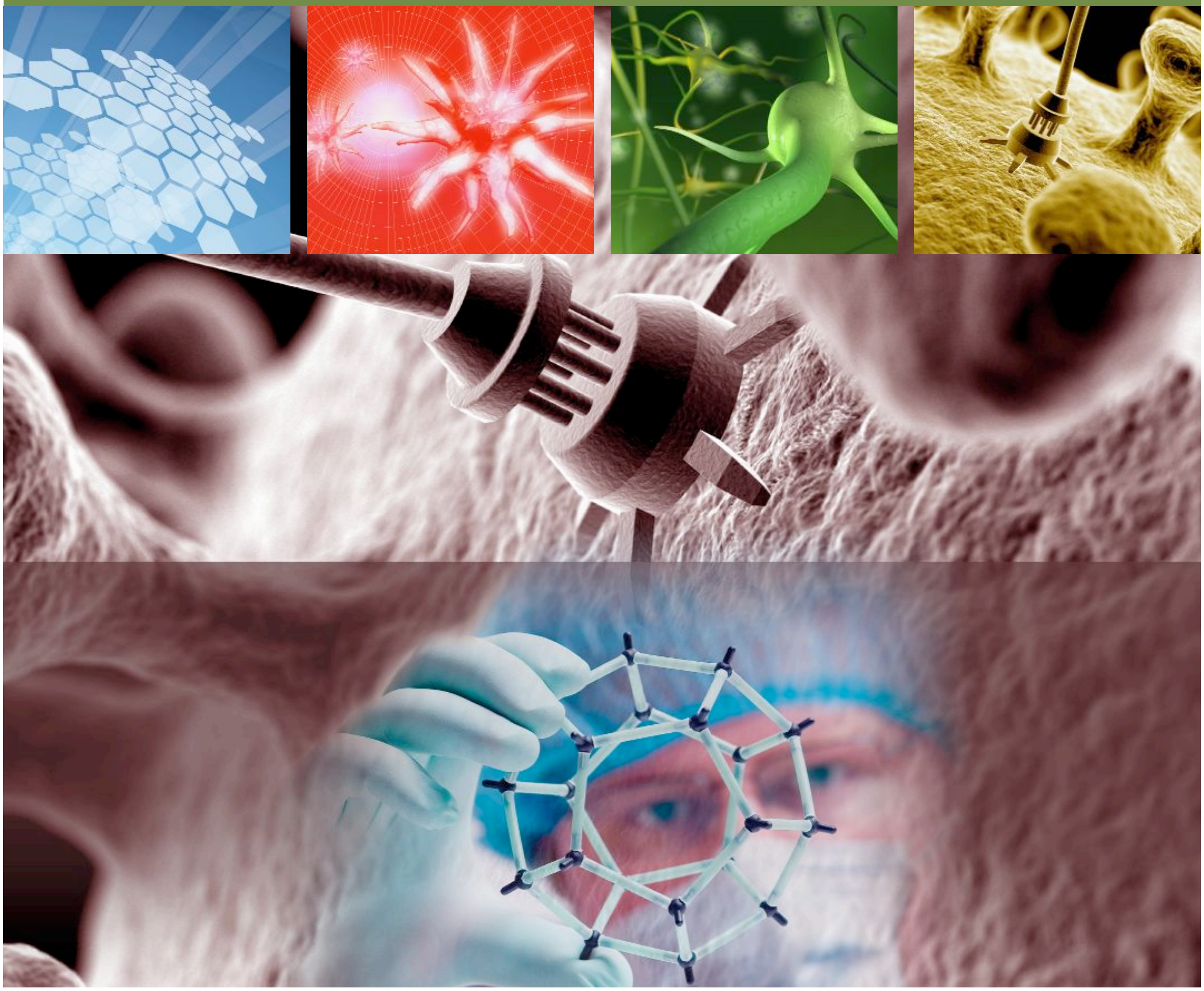
Canadian Workshop on Multidisciplinary Research on Nanotechnology:

Gaps, Opportunities and Priorities



Edmonton, Alberta | January 22–24, 2008

Environment Canada / Environnement Canada

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National Research Council Canada / Conseil national de recherches Canada

National Institute for nanotechnology / Institut national de nanotechnologie

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Canadian Institutes of Health Research
160 Elgin Street, 9th Floor
Address Locator 4809A
Ottawa, Ontario K1A 0W9 Canada

www.cihr-irsc.gc.ca

Also available on the Web in PDF and HTML formats

Cat. No.: MR21-133/2008E-PDF
ISBN 978-1-100-10855-1

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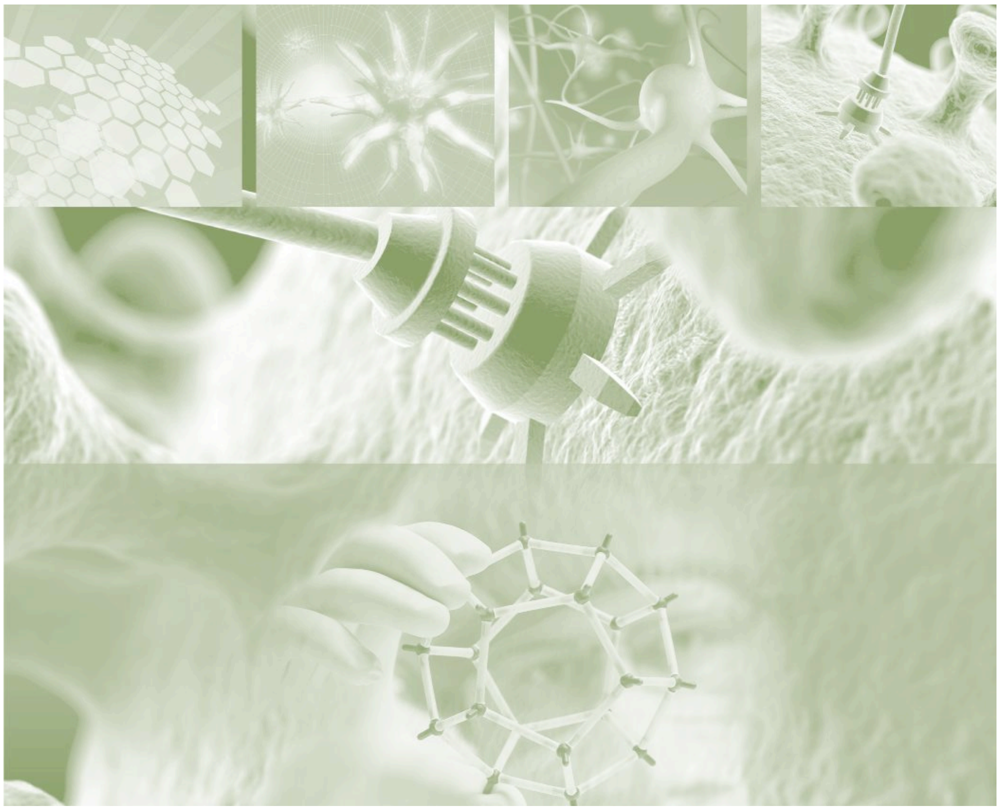

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Disclaimer:

The contents of this report are a reflection of the comments and opinions expressed by the participants during the workshop. Although every effort has been made to accurately summarize the consensus views of the majority of participants, no guarantees as to the accuracy and completeness of this report can be made. This report does not necessarily reflect the views of the sponsoring agencies.

Executive Summary

Nanotechnology – the application of nanoscience research – holds great promise for improving our lives and effecting profound scientific, medical, economic and cultural change on society. As such, all the potential implications of nanotechnology need to carefully examined and considered. In this regard, the Canadian Workshop on Multidisciplinary Research on Nanotechnology: Gaps, Opportunities and Priorities, held from January 22–24, 2008, in Edmonton, Alberta, was a seminal event. While it was not the first-ever multidisciplinary workshop on nanotechnology in Canada, it was the first time such a meeting had been convened by such a broad-based partnership of organizing agencies, with so many opportunities for wide-ranging discussion across disciplines, sectors, regions and jurisdictions.

The workshop was organized by the three federal granting agencies (Canadian Institutes of Health Research, Natural Sciences and Engineering Research Council of Canada and Social Sciences and Humanities Research Council of Canada), the National Research Council National Institute for Nanotechnology, Environment Canada, Health Canada, and Industry Canada. To date, the workshop sponsors have individually and collectively implemented a number of nanotechnology-related research programs designed to create new knowledge and apply it to the benefit of Canadians. Although much of this research is still at an early stage, it is a critical to have a thorough discussion and analysis of the key research gaps and issues that remain to be addressed.

The workshop brought together more than 80 participants from health, physical and social sciences, humanities and ethics, industry, citizen's groups and government. Collectively, they identified and prioritized key research gaps in nanotechnology, especially as they related to the ethical, legal, social, economic, environmental and health impacts and risks of nanotechnology, and the regulatory and governance mechanisms needed to address them.

Workshop Overview

The workshop steering committee identified a number of general themes or topics to be considered by the meeting participants:

1. Ethics and Related Domains
2. Policy, Regulatory Development and Governance
3. Science, Environmental and Health Risks
4. Social Science and Humanities Perspective

A series of keynote addresses provided the foundational support for group discussions within each theme. These theme areas were not meant to be definitive categories of potential research needs, but starting points for organizing group discussions. The major activity of the workshop centred on participant discussions in the areas of research gaps and emerging priorities in nanotechnology research.

This workshop report attempts to capture the dynamics of the workshop proceedings, and to articulate the multiple recurring and inter-related themes that were identified, explored and addressed by workshop participants across all domains of nanotechnology research. Rather than following a strict chronological or thematic sequence, this report attempts to capture the substance of the workshop proceedings in a coherent fashion.

Key Research Gaps

The semantic question —what is *nanotechnology* exactly—was raised by many participants during the workshop. Participants identified the absence of a universal taxonomy and accepted nomenclature as a distinct and fundamental gap underpinning the whole discussion of nanoscience and nanotechnology. Nevertheless, participants agreed that work must begin now on identifying specific areas of concern across the potential domains of nanotechnology.

After a full day of group discussions among participants, an extensive list of key research gaps in nanotechnology was developed for each of the four themes of the workshop. This list was subsequently consolidated into a master list of common research gaps/questions across all domains of nanotechnology. General headings include:

A. Basic Science Gaps and Research Challenges
B. Research Gaps in the Broader Ethical, Legal, Economic and Social Contexts
C. Health and Environmental Issues and Risks
D. Governance, Regulatory and Policy Gaps
E. Public Engagement and Communication Needs
F. Challenges for Interdisciplinary Collaborations

Please see the full report for the detailed list of key research gaps in nanotechnology.

Establishing Priorities

Rather than rank the detailed list of established research gaps, participants were asked to reflect on setting short- and long-term priorities. Short-term priorities were defined as areas of research that are critical to address in the near term. Many of these priorities are inherently complex and will not be adequately resolved in this timeframe, but progress toward them needs to begin. Long-term priorities were defined as key areas of research with a longer-term horizon, and which cannot be addressed until some progress has been made on the short-term priorities. General headings include:

Short-term Priorities

A. Development of Analytical Tools and Baseline Studies
B. Development of Science Research Agendas
C. Development of a Canadian Governance Regime

Longer-term Priorities

A. Research and Training
B. Economic Development
C. Fostering a Canadian Nanotechnology Strategy

Please see the full report for the detailed discussion of short- and long-term priorities.

Conclusion

The main goal of this workshop was to develop a list of key nanotechnology research gaps that could serve as a starting point for future targeted funding programs. The extensive list provided here offers a clear set of research needs that is not limited to any one field, discipline, or theme of research. These gaps highlight common concerns and issues across all domains of research that will need to be addressed for nanoscience and nanotechnology to have their desired impacts. Many of these key research gaps will require multidisciplinary approaches, as the issues raised are broader and more inter-connected than any one agency, discipline or field could resolve on its own.

A second major goal of this workshop was to provide general guidance on relative priorities for nanotechnology research. This exercise was not intended to provide a detailed timeline or sequence of activities, but to elucidate fundamental imperatives and priorities. Responsibility for enacting these relative priorities does not fall to any one specific group or audience. Rather, participants and sponsors were encouraged to consider these relative priorities when developing their own research programs or strategic exercises.

In addition to these key outcomes, another expectation of this workshop was to build greater linkages among participants from different disciplines and fields and help create greater mutual awareness of the potential positive outcomes of nanotechnology as well as the potential risks and needs. The goal was to develop a greater understanding of how stakeholders from different backgrounds, disciplines and perspectives could work together to move this research agenda forward. The future health of nanotechnology in Canada can only be secured if the science is advanced within the bounds of a multidisciplinary framework, supported by adequate tools and resources. Only through the concerted efforts of individuals in all disciplines that exert an influence over the present and future course of Canadian research will nanotechnology safely achieve its potential benefits for all of society.

Introduction

On January 22, 2008, the Canadian Workshop on Multidisciplinary Research on Nanotechnology: Gaps, Opportunities and Priorities convened in Edmonton, Alberta. The three-day workshop was coordinated by:

- Canadian Institutes of Health Research (CIHR)
- Environment Canada
- Health Canada
- Industry Canada
- National Research Council Canada - National Institute for Nanotechnology (NINT)
- Natural Sciences and Engineering Research Council (NSERC)
- Social Sciences and Humanities Research Council of Canada (SSHRC)

Through this initiative, the sponsors brought together experts and interested stakeholders to discuss and identify gaps in nanotechnology research in Canada, particularly as they relate to NE3LS issues (i.e. nanotechnology ethical, environmental, economic, legal and social issues), health impacts and risks and the regulatory mechanisms needed to address them. There was a particular focus on bringing together participants from different disciplines, backgrounds and perspectives, to bring an interdisciplinary approach to identifying research gaps and setting priorities. It is expected that research results in the areas identified through this exercise will better position Canada to take advantage of the benefits of nanotechnology, while avoiding or mitigating the potential adverse impacts of nanotechnology on human health, the environment and society in general. Potential outcomes of the meeting included identifying research gaps and setting priorities in nanotechnology research.

Workshop Background

Nanoscience is the study of phenomena and the manipulation of materials at the atomic, molecular and macromolecular scales. At the nanoscale, certain properties of matter (including melting point, boiling point, electrical conductivity, etc.) can differ significantly from those observed at the macro-scale. Nanotechnology, the application of nanoscience research, has the potential to effect profound scientific, medical, economic and cultural change in society. Indeed, the perceived benefits have inspired governments around the world, including the Canadian government, to invest heavily in nanoscience and nanotechnology research and development. In 2005, the public and private funding of nanotechnology in Canada was approximately $246 million, and global R&D investments totalled $9.6 billion.[1]

[1] Overview of Nanotechnology Research in Canada 2006, Office of the National Science Advisor

The Government of Canada's *Science and Technology (S&T) Strategy – Mobilizing Science and Technology to Canada's Advantage* speaks to collaborative and entrepreneurial research that sees partnership and integration as keys to unleashing Canadian innovation. In particular, the strategy seeks to position Canada at the leading edge of important developments that generate health, environmental, societal and economic benefits. Moreover, the strategy sees broad, transparent and efficient regulation as an enabler of safe and progressive science and technological activity. This workshop is an example of cooperation and coordination among the Canadian funding agencies and government departments that share a common interest in the emerging area of nanotechnology.

To date, the workshop sponsors have individually and collectively implemented a number of nanotechnology-related programs designed to create new knowledge and apply it to the benefit of Canadians. However, it was recognized that a wide-ranging discussion and analysis of the key research gaps and issues remains to be addressed – especially with regard to the ethical, legal, social, economic, environmental and health impacts and risks of nanotechnology, and the regulatory mechanisms needed to address them. Prioritization of identified research gaps is critical, along with determination of the best mechanisms by which to support research in these areas. Thus, this workshop was designed to bring together interested stakeholders from different fields, disciplines and backgrounds to work together to identify and prioritize key areas in nanotechnology where more research is urgently needed.

Potential Research Themes/Topics

The workshop steering committee identified a number of general themes or topics to be considered by the meeting participants:

1. Ethics and Related Domains
2. Policy, Regulatory Development and Governance
3. Science, Environmental and Health Risks
4. Social Science and Humanities Perspective

These theme areas were not meant to be definitive categories of potential research needs, but rather a starting point for further discussion. There is considerable overlap among these areas, and it was expected that common concerns or needs would be identified across them.

Defining the Science, Policy and Ethics Constituencies

In the context of the intended objectives, the core constituencies from which participants were drawn were characterized in the following manner:

- **Science:** the entire range of nanoscience- and nanotechnology-related

disciplines, including basic laboratory science, academic and private-sector research and applications up to commercialization
- **Law and Policy:** Government; funding organizations; NGOs; public and consumer groups; and any agency or entity that directs, supports or has an impact on nanoscience and nanotechnology policy development or its implications
- **Ethics and Social:** Organizations that shape, refine, constrain or otherwise contribute to the nanoscience debate; social science and ethics research

Links and overlaps exist among the many perspectives brought together to discuss the whole span of Canadian nanotechnology; accordingly, many workshop participants possessed expertise relevant to more than one constituency. The viewpoints offered by participants produced debate and cross-communication at many intersections along the continuum of gaps, opportunities and priorities. Nonetheless, these three broadly defined constituencies also projected distinct and effective perspectives onto the current Canadian nanotechnology landscape.

Workshop Report – Structure and Objectives

This report attempts to capture the dynamics of the workshop proceedings, and to articulate the multiple recurring and inter-related themes that were identified, explored and addressed by workshop participants. Rather than following a strict chronological sequence, this report attempts to capture the substance of the workshop proceedings in a coherent fashion.

Workshop Format and Structure

Keynote Addresses: Setting the Stage for Group Discussions

The workshop began with four keynote presentations that were primarily intended to provide basic background information to participants to assist them in framing the general terms of discussions over the remainder of the meeting. A summary of each of these keynote addresses is presented in Appendix A.

Working Tables: Identifying the Most Critical Nanotechnology Research Gaps

The four themes selected by the workshop steering committee formed the basis of the work carried out by participants. Participants were grouped into working tables, based on their own choice of theme. The total number of working tables was dependent on the number of interested participants for each theme. All working tables were asked to identify the most critical nanotechnology research gaps in relation to their assigned theme. Individual opinions and viewpoints were solicited, rather than the official policy position of any institution, agency or group.

Each working table reported back its findings to a plenary session. Key research gaps were then consolidated from all the working table presentations, and an interim summary was produced for each of the four themes. Due to the large number of common issues raised among the four themes, the four interim summaries were further consolidated into a master list of research gaps across all domains of nanotechnology research. This master list is organized into several sub-areas, representing the common key issues identified by the participants for each of the four themes.

Working Tables: Prioritizing Nanotechnology Research Gaps

For prioritizing nanotechnology research gaps, participants were subsequently grouped into multidisciplinary tables with the objective of translating complex cross-disciplinary research requirements and knowledge gaps into a set of identified priorities.

Working table groups were challenged with integrating what they had heard so far, isolating common themes, and organizing priorities that resonate across the whole spectrum of issues. They were asked to specifically identify short-term priorities, even though they might not come to fruition for some time. Participants were also asked to generate long-term priorities that also must be addressed. Note that participants were not asked to rank the research gaps identified on the previous day, but comment in general on perceived priority areas.

The Most Critical Nanotechnology Research Gaps

The semantic question —what is nanotechnology exactly—was raised by many participants during the workshop. Participants identified the absence of universal taxonomy and accepted nomenclature as a distinct and fundamental gap underpinning the whole discussion of nanoscience and nanotechnology. Nevertheless, participants agreed that work must begin now on identifying specific areas of concern across the potential domains of nanotechnology.

The summary of the working table discussions for each of the four themes was consolidated into a master list of research gaps that span all areas of nanotechnology research (presented below). This master summary has been organized into several categories that encompass all the general themes of the workshop, as a number of common issues and perspectives were raised among the various themes. These categories, and the specific points within each category, are not in any particular order.

Key Research Gaps and Needs

A. Basic Science Gaps and Research Challenges

- A comprehensive inventory of science and technology expertise in Canada, across all disciplines, is currently lacking. How could such a survey be conducted for nanotechnology research? What areas and aspects would be most relevant for nanotechnology?
- What are the most pressing instrumentation needs for the study of nanomaterials, including detection, characterization, assessment of exposure, nanotoxicity and development of predictive models? What other metrological approaches need to be established for nanoscale materials?
- What research is required to gain a clearer understanding of nanomaterials behaviour in the major matrices of water, air, and soil? What are the relevant properties and indicators that would serve as a foundation to an understanding of the physiochemical properties of nanomaterials?
- What process could be developed for evaluating potential nanomaterial lifecycle assessments, including data against a variety of endpoints that would be relevant to human health and the environment?
- How can we evaluate the relative impacts and risks of nanomaterials in a biological context? What are the potential penetration parameters across natural barriers and defences (e.g. relationship between size/structure and penetration, active vs. passive transport, etc.)? What approach should be taken to understanding behaviour at the cellular level when exposed to nanoscale

materials? Would a cellular level understanding help serve to validate current test methods or arrive at new ones?

- Given the limited funding available for assay development in nanotechnology research, how should we rationally prioritize research projects? How can we differentiate between the "need to know" and the "nice to know" research in this emerging area?
- Are current reference samples appropriate for nanoscale materials?
- Currently, the term nanotechnology encompasses a large number of different technologies and approaches, with distinct issues and needs. Would it be advantageous to "decouple" these various technologies rather than dealing with all the potential aspects of nanotechnology under one single term? How could a clear basis for appropriate groupings of technology be established? Are there aspects of nanotechnology that should remain combined for some research purposes?

B. Research Gaps in the Broader Ethical, Legal, Economic and Social Contexts

- What impacts are emerging technologies such as nanotechnology likely to have on the social contract and cultural aspects of our lives, both negative and positive? Could their effects on social cohesion, human security, privacy, health and perceived well being be changing and, if so, what are the impacts of these changes? For example, what are the implications of technologies that allow some individuals to buy longer life or better health and to what extent are they acceptable to Canadian society? What are the appropriate tools for measuring them and how do we find them?
- Could the study of science and technology innovation as well as how social science has influenced basic science in other fields be relevant for nanotechnology? Are there common research approaches to emerging and converging technologies that could be examined for more specific nanotechnology issues? Are there relevant inventories of current research in other social science fields that may be relevant for nanoscience more broadly?
- What has been learned from the fields of neuroethics (neuroscience and ethics) and bioethics (including genomics, stem cell research, etc.) that could be relevant for nanoethics? What else could be involved in helping to understand the transferability of this knowledge and experience?
- What place does nanoscience currently occupy within the existing research, ethical, legal and economic research communities? What research would be required to develop a fuller understanding of what nanoscience currently encompasses, and what it may potentially encompass, in all disciplines?
- Are there studies of the effect of ongoing rapid change on economic and social structures that may be relevant for nanotechnology? What have the impacts of nanotechnology been to date? What should and will influence

plans for future re-organization? How can research into economic and business models, including commercialization strategies, be aligned with ethics and related domains? For example, what ethical constructs can be established to cover academic/government/industry partnerships?

- Are the emerging nanotechnology intellectual property patterns consistent with other technology fields, such as biotechnology? Are there lessons about the legal and ethical implications to be learned from biotechnology? What are the current approaches in marketing and labeling of nanotechnologies to the public? What would be the most effective labeling approaches (e.g. informative, not directive)?
- What are the societal acceptance or rejection limits of certain new technologies? Are they regionally or internationally different, and how are they linked to culture? For example, bioengineered foods created a huge outcry in the United Kingdom. However, there was relatively little concern about them in Canada and the United States.
- How does consumer behaviour affect the overall impact of nanotechnology on society? What drives consumer willingness to buy some products but not others? Can we determine which nanoproducts may be acceptable and which may be objectionable?
- Are there ethical issues posed by surveillance in a nano-enabled world? Is it possible to determine the extent to which privacy concerns could be affected by nanotechnology? Are these distinct issues for nanotechnology, or are differences just a matter of degree? What sorts of disclosure requirements should surround nano-surveillance, and what would the role of government be? Is it possible to identify historical mechanisms that have been applied to balance benefit against real or perceived losses of privacy or freedom?
- What are the ethical considerations in deciding which aspects of nanotechnology should be publicly funded, who should have input into those decisions, how those decisions should be made and how the assessment of benefit to the public should take place? Is it appropriate, or even possible, for current ethical decisions to bind future generations of Canadians? Can ethical decisions be made in contexts that are globally applicable?

C. Health and Environmental Issues and Risks

- How can we better understand the intricacies of detecting nanomaterials and their behaviour in complex systems, such as human bodies or the environment?
- Predictive models for human health will require a range of data on chemical properties, physiological functions, pharmacokinetics (distribution in the body, absorption, excretion and metabolism) and toxicological information.
- What degree of exposure to nanomaterials is already happening now? What materials are people or the environment being exposed to? Are there any

monitoring programs in place? What would be required to develop the appropriate metrology for assessment? What would be appropriate indicator species for nanomaterials? How should these be validated?

- In terms of occupational health and safety, what are the specific issues surrounding protection of those who work with nanomaterials? How are decisions about worker protection currently being made in industry and government labs? What are the most appropriate tools to measure the extent of worker risks, including physical tools (metrological) and theoretical modeling tools?
- The traditional industrial hygiene model uses engineering controls, administrative controls and personal protective equipment to deal with issues of occupational health and safety. Is this approach adequate and/or sufficient for dealing with nanomaterials? Are specific, precautionary adaptations of the traditional approach warranted?
- How do we ascertain that models for environmental fate and transport are valid for nanomaterials? How do we ascertain that existing environmental monitoring/detection techniques/programs are valid for nanomaterials (i.e. what tools and methodology are required)?
- Persistence is relevant to toxicity. It is not known what happens when nanomaterials agglomerate in the environment. Do they continue to be environmentally available and thus a potential human health risk, or are they no longer persistent in terms of bioavailability and toxicity?
- What are the environmental exposures to, and potential health risks of, nanomaterials for emergency responders? What are the risks over the full lifecycle of these materials?
- How can emergency preparedness and contingency planning capacity in the area of nanotechnology safety best be developed, incorporating different disciplines and fields (e.g. information clearinghouses, coordinated outreach strategies, etc.)?
- How should the various professional societies in Canada that may be affected by nanotechnology be engaged? What role should they have in initiating and mediating debate around environmental and health issues?
- What are the potential benefits of nanotechnology in an environmental context? How can environmental remediation technologies, water filtration and purification and safe food practices be enhanced by nanotechnology? How do we meaningfully capture the benefits of nanotechnology and appropriately weigh them against the risks?

D. Governance, Regulatory and Policy Gaps

- Who should lead in championing research into the human health and environmental risks of nanotechnology? Within the Canadian context, who should drive policy and governance issues in the near term? Who should drive policy and governance in the next five-to-ten years as nanoscience and the technologies it spawns continue to accelerate?

- What are the potential risks of not developing a coordinated national nanotechnology strategy for Canada? For example, could integration of nanotechnology into such projects as pollution prevention or remediation capacity be at risk in the absence of any mechanism for assessing their impact?
- Given that there are no well-articulated governance rules for nanotechnology, and the regulatory environments for nanomaterials and products containing them is unclear, how should we guide the development of a rational approach to governance? Given the complexity of Canadian governance models, including federal, provincial, territorial and municipal jurisdictional issues – and the complex inter-relationship among government, the private sector and the not-for-profit sector – what kind of practical modeling of governance structures could be developed? Would a comprehensive survey of available resources be useful? How should such a survey be conducted?
- Are there appropriate interim approaches to governance that could be explored and rolled out while broader comprehensive governance and policy is being developed? What regulations and measures must be put in place immediately while waiting for a new regulatory framework for nanoproducts to be developed? Should we prioritize regulations for products that are likely to be before regulators in the very near future (e.g. nanoencapsulated nutrients in foods)?
- What are the best measures for a risk-benefit analysis in nanotechnology? Potential research gaps could include: risk tolerance, social acceptance of risk, issues of consumer choice, life-cycle analysis and social and economic consequences from both local and global perspectives.
- Are there lessons learned in the governance of other emerging technology areas (e.g. genomics and biotechnology) that would be relevant in the design and implementation of a Canadian policy and strategy in nanotechnology? Are there lessons learned with nanotechnology that can be used on other new and emerging technologies?
- Would the spectrum of acceptable risks be different in areas where there are significant expected benefits from nanotechnology (e.g. new cancer treatments, pharmaceuticals, etc.)?
- At present, a great deal of attention is focused on technologies with large potential economic impacts. What about the interface between government and small- and medium-sized enterprises? How can the impetus to ensure domestic commercialization of Canadian research and development expertise be reconciled within a governance framework?
- While there is a clear knowledge gap in terms of fundamental research and the application of research results, there is also a lack of vision about what aspects of nanotechnology should be addressed in the policy realm: the cycle

of development, individual products or the process as a whole? Whose task should it be to build an updated policy framework, in the absence of underlying principles?

- How can the resources – both human and financial – be mobilized to accumulate the necessary scientific data that are needed for proper risk assessments of nanomaterials?
- How can we ensure that policies are not out of step with, or lagging behind, what is happening elsewhere in the world, and that there is a thorough understanding of the impact of intervention with various stakeholders? What is the possibility of, and the precedent for, voluntary approaches to nanotechnology regulation?
- What are the potential parameters needed to govern the scope of monitoring of industrial nanotechnology operations and current products and research? How can we ensure appropriate resources are allocated for effective application, once appropriate measures are identified?
- How can Canada ensure that its knowledge respecting Ethics, Health and Safety (EHS) are shared appropriately with less-advantaged countries?
- Given that research communities and granting agencies often tend to operate in silos, what approaches will allow for truly multidisciplinary research to be integrated both in terms of funding and outcomes? How can the distinct peer-review methodologies for the social sciences, physical sciences and biomedical sciences be successfully integrated to accommodate meaningful partnerships?

E. Public Engagement and Communication Needs

- Can social science communication and knowledge translation (KT) expertise be deployed to help develop communication strategies that are tailored to the intended audience and reflect an appropriate level of complexity? What information do individuals need to be able to make good decisions, and is it possible to frame it in a way that allows good decision making without a highly technical knowledge of the science implicit in nanotechnology? How do we inform members of the public about safety issues without overloading them with information to the point where they fail to respond, or respond inadequately?
- What are the significant gaps between public deliberation, level of scientific understanding and public policy? What translational activities could move beyond the gathering of information to the incorporation of that knowledge into policy in the public interest? What are the best ways to engage the public, decision makers, the media and other stakeholders in nanoscience research? How do you assess what tools need to be developed or applied for greater societal engagement, and how do you measure their effectiveness? What can we learn from activities undertaken in other jurisdictions?

- What previous communication campaigns and strategies have been attempted with other new and emerging technologies? In Canada? Elsewhere? Are there important elements with regard to marketing and labeling issues, public response, informed decision-making ability and the creation of public capacity that could be relevant for nanotechnology?
- How can decision makers be better informed of the state of public opinion and values? How can appropriate avenues for meaningful communication among stakeholders be built?
- How could the fine arts, drama and other ways of building interest and understanding be used to inform public discussion on nanotechnology? Creative visualization of modest changes in the future can occur through the fine arts. How could current predictive modeling approaches underway in other disciplines be adapted to nanotechnology?
- What are the public concerns about the EHS aspects of nanotechnology? What are the effects of civic and public management on nanotechnology, including the potential role of NGOs and interest groups and the interface between the general public and research, policy, regulation and governance communities? How can the critics of nanotechnology be incorporated into governance and policy discussions?
- Once decisions about whether and how to fund nanotechnologies and research are made, based on social priorities, how do you determine the best way to fairly distribute the benefits of those investments?

F. Challenges for Interdisciplinary Collaborations

- Issues of knowledge translation and communication are crucial in determining how to facilitate multidisciplinary collaboration among disciplines. How do we communicate findings within our own peer groups and to other groups? How are approaches similar and how do they differ between disciplines (e.g. social sciences, physical sciences, biomedical sciences, etc.)? Are there existing models that could be examined to help build such collaborations for nanotechnology research?
- What types of training and mentoring programs are needed to facilitate effective multidisciplinary teams? Who should lead the development of these training programs, and how should they be managed?
- How could interdisciplinary science teams incorporate policy and governance issues, and what are the practical parameters of their collaborative operation?
- Is it feasible to bring together experts from different backgrounds to help develop a common framework for the assessment of environmental and human health risks of nanotechnology? Or do individual technologies need to be assessed separately?
- How can broader perspectives be incorporated into nanoscience education/curriculum development at all levels? Can research into what

learning styles work at different ages and stages of life lead to a greater commitment to lifelong curriculum development? What organizations are relevant and interested in this discussion? How can they be mobilized to collaborate?

- Is there a need for research into cognitive models of how to conduct foresight and forecasting among disciplines? Does our ability to forecast affect our relationship with emerging technology?

Nanotechnology Research Priorities

With research gaps identified, participants were grouped into multidisciplinary tables and asked to develop a relative list of potential priorities, based on everything they had heard over the preceding two days. Rather than prioritize the actual list of research gaps established for each of the four theme areas, participants were asked to consider all areas of nanotechnology research broadly when developing their priorities. For this portion of the workshop, participants were asked to consider both short-term and long-term priorities.

Short-term priorities were defined as areas of research that are critical to address in the near-term. Many of these priorities are inherently complex and will not be adequately resolved in the near term, but progress toward them needs to begin. In many cases, these short-term priorities are also reflected in longer-term goals.

Long-term priorities were defined as key areas of research with a longer-term horizon. Many of these priorities cannot be addressed until some progress is made on the short-term priorities. Classification as a long-term priority was not meant to imply that these priorities were less important than short-term priorities, only that short-term priorities need to be addressed first.

Rather than rank these priorities in a definite order, participants chose to emphasize specific key areas of research within both the short-term and long-term time frames. Note that these groupings are in no particular order, and simply represent a summary of working table discussions on priorities.

The results of these discussions are summarized below.

Short-term Priorities

A. Development of Analytical Tools and Baseline Studies

Virtually all participants identified the need for greater basic understanding of nanomaterials and their interaction with biological systems. Development of analytical tools for the detection and characterization of nanomaterials is of paramount importance. Existing methodology needs to be expanded in the area of physical and chemical characterization of nanomaterials, as there is a great need for tools and techniques to distinguish nano from macro properties of the same material. Bioanalytical, metrological, and performance matrices for nanomaterials, as well as standardization of test methods and reference materials, are key issues.

In order to perform the necessary lifecycle assessment, understanding of potential biological interactions with nanomaterials is also critically needed. This requires determination of pharmacodynamic/pharmacokinetic properties and distribution effects for different nanomaterials. New tools are needed for predictive biomodeling of nanomaterial-biological interactions, including mechanistic studies to understand the specific biochemical properties of nanomaterials that are potentially relevant for EHS issues.

Development of a consistent nomenclature and taxonomy would facilitate communication among all stakeholders, although this would be hard to achieve in the short term. Coordination with international activities already underway in this area is important. An inventory of international and national nanotechnology activities that correlate classification schemes with research and discoveries could prove an aid in multidisciplinary collaborations.

B. Development of Science Research Agendas

Participants felt that a coherent funding strategy that includes health, social and physical scientists would be beneficial. Such a strategy should contain frameworks for facilitating interactions among cross-disciplinary researchers and multidisciplinary teams for effective projects. This could include holding regular national forums similar to this one, bringing together scientists, government representatives, economic decision makers and consumers.

Participants also felt it was important to explore communication models more broadly for engaging scientists, industry and the public to promote better understanding of the risks and benefits associated with nanotechnology. This would lead to greater stakeholder empowerment and informed decision making. This should be informed by NE^3LS issues, learn from the experience of other platform disciplines and create a framework capable of being used on other new and emerging technologies.

C. Development of a Canadian Governance Regime

For a number of participants, the ideal governance regime is a comprehensive Canadian regulatory framework that can be translated across jurisdictions and sectors, in which all stakeholders can continuously interact and have input – not toward a specific goal, but in an ongoing interactive forum, with particular attention to ensuring equitable access to the benefits of nanotechnology.

In the short term, it was felt that alternatives to traditional regulatory structures should be explored that could facilitate the responsible development of nanotechnology in the immediate future, either in place of formal regulatory structures or while these frameworks are being developed. A system for monitoring technology trends, economic development, investment in nanotechnology and social integration was also seen as desirable.

Several participants felt the need to have identified national champion(s) for nanotechnology –an individual, organization, or group of organizations – who could promote the proactive engagement of physical sciences, social sciences and humanities, industry, government and the public.

Longer-term Nanotechnology Priorities

A. Research and Training

In the longer term, participants recommended the incorporation of emerging research results on toxicity and biointeractions into ongoing research projects. More broadly, this could also involve tracking economic, social, environmental and physical effects of nanotechnology as part of research projects, with the goal of using these data to reengineer nanoparticles to make them safer or to develop new applications. Using these findings to develop new applications to mitigate possible harmful effects of nanomaterials was also highlighted. Participants felt that ensuring that inventoried information is fed back into the research system will yield recurring cycles of improved products and safer outcomes.

It was felt that there are significant opportunities to leverage research to enhance Canadian strategic niches and associated human capacity by identifying strategic issues where a more focused powerful impact is possible. An evaluation of the training of highly qualified people in nanotechnology will be necessary, which will provide further insight into the success of multidisciplinary approaches and assist in designing training approaches in the future.

B. Economic Development

While participants felt there should be a continued focus on facilitating research and development of nanomaterials, a number also emphasized the need to ensure that it leads to commercialization that benefits Canadians. There is a need to evaluate different approaches to intellectual property to determine the most effective devices for ensuring copyrights, patents, etc., to promote and protect Canadian innovation. Studying the reasons for limited industrial engagement in the nanotechnology sector in Canada and developing a plan to encourage heightened private-sector involvement was also suggested.

C. Fostering a Canadian Nanotechnology Framework/Strategy

To develop a coherent national nanotechnology framework or strategy for Canada, participants felt that dedicated resources, defined deliverables, interfaces with other emerging technologies and potential opportunities for convergence need to be developed. Annual national forums on nanotechnology that unite social and physical scientists, regulators, industry and representatives of the public were proposed to help ensure that knowledge transfer on risk can continue to evolve. Participants also highlighted the need for integration with other international strategies for using nanotechnology to promote the public good and ensuring that the concept of equitable access to benefits is applied consistently.

Coordination was mentioned repeatedly, sometimes in the context of leadership and sometimes in terms of resources and support. There was also general agreement that "all the funding in the world" will not address the issues raised, unless the right set of tools is used to appropriately deploy resources. Specifically, there was a perceived lack of research capacity in this field, which needs to be addressed through targeted programs. Communication, public engagement and a whole array of critical science gaps in terms of environment, health impacts and nanomaterial characterization were also major points.

Conclusions and Recommendations

This report provides a summary of the participant discussions at the Canadian Workshop on Multidisciplinary Research on Nanotechnology: Gaps, Opportunities and Priorities. It details the key nanotechnology research gaps that were identified by participants at the workshop, and outlines a general set of recommended priority areas.

The main goal of this workshop was to develop a list of key nanotechnology research gaps that could serve as a starting point for future targeted funding programs. While not ranked in any particular order, the extensive list provided here offers a clear set of research needs that is not limited to any one field, discipline or theme of research. These gaps highlight common concerns and issues across all domains of research that will need to be addressed for nanoscience and nanotechnology to reach their desired impacts. Many of these key research gaps will require multidisciplinary approaches, as the issues raised are broader and more inter-connected than any one agency, discipline or field could resolve on its own.

A second major activity of this workshop was to provide general guidance on relative priorities for nanotechnology research. This exercise was not intended to provide a detailed timeline or sequence of activities, but to elucidate fundamental imperatives and priorities. Responsibility for enacting these relative priorities does not fall to any one specific group or audience. Rather, participants and sponsors were encouraged to consider these relative priorities when setting their own research programs or strategic exercises.

In addition to these key outcomes, another expectation of this workshop was to build greater linkages among participants from different disciplines and fields and help create greater mutual awareness of the potential positive outcomes of nanotechnology as well as the potential risks and needs. Over the course of the workshop, participants returned to core concepts that confirm a fundamental need to proceed on a resolutely multidisciplinary basis. These key concepts/recommendations were identified as important cornerstones for progress in dealing with the issues:

- Better coordination and integration of all disciplines in nanotechnology is necessary.
- Multidisciplinary working groups are needed to ensure open dialogues and access to ongoing nanotechnology debates.

- Funding is important not only for basic science but also across the entire spectrum of policy development, governance and social and ethics research.
- Public engagement and its facilitation by all nanotechnology stakeholders is needed.

The emphasis placed on identifying gaps, opportunities and priorities in Canadian nanotechnology encouraged a range of opinions on how current strengths can be enhanced and weaknesses resolved. But it also led to a greater understanding of how stakeholders from different backgrounds, disciplines and perspectives could work together to move this research agenda forward. The future health of nanotechnology in Canada can only be secured if the science is advanced within the bounds of a multidisciplinary framework, supported by adequate tools and resources. Only through the concerted efforts of individuals in all disciplines that exert an influence over the present and future course of Canadian research will nanotechnology safely achieve its potential benefits for all of society.

Multidisciplinary Research on Nanotechnology: Summary of Gaps, Opportunities and Priorities

A. Key Research Gaps and Needs

1. Basic Science Gaps and Research Challenges
2. Research Gaps in the Broader Ethical, Legal, Economic, and Social Contexts
3. Health and Environmental Issues and Risks
4. Governance, Regulatory and Policy Gaps
5. Public Engagement and Communication Needs
6. Challenges for Interdisciplinary Collaborations

B. Short-term Research Priorities

1. Development of Analytical Tools and Baseline Studies
2. Development of Science Research Agendas
3. Development of a Canadian Governance Regime

C. Long-term Research Priorities

1. Research and Training
2. Economic Development
3. Fostering a Canadian Nanotechnology Framework/Strategy

D. Recommendations

1. Implement multidisciplinary working groups
2. Coordinate and integrate all disciplines in nanotechnology
3. Ensure funding for basic science, policy development, governance and social and ethics research
4. Facilitate public engagement

APPENDIX A: Keynote Presentations

The workshop began with four keynote presentations along the general themes identified by the workshop steering committee:

1. Ethics and Related Domains
2. Policy, Regulatory Development and Governance
3. Science, Environmental and Health Risks
4. Social Science and Humanities Perspective

These presentations were primarily intended to provide basic background information to participants to assist them in framing the general terms of discussions over the remainder of the meeting.

Theme 1: Ethics and Related Domains

Keynote: Nanotechnology – Technological Development and the Significance of NE^{3}LS Issues

Lorraine Sheremeta, LLM
Research Associate, Health Law Institute, University of Alberta
Research Officer, National Institute for Nanotechnology, Edmonton, Alberta

The legal implications attached to nanotechnology's increasing importance in both science and consumer applications present a set of key emerging issues. NE^{3}LS is an important aspect of nanoscience research, because it recognizes that particles in the 1–100 nm range have fundamentally different physical and chemical properties than their macro-scale counterparts. The trend toward the development of distinct nano-based products, coupled with the ongoing enhancement of existing consumer products with nano-applications, has the potential to span and affect all human endeavours. In this context, understanding the entire nanoparticle lifecycle becomes paramount.

NE^{3}LS research includes the consideration of a number of potentially conflicting factors, including the potential for societal transformation; the risk to humans from the research stage through the ultimate disposal of nanomaterials; the drive for profit; and the relatively short timelines available to achieve positive results.

The Canadian nanotechnology sector faces unique challenges. In addition to geography that inhibits research contacts, no national strategy is currently in place, and the various provincial nano-initiatives are not necessarily coordinated to maximize research efficiencies. Canada's situation stands in stark contrast to a US research effort that will direct approximately $1.4 billion into nanotechnology in 2008.

Legal and jurisdictional issues in Canada are also important in efforts to take NE3LS research forward. The overlapping mandates of Environment Canada, Health Canada, and various provincial occupational health and safety agencies has led to significant regulatory complexity. For example, the language of applicable current regulations for new substances does not contemplate altered mass quantities for the reporting of certain nano-scale materials.

Public perception concerning the current state of nanotechnology was also discussed in this session. While nanotechnology and its applications have been depicted in both a positive and negative light relative to the public good, the risks associated with nanotechnology remain relatively unknown. NE3LS research is seen as a potential means to bridge these gaps.

Theme 2: Policy, Regulatory Development and Governance

Keynote: Public Policy and Nanotechnology — Choices and Implications

David Muddle
Regional Director, Healthy Environments and Consumer Safety, Health Canada

Nanoscience and nanotechnologies will have an impact on the frontline programs and services provided by a number of public agencies. This presentation focused on this impact. The regulation of products is the most visible area of concern at this intersection between nanoscience/nanotechnology and public policy.

Four elements were identified in the context of "a public policy primer":

- "Public Policy 101" (how public policy is defined)
- Policy design and frameworks
- Nanotechnology and public policy
- Health Canada's draft framework for regulating the products of nanotechnology

Public policy was defined as a conscious choice made by government – including the option to choose action or inaction – depending on the policy direction selected. Public policy was characterized as a broad framework that lends itself to the use of specific policy instruments or tools that are connected to the related concepts of values, choices and moral acceptability. The distinction was made between rational decision making and value-based decision-making processes.

Public policy has to balance differing interests. International policy making in particular will involve multiple perspectives, all of which are inherently value-based. Risk-benefit ratio was cited as an important consideration in this policy context.

In terms of establishing framework policies to govern complex issues, public authorities often try to set parameters within which others can leverage existing capacity and work. This approach recognizes the inherent limitations of government, particularly regarding the cost of overseeing such development. Nanotechnology presents a challenge for policy makers, given that nanotechnology is a convergence of both the revolutionary and the familiar. The speed of nanotechnological innovation and the rapidly decreasing cost per unit in some nano-sectors are two of the challenges facing government.

A goal of government regulation is assisting the public in making sound decisions. This requires a solid evidence base and a robust risk-decision-making framework. Health Canada is attempting to frame these discussions as it explores issues around nanotechnology and the department's existing mandate and authorities.

Theme 3: Science, Environmental and Health Risks

Keynote: Nano-risk or Nano-myth? A Science Perspective on Safe Nanotechnology

Andrew Maynard, PhD.
Chief Science Advisor, Project on Emerging Nanotechnologies, Woodrow Wilson International Centre for Scholars, Washington, D.C.

A number of perspectives was explored in the third presentation. Three elements of nanoscience – that it is small, that it is strange (to the uninitiated) and that it is highly sophisticated – were emphasized as a means of establishing the uniqueness of the field.

Nanotechnology represents a remarkable opportunity to better our existing world and quality of life. In addition to prospective wealth generation – estimated at $2.6 trillion in the next generation – nanotechnology heralds a world of better and more durable consumer products. The development of higher-quality materials, more efficient energy storage, better water quality and more effective pharmaceuticals all have the potential to improve everyday life for many people. However, nanotechnology can only fulfill this predicted promise if it is sustainable.

Sustainable nanotechnology is built on three foundational concepts: a balance of benefits vs. risks, response and regulation.

Determining risk is of primary importance. Nanomaterials have shown physical and electrochemical qualities that raise new and challenging questions for science. Of particular importance is the recognition that nano-risks are often scale-specific hazards—for example, in the observed characteristics of differing sizes of zinc oxide and titanium dioxide nanoparticles. The relationship between the limits of conventional understanding of particle behaviour and unconventional understanding was illustrated. Particle structure, as expressed by particle size and particle shape, and the potential toxicity of certain nanoparticles, is an important nanoscience frontier.

Further examples of scale-specific hazards were presented:

- The "translocation rate" of two different-sized particles as observed in the human lung and the human liver;
- the ability of certain nanoparticles to seemingly avoid the conventional blood–brain barrier and achieve entry directly into the human brain via the nose and its related nerves; and
- the perceived insufficient protection by healthy human skin, traditionally regarded as a significant barrier to toxic particles, against potential nanoparticle entry into human systems.

Nanobiological interactions were also identified as a potential risk. DNA research has long been understood to have the potential for initiating profound changes at the molecular level. By extension, the possibility now exists for nanoparticles to modulate and ameliorate certain diseases.

The hazards presented by various aspects of nanotechnology are imperfectly understood. No significantly grounded knowledge base yet exists to perform the thorough risk assessments required to safely advance nanoscience and nanotechnology. To address that deficiency, several necessary steps were set out. Starting with the premise that knowledge reduces risk, priority was given to the general research necessary to provide an appropriate knowledge base:

- **"Decouple" nanotechnologies:** Pull the various technologies apart and examine specific applications from a risk/safety perspective. The term "nanotechnology" must not be limited to a single area; decoupling the wider technologies into specific applications will have the additional benefit of requiring applications to be explained in common language that can be more clearly understood by broader segments of society.
- **Establish boundaries:** Which types of nanoparticles are likely to enter the body? Which of these particles are likely to interact with the body? Nanoparticles as conglomerates, aggregates, and aerosolized forms were each considered in this context.

- **Consider unintended use and consequences:** What measures are in place to deal with scenarios in which "someone does something stupid" with the technology?

With general research objectives established, specific research can be targeted at the following "five grand challenges"—concerns that arise in any consideration of the safe handling of nanotechnology:

- Proper instrumentation and keen attention to the principles of metrology;
- effective and relevant nanotechnology toxicity testing; for example, the screening of fibre-shaped nanoparticles;
- prediction systems and the potential impact of new nanomaterials;
- life cycles—the impact, both present and future, of nanomaterials from creation to disposal/destruction; and
- strategically focused research.

Theme 4: Social Sciences and Humanities Perspectives

Keynote: Building Bridges – Engaging the Social Sciences, Humanities, and Fine Arts in the Debate about the Future of Nanotechnology

Ken Coates, PhD.
Dean, Faculty of Arts, University of Waterloo

Social sciences, the humanities and fine arts, as areas of research, do not currently occupy a position of primacy in nanotechnology. However, it is clear that many fields within the social sciences have a significant collaborative role to play within the context of nanoscience. To be successfully elevated to the position of importance it deserves in Canada, nanotechnology must be resolutely multidisciplinary. The phenomenal public fascination with what nanotechnology and its applications can achieve is a useful springboard from which Canadian society can truly embrace the future.

A fundamental shift in Canadian educational practices on both sides of the science and humanities divide can help increase public engagement. Grade 11 was identified as a natural demarcation point; scientific literacy declines markedly among non-science students from that point forward. Participants expressed concern that modern society has "sucked the wonder" out of Canada's young people: students expect their educators to deliver information in bite-sized and entirely digestible pieces, and educational institutions now teach accordingly. This is a society that has become risk averse, one in which failure is feared. However, the challenges of a nanotechnology-enabled world suggest an opposite approach is warranted.

Educational issues in the context of the social science/hard science dichotomy lead to broader consideration of the role of the media and the engagement of the public in the nanotechnology debate. This challenge is exacerbated by the relatively low level of science journalism in this country, although some exceptions were noted.

Participants were encouraged to explore the relative lack of shared ideas and common language among physical science, social science, fine arts and the humanities. The effectiveness of creating linkages across disciplines as a means of explaining modern science and promoting a better understanding of nanoscience to the general public was stressed. In the absence of better educational approaches for using the social sciences in the nanotechnology realm, Canada's nanoscience research will lack an essential element: loyalty to a regionally rooted research structure. This is a negative consideration in an increasingly global environment. The ability to cross disciplinary boundaries would strengthen Canada's ability to lead in nanotechnology research and innovation.

APPENDIX B: Additional Presentations

Four additional presentations took place over the three days of the meeting. Each provided information on relevant aspects of nanotechnology.

Efforts by the Government of Alberta to Support its Nanotechnology Sector

Ronald Dyck, PhD.
Assistant Deputy Minister of Research, Alberta Advanced Education and Technology

Alberta seeks to capitalize on the commercial opportunities presented by nanotechnology, as a means both of boosting the educational capital of its citizens and its institutions, and of exploiting emerging markets for nanotechnology-enhanced products. The province has developed and adopted a comprehensive nanotechnology strategy, announced investment of $130 million over the next five years, and recently announced a $100 million accelerator for nanotechnology.

The province is strongly committed to nanotechnology and is home to an emerging cluster of more than 45 companies selling nano-related products.

Strategies are often developed from the front end. Alberta's success is predicated on its having built backwards—beginning with a vision of where they wanted to arrive (producing 2% of the world's nanoproducts)—and then asking key questions about what it would take to get there in terms of business and investment attraction, workforce development, infrastructure and partnering.

The strategy also focuses on developing nano-enabled products and technologies, specifically aimed at the province's key industries:

- Energy and environment
- Health and medical technologies
- Agriculture
- Forestry

Nanotechnology: Accelerating Alberta's strategy

Peter Hackett, PhD.
President and CEO, Alberta Ingenuity Fund

This address was predicated on the notion that "we are but stones in the river in this flow of technology". We may not be moved by it, but we cannot stop it; it will flow around us and keep going, and like stones in a river, we will be shaped by its currents—whether we choose to be or not.

There is a clear need to adapt quickly and effectively to today's rapidly increasing rates of innovation. Alberta Ingenuity's Nanotechnology Accelerator is designed to help nanoscience and development in the province keep pace with that degree of innovation.

The Accelerator takes advantage of the strong risk-taking, entrepreneurial spirit in the province, and tries to match individuals' creativity with society's capacity to accept innovation by funding goal-oriented projects, designed to have maximum impact.

It was noted that when agendas are set, voices are often absent from the table. The developing world rarely has a place in the process. The development of an innovation economy in the developing world would be a positive outcome. The mobilization of resources and efforts to foster exponential innovation in the developing world might counterbalance some serious challenges, and consideration of that fact should be part of developing partnerships and moving regional, national and global nanotechnology innovation strategies forward.

The Purpose and Function of the National Institute of Nanotechnology (NINT)

Nils Petersen, PhD
Director General, National Research Council, National Institute for Nanotechnology

This presentation, which introduced the National Research Council National Institute of Nanotechnology (NINT) and described some of the critical research and inter-relationships that it fosters and supports, began with an historical description of the advance of science over several eras. Each of these distinct scientific periods was based on scale:

- The meter scale, characterized by tools and implements like swords, spears, ploughs and the wheel;
- the millimeter era, which allowed humans to work in much smaller scales and design tools that allowed humans to do new things like navigation;
- the micrometer scale, which saw the invention of the microscope and the evolution of sophisticated medical tools and observations of cellular activity; and
- the nano scale, which is heralding a new set of technologies that are revolutionizing human society.

Nanotechnology is occurring at a point in time when there is convergence between understanding the worlds of physics and biology. This will also have a revolutionary impact. Nanotechnology is inevitable; it is already happening and it does matter profoundly to Canadian and global society. It is important to continue the quest for understanding through fundamental knowledge of physical phenomena, the development of new applications and methodologies for assessing their impacts.

The value of NINT is that it creates a relationship between an academic research environment and the National Research Council. By pairing research and applied science in a trans-cultural institute, it is possible to achieve the twin goals of creating research results and facilitating the translation of those results into economic development.

Working Together for the Responsible Development of Nano-scale Materials: An Industry Perspective

Terry L. Medley, J.D.,
Director of Global and Corporate Regulatory Affairs, DuPont, Inc.

Participants from all disciplines directed considerable attention to the multi-faceted question of risk assessment. This presentation concerning the newly-developed Nano Risk Framework was presented by Terry Medley.

The framework, as devised by a team sponsored by DuPont, is designed to ensure the responsible development of nano-scale materials.[2] DuPont sought a framework that would produce risk-management outcomes that are practical, comprehensive, transparent, and flexible. DuPont has published this framework so that its risk-management process can be used in industry and government.

The framework overview can be summarized as follows:

1. Describe the proposed nanomaterial and its intended application.
2. Profile the lifecycles in three distinct ways: the nanomaterial properties; inherent hazards; and associated exposures.
3. Evaluate risks.
4. Assess risk management.
5. Decide, document, and act.
6. Review and adapt.

Workshop participants referred to the DuPont Nano Risk Framework when considering the lack of a comprehensive risk-assessment tool available to the science, policy and ethics constituencies. The framework was also considered in the priority-identification process that brought the workshop to its conclusion.

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[2] These materials were provided to all workshop participants; the materials and supporting information can be found at www.NanoRiskFramework.com

Acknowledgments

Steering Committee

Lori Engler-Todd, Health Canada

Jaime Flamenbaum, CIHR

Laurent Gémar, Health Canada

Stella Kemdirim, Environment Canada

Eric Marcotte, CIHR

Terry McIntrye, Environment Canada

Craig McNaughton, SSHRC

David Muddle, Health Canada

Barbara Muir, NSERC

Jeffery Nerenberg, NSERC

Marsha Permut, Industry Canada

Lori Sheremeta, NINT

The steering committee wants to acknowledge the support given to this initiative by

Kelly Borecki, Health Canada

Lynne Cayer, CIHR

Yumna Kanda, CIHR

Kimberley Mageau, CIHR

Micheline Prezeau, CIHR

Melanie Sabourin, CIHR

Participant List

Note : Participant primary affiliation based on information available at the time of the workshop (January, 2008).

Last Name	First Name	Institution	Status
Adlakha-Hutcheon	Gitanjali	Defence Research & Development Canada	Participant
Alton	David	University of Alberta	Participant
Atkinson	Andy	Environment Canada	Participant
Beaudry	Nicole	Commission de l'ethique de la science et de la technologie	Participant
Berezan	Candice	Alberta Advanced Education and Technology	Participant
Bernatchez	Stephane	Health Canada	Participant
Blakey	David	Health Canada	Participant
Brommeland	Rick	National Research Council of Canada	Participant
Bucci	Lucie Marisa	Université de Montréal	Participant
Burgess	Michael	University of British Columbia	Participant
Carlson	Linda	Health Canada	Participant
Caulfield	Tim	University of Alberta	Participant
Chan	Warren	University of Toronto	Participant
Coates	Ken	University of Waterloo	Speaker
Cohen	Michael	Canadian Food Inspection Agency	Participant
Cramb	David	University of Calgary	Participant
DallaVia	Renzo	Centre for Health and Safety Innovation, IAPA	Participant
Davis	Thomas A	Environment Canada	Participant
Deleury	Edith	Commission de l'ethique de la science et de la technologie	Participant
Dyck	Ronald	Research Innovation and Science	Speaker
Einsiedel	Edna	University of Calgary	Participant
Engler-Todd	Lori	Health Canada	Participant
Flamenbaum	Jaime	Canadian Institutes of Health Research	Organizer
Foster	Trina	Council of Canadian Academies	Participant
Gémar	Laurent	Health Canada	Organizer
Goss	Greg	University of Alberta	Participant
Green	Doug	Health Canada	Participant
Grutter	Peter	McGill University	Participant
Hackett	Peter	Alberta Ingenuity	Speaker

Participant List, continued

Last Name	First Name	Institution	Status
Haydon	Brian	Canadian Standards Association	Participant
Hosein	H. Roland	General Electric	Participant
Illes	Judy	University of British Columbia	Participant
Jegen	Alain	Sustainable Development Technology Canada	Participant
Katz	David	Department of Industry and Resources	Participant
Keating	Bernard	Université Laval	Participant
Kemdirim	Stella	Environment Canada	Organizer
Klugerman	Abbey	Health Canada	Participant
Kranakis	Eda	University of Ottawa	Participant
Lennox	Bruce	McGill University	Participant
Linkov	Igor	US Army Engineer Research and Development Center	Participant
Liu-Shum	Alice	Health Canada	Participant
MacDonald	Chris	St Mary's University	Participant
Marcotte	Eric	Canadian Institutes of Health Research	Organizer
Materi	Wayne	National Research Council of Canada	Participant
Maynard	Andrew	Woodrow Wilson International Center for Scholars	Speaker
McIntyre	Terry	Environment Canada	Organizer
McKenzie	Robert	Industry Canada	Participant
McLachlan	Stephane	University of Manitoba	Participant
McNaughton	Craig	Social Sciences and Humanities Research Council of Canada	Organizer
Medley	Terry	DuPont Company	Speaker
Mehta	Michael	University of Alberta	Participant
Muddle	David	Health Canada	Organizer
Muir	Barbara	Natural Sciences and Engineering Research Council of Canada	Organizer
Muscati	Sina	Health Canada	Participant
Nerenberg	Jeffery	Natural Sciences and Engineering Research Council of Canada	Organizer
Nielsen	Elizabeth	Consumers Council of Canada	Participant
Permut	Marsha	Industry Canada	Organizer
Petersen	Nils	National Research Council of Canada - National Institute for Nanotechnology (NINT)	Speaker

Participant List, continued

Last Name	First Name	Institution	Status
Prendergast	Philip	Health Canada	Participant
Rancourt	Jason	Health Canada	Participant
Rapold	Patricia	Health Canada	Participant
Reiner	Peter	University of British Columbia	Participant
Roseman	Mark	Ontario Ministry of Research and Innovation	Participant
Semalulu	Souleh	Health Canada	Participant
Sheremeta	Lori	National Research Council of Canada - National Institute for Nanotechnology (NINT)	Organizer
Singh	Baljit	University of Saskatchewan	Participant
Skipper	Nigel	Health Canada	Participant
Stanton-Jean	Michelle	Université de Montréal	Participant
Steele	Alan	National Research Council of Canada	Participant
Stepanova	Maria	National Research Council of Canada	Participant
Tufenkji	Nathalie	McGill University	Participant
Veinot	John	University of Alberta	Participant
Walters	Gregory	Saint Paul University	Participant
Wolbring	Gregor	University of Calgary	Participant
Woodside	Michael	National Research Council of Canada	Participant
Yada	Rickey	Department of Food Science	Participant
Yoon	Ken	Northern Nanotechnologies	Participant