# Nanotechnology Risk Screening using a Structured Decision Making (SDM) Approach: A summary of results from a nanotechnology experts workshop

## Summary Report

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## Background

Regulators and risk assessors face a substantial challenge in managing potential risks from emerging nanotechnologies. Despite the availability of more than 1,300 nano-enabled consumer products, and projections of more than $1 trillion in goods by 2015, from a risk-management perspective important information gaps remain concerning the types, volumes, uses, and net benefits of nanomaterials currently on the market. Furthermore, a high degree of scientific uncertainty over the relationship between nanomaterial characteristics and behaviour makes it difficult to anticipate health and environmental implications, leaving existing risk assessment methodologies poorly suited for a comprehensive assessment of benefits, costs, and risks. Despite these uncertainties, decision-making cannot be put on hold until all of the desired information becomes available.

The responsible development of new nanomaterials and nano-enabled products requires that potential risks are understood and managed before harmful implications occur. Risk assessment approaches based on predictive quantitative models (e.g. nano QSARs) show promise for anticipating risk, however they are still in the early stages of development, and comprehensive and widely-available tools may be a decade or more away. These concerns have been highlighted in numerous scientific reviews, but no consensus has yet emerged about how to move forward. Until such time as more rigorous quantitative assessment tools can be developed, there is a clear need for a robust screening methodology to inform nanomaterial risk management decision-making in regulatory agencies and industry.

## Expert Judgment in Risk Screening

In situations where scientific uncertainty is high, or when new technologies emerge, experts are often consulted to help decision makers form opinions and strategies[1]. Continuing uncertainty about the potential risks of ENMs means that expert judgment will play an important role in assessing and regulating risk. A number of promising expert-driven approaches have been proposed in the nanotechnology domain, including the use of MCDA techniques [2], Control Banding approaches[3], and influence-diagram based models that take into account the ways that ENM physical-chemical phenomena determine complex biological behaviour[4]. Such tools can enable risk assessors and regulators to review and manage risks in the near term, while robust quantitative risk assessment methodologies are developed for engineered nanomaterials. However, there is little agreement between experts on how to utilize nanomaterial properties data to estimate risk outcomes, and how best to structure a screening framework. Consequently, little progress has been made toward the development of widely available tools that enable decision makers to evaluate risks. There is a clear need for a robust risk screening methodology that provides a consistent foundation for the utilization of available data and expert judgment to evaluate nanomaterial risks.

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[1] R M Cooke, "Experts in Uncertainty: Opinion and Subjective Probability in Science" Cary, NC. Oxford University Press (1991).

[2] I Linkov et al., "Multi-Criteria Decision Analysis and Environmental Risk Assessment for Nanomaterials," *Journal of Nanoparticle Research* (January 1, 2007).

[3] SY Paik, DM Zalk, and P Swuste, "Application of a Pilot Control Banding Tool for Risk Level Assessment and Control of Nanoparticle Exposures," *Annals of Occupational Hygiene* 52, no. 6 (2008): 419.

[4] Kara Morgan, "Development of a Preliminary Framework for Informing the Risk Analysis and Risk Management of Nanoparticles," *Risk Analysis* 25, no. 6 (December 1, 2005).

## Workshop Overview

Given this context, Dr. Milind Kandlikar, doctoral student Christian Beaudrie, and Dr. Terre Satterfield from the Institute for Resources, Environment and Sustainability (IRES) at the University of British Columbia (UBC), worked closely with decision analysts Robin Gregory (Decision Research), Graham Long (Compass Resource Management Ltd.) and Tim Wilson (Compass), to organize a Nanotechnology Risks Expert Workshop. The two-day workshop was held at UBC on May 24th and 25th 2012, with the aim of building upon recent expert-based research on the benefits and risks of nano-scale technologies to create a robust *framework for screening human health and environmental risks from nanomaterials*. The workshop focused on several gaps in the nano-risk literature to pilot and refine an initial risk-screening framework developed by the workshop organizers. Key goals for the workshop were to:

1) **Develop an overall bi-directional framework to structure expert judgments of nanomaterial risk assessments**
   a. *To enable forward extrapolation from known ENM properties to estimate exposure and hazard potential from specific nanomaterials and their application (e.g., can be used to identify hot spots for risk, or for comparing and ranking risks from ENMs or products)*
   b. *To enable backwards extrapolation from specific health or environmental concerns to identify problematic ENM characteristics (e.g., can be used to re-engineer ENMs to minimize risks)*
2) **Construct measures and scales for nanomaterial properties and behaviours**

   *For key properties of nano particles, create standard measurement categories and scales as an aid to comparing risks and benefits across different materials*
3) **Suggest a consistent foundation for future expert elicitation of the risks of nanomaterials and thereby facilitate comparisons of impact pathways**

The workshop engaged experts from the nanotoxicology, human exposure, and environmental fate and transport domains, including:

**Vincent Castranova**
Chief, Pathology & Physiology Branch, NIOSH

**Yoram Cohen**
Center for Environmental Implications of Nanotechnology
Professor, Chemical and Biomolecular Engineering
University of California, Los Angeles

**John D. Fortner**
I-CARES Career Development
Assistant Professor
Department of Energy, Environmental and Chemical Engineering
Washington University in St. Louis

**Greg Goss**
Fellow, National Institute of Nanotechnology
Director, Office of Environmental Nanosafety
Professor, Dept of Biological Sciences, School Public Health, University of Alberta

**Gunter Oberdorster**
Professor of Environmental Medicine
University of Rochester

**Sam Paik**
Industrial Hygienist
Lawrence Livermore National Labs

**Gurumurthy Ramachandran, Ph.D., CIH**
Professor and Director of Industrial Hygiene Program
Resident Fellow, Institute on the Environment

Division of Environmental Health Sciences
School of Public Health
University of Minnesota

**Navid Saleh**
Assistant Professor
Civil and Environmental Engineering
University of South Carolina

At the end of this workshop, it was agreed by all participants that a robust Nanotechnology Risk Screening Tool (NRST) would be helpful to many of the key stakeholders: the nano materials industry, academic nano researchers, government regulators, and other groups with a special interest in the future of nano materials.

*This workshop was made possible by the generous support of the Center for Nanotechnology in Society, at the University of California, Santa Barbara (CNS-UCSB), the Center for Environmental Implications of Nanotechnology (CEIN-UCLA) at the University of California, Los Angeles, the Liu Institute for Global Issues, and the Institute for Resources, Environment and Sustainability, University of British Columbia. A full agenda of the two day workshop is available in Appendix A.*

## Literature review

An in-depth literature review of expert-elicitation studies aimed at screening nanomaterial risks revealed several shortcomings. In general, there is a lack of consensus in which physical-chemical properties determine environmental and biological behaviours of nanomaterials. Further, there is little agreement on the relationships between physical-chemical properties, making it difficult to develop causal models to estimate human health or environmental hazards using basic information about physical-chemical properties.

In summary, the literature review found:

- no common language, scales, or measures to describe physical-chemical properties and their relationship to higher order biological and environmental effects
- little agreement on
    - which properties are most important for determining biological behavior
    - organization of properties into a hierarchical categories (categories / sub-categories),
    - how physical-chemical properties relate to health and environmental endpoints

Based on these findings, physical-chemical properties deemed important in determining environmental and biological behaviours of nanomaterials were organized into a simple categorization framework (the initial 'hazards' framework is illustrated in **Figure 1**), as follows:

- <u>primary physical or intrinsic properties</u> which can be *directly measured*: examples include particle size, chemical composition, and shape/aspect ratio.

- secondary physical or extrinsic properties which only *become apparent based on the medium in which the nanomaterial is placed*: examples include dispersability, solubility, and agglomeration.

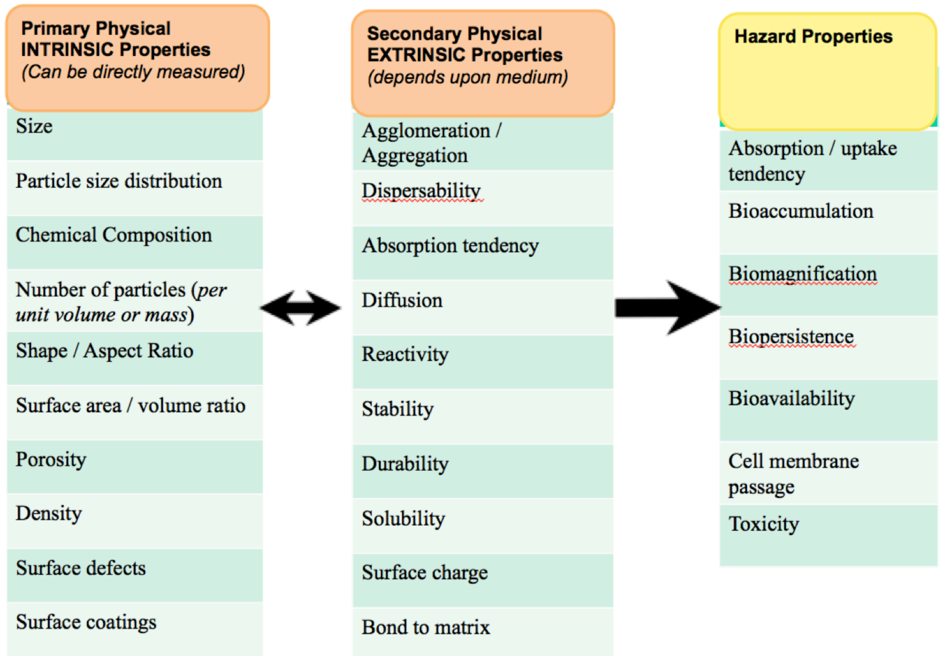



**Figure 1 | Initial primary/secondary properties categorization scheme for nanomaterial 'hazards' based on literature review**

These latter terms are used in nearly all descriptions of nanomaterial benefits and risks but their use is vague and inconsistent, inviting misunderstanding and poor communication. This finding became the central motivation for the use of a Structured Decision Making (SDM) approach in this research. As a result, a primary goal for the workshop was to provide suggestions for the precise and consistent use of these descriptors through the development of a common vocabulary, clearly defined measures or attributes, and influence diagrams to understand the relationships between properties. This approach will help to operationalize an overall framework (*research goal #2*) and enhance the ability of risk researchers to estimate and compare the human health and environmental risks of different nanoproducts (*research goal #1*).

Detailed findings from the literature review will be outlined in a forthcoming journal publication.

## Initial Risk Screening Framework

In preparation for the Nanomaterial Risks Experts Workshop, C. Beaudrie, M. Kandlikar, and T. Satterfield, worked with R. Gregory, G. Long, T. Wilson to develop an initial risk-screening framework based on the literature review and initial categorization scheme. The framework was presented to invited experts to prompt discussion of the pros and cons of different risk screening options. To support this activity several nano-silver and carbon nanotube (CNT) based products were characterized in detail to serve as test cases for the evolving framework (Appendix C).

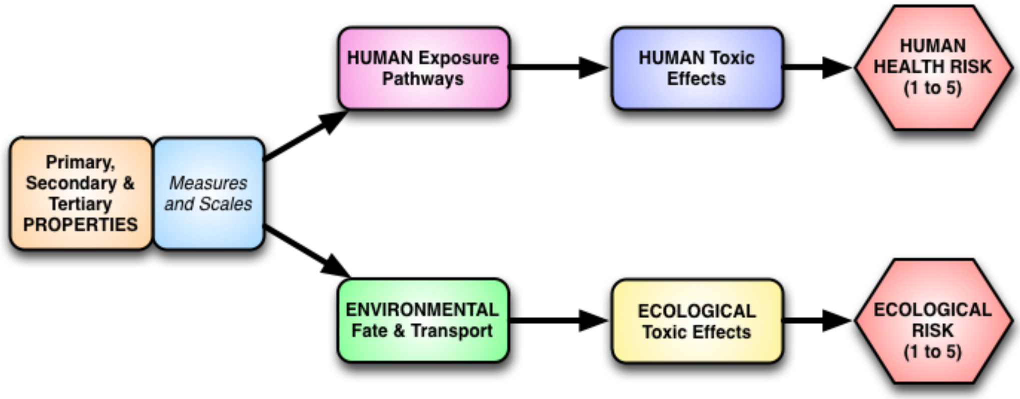



**Figure 2 | Initial Risk Screening Conceptual Overview**

In discussing the immediate needs for such a framework, a useful application around which efforts could coalesce and be organized emerged:

> *Imagine that a web-based risk screening tool were available to regulators and manufacturers of nano-enabled products. Its purpose would be to provide quick and easily understandable insights about whether a proposed product is likely to pose a risk to either human or environmental health.*
>
> *The tool would ask a series of questions that a manufacturer could reasonably answer. These questions would refer to both hazard and exposure elements. Ideally, answers would be in the form of drop-down boxes from which the user could easily select a response. The output of the tool could include an explicit rating of expected regulator concern, and might also include suggestions on which aspects of a product could be changed to reduce the level of concern.*
>
> *The web-based screening tool would not take long to complete, only 20-30 minutes. To the extent possible, the structure of the questions asked would mirror the thinking and concerns of regulators. In addition to providing initial information, the tool would provide a structured basis for discussions among manufacturers and regulators by highlighting a set of key hazard- and risk-management issues that are of concern to regulators and over which manufacturers have some control.*

## Nanotechnology Risk Screening Tool

The two tasks of organizing knowledge so that it aids decision makers, and eliciting information from experts, are central to an emerging approach to decision-support known as Structured Decision Making (SDM). The approach, based on decision analysis and applied work in the social sciences, involves the systematic application of common-sense logic to tough decision problems[5]. In the many cases where reliable consequence data and impact-assessment models are not available to help predict the likely benefits, costs, and risks of activities, SDM approaches often are used to elicit information from a range of recognized experts with the goals of

[5] Robin Gregory et al., *Structured Decision Making*, (John Wiley & Sons, 2012).

identifying the best available knowledge, encouraging discussions regarding any differences in opinion, and providing judgements with respect to proposed actions. These judgements typically involve assigning discrete probabilities to events, identifying consequences using performance measures (or attributes) and defined impact scales, or developing probability distributions for specified impacts and pathways[6].

The Nanotechnology Risks Experts Workshop utilized an SDM approach to further refine a detailed yet initial NRST framework developed by the workshop organizers. Deliberation with the invited nanotechnology experts over two days resulted in a sketch of an initial NRST framework and web-based interface that would enable stakeholders with limited experience in risk assessment to pinpoint areas of concern along the nano product life cycle, and to identify opportunities for re-engineering products to minimize risks.

*An online demonstration of the concept is available here:*
*nanoscreen.org*

*The online demonstration tool is a mock-up intended to demonstrate what a fully operational screening tool would look like. Further work is planned to develop the model underlying the interface (see 'Next Steps').*

As can be seen in the online demonstration the NRST would start by confirming that the product or application in question does in fact possess nanomaterials and is therefore applicable to nano risk screening (**Figure 3**). This consists of confirming inherent evident properties of nanomaterials, for example size and specific surface area. If nanomaterial is confirmed the screen would continue; otherwise, the screen would end with appropriate notifications (e.g., to research other applicable screening requirements such as chemical screening).

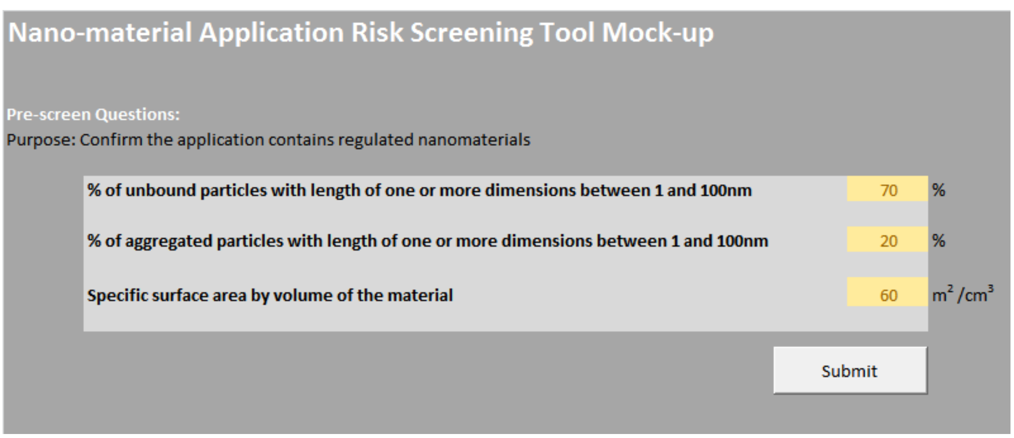



**Figure 3 | Confirm Screening Requirement**

The in-depth screen would solicit measureable nanomaterial properties and information on the application exposure characteristics (**Figure 4**). This includes primary physical or intrinsic properties of nano particles, which can be directly measured: examples include *size, chemical composition,* and *shape/aspect ratio*.

[6] M G Morgan and M Henrion, *Uncertainty: a Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis*, (Cambridge, New York: Cambridge University Press, 1990).

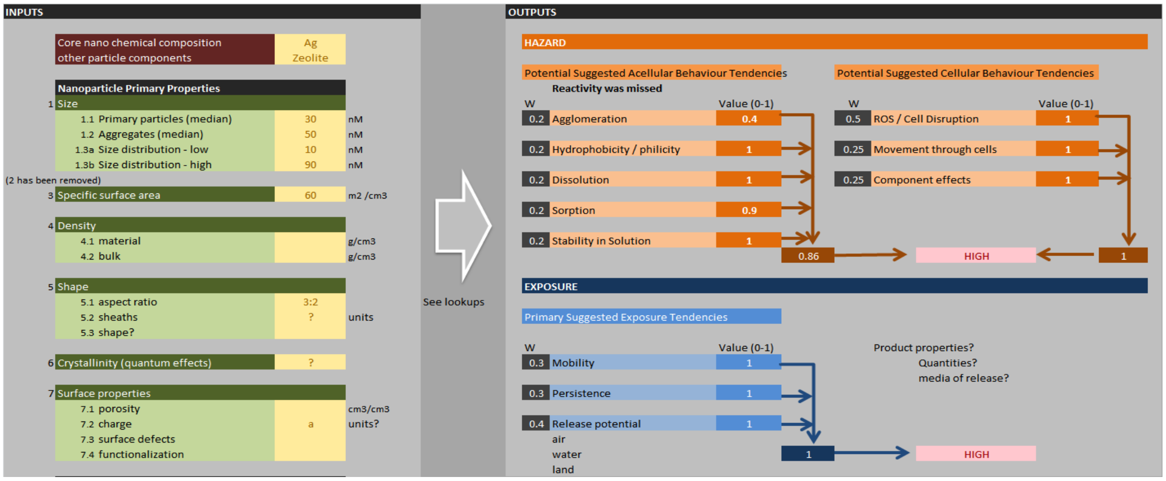



**Figure 4 | Inputs and Transparent Outputs**

The model would then determine:

- potential secondary physical or extrinsic hazardous behavioural properties of nano materials which only become apparent based on the medium in which the nanomaterial is placed: examples include *dispersability*, *solubility*, and *agglomeration*.
- Potential cellular behavioural properties, including *tendency to cause cell disruption or form reactive oxygen species (ROS), ability to move through biological barriers, other component effects*
- Suggested exposure tendencies based on the product application and lifecycle stage: examples include *mobility*, *persistence* and *release potential*.

These would be expressed as individual and rollup hazard/exposure risk ratings using situational weighting for significance in the examined context.

The final step would be to display the overall risk as a product of hazard and exposure ratings (**Figure 5**). As risk is a function of potential consequence and probability of occurrence - each of which varies dramatically depending upon hazard and exposure - the threshold for concern would be variable depending upon the assessed context.

Threshold of Concern: 0.4

| ***Risk Index*** | | Hazard | | | | | |
|---|---|---|---|---|---|---|---|
| | | **0** | **0.2** | **0.4** | **0.6** | **0.8** | **1** |
| Exposure | **0** | 0 | 0 | 0 | 0 | 0 | 0 |
| | **0.2** | 0 | 0.04 | 0.08 | 0.12 | 0.16 | 0.2 |
| | **0.4** | 0 | 0.08 | 0.16 | 0.24 | 0.32 | 0.4 |
| | **0.6** | 0 | 0.12 | 0.24 | 0.36 | 0.48 | 0.6 |
| | **0.8** | 0 | 0.16 | 0.32 | 0.48 | 0.64 | 0.8 |
| | **1** | 0 | 0.2 | 0.4 | 0.6 | 0.8 | 1 |

*This nanomaterial application is of concern. See/do/etc.*

**Figure 5 | Summary Risk Spectrum**

In addition to the NRST framework concept, initial models and definitions for primary (inherent) and secondary (emergent and/or behavioural) nanomaterial properties and their relationship to exposure potential and toxicity were developed. These initial models underlie the functionality of the NRST framework concept, and will be further developed based on literature review and expert input.

Overall, this risk screening approach based on nanomaterial physical/chemical properties forms a basis for establishing a consistent and robust risk-management framework, and for providing essential information to inform decision-making. The NRST framework is thus designed to enable users in government and industry to review and compare the characteristics of current and future nano-products, estimate potential outcomes, and determine which properties could be altered so as to reduce their likely environmental and health risks.

The preliminary NRST model including toxicity and exposure models can be found in Appendix B. Preliminary toxicity measures and scales, and toxicity and exposure screening criteria were also developed during the workshop, and are also summarized in Appendix B.

## Lessons Learned and Next Steps

The workshop experts reaffirmed published findings that there is a high degree of scientific uncertainty over the relationship between nanomaterial characteristics and their behavior once incorporated into various materials and/or products. This includes a lack of high-quality field data. As a result, the predominant source of knowledge of nanomaterial behaviours resides in the minds of experts, including individuals drawn from the domains of nanotoxicology, human exposure, and environmental fate and transport. Thus, the development of an effective and defensible risk-screening tool relies on the thoughtful elicitation and structuring of knowledge from selected representatives of these expert groups (e.g, Morgan, 2005; Fauss, Gorman & Swami, 2009; Berube et al, 2010: Linkov et. al., 2011). A necessary goal of the next phase in NRST development is to structure precise and consistent use of risk descriptors, through the creation of clearly defined measures or attributes that will both (a) operationalize the overall framework and

(b) enhance the ability of risk researchers to estimate and compare the human health and environmental risks of different nanoproducts.

Further development of the existing initial risk screening framework would provide:

- a rigorous means to characterize the inherent and emergent properties of nano materials using explicit scales of measureable data;
- a mechanism for synthesizing and comparing existing data with expert judgement
- a means to track current understanding of nano-material properties and behaviours, identify key gaps in knowledge, and reduce uncertainty over time;
- an ability to identify and screen potential human/environmental hazard and exposure pathways associated with the manufacture, use, and disposal of nano-enabled products.

The investigators are currently seeking additional funding to further develop the NRST concept developed in this initial workshop. Our goal is to secure funding to develop the NRST into a proof-of-concept tool, with the goal of partnering with a governmental department to launch and host the tool for industry and regulator use. Five main tasks envisioned for the development of the NRST proof of concept include:

1. Refine the proposed NRST framework based on literature review and expert interviews (structure, logic and sequence)
2. SDM Workshop 1: Elicit expert review and feedback on NRST framework
3. Revise and translate NRST framework into a proof-of-concept web tool
4. SDM Workshop 2: Elicit expert critique/support of proof-of-concept
5. Finalize proof-of-concept web tool and accompanying technical report

The result would be a robust, well-documented NRST framework and proof-of concept web tool that could be evaluated for further improvement and operationalization as part of a subsequent web-tool development phase.

A peer-reviewed publication based on the outcomes of this initial Nanotechnology Risks Experts Workshop and NRST development exercise, is planned for 2013.

## Thank-You

We would like to sincerely thank all of the expert workshop participants for their time and support in aiding in the development of the preliminary NRST concept. We are also grateful for the generous support of the Center for Nanotechnology in Society, at the University of California, Santa Barbara (CNS-UCSB), the Center for Environmental Implications of Nanotechnology (CEIN-UCLA) at the University of California, Los Angeles, and the Liu Institute for Global Issues at the University of British Columbia.

## APPENDIX A – Workshop Agenda

**Thursday, May 24th**

9:00 Introductions
9:30 Workshop Overview & Intro to Structured Decision Making
9:45 Introduction of the preliminary Risk Screening Framework
*10:30 Tea / Coffee break*
10:45 Detailed Case Studies using the Risk Screening Framework
11:30 Discuss & Revise Risk Screening Framework
*12:15 Lunch*
1:30 Development of Toxicity and Exposure Components (*breakout groups*)
*3:00 Tea / Coffee break*
3:30 Review and Refinement of Toxicity and Exposure Components (*full group*)
*5:00pm Close for the day*
*5:00 – 6:45pm Wine and Cheese – Sponsored by the Liu Institute*
*7:15pm Dinner at Bridges Restaurant on Granville Island*

**Friday, May 25th**

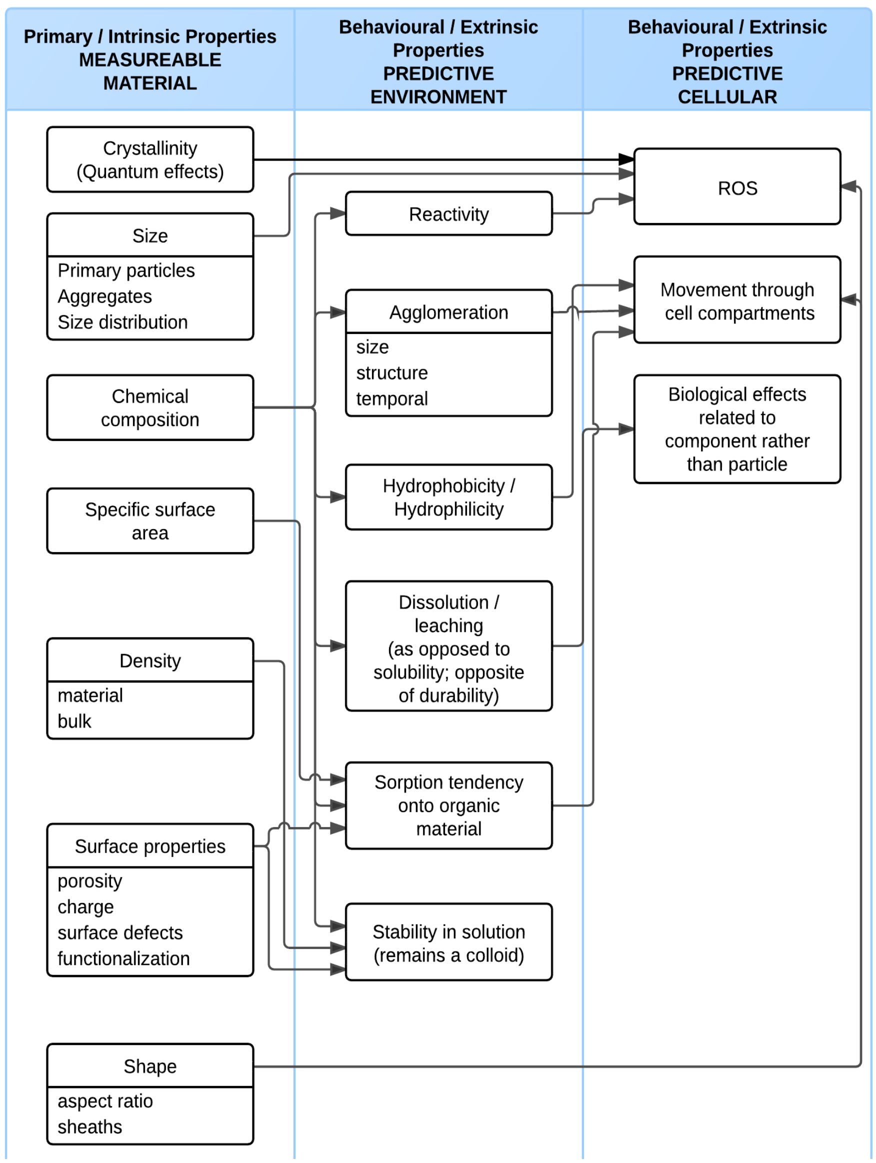
9:00 Review of Day 1 and Thoughts
9:30: NRST Mock-Up Introduction and Discussion (*full group*)
*10:30 Tea / Coffee break*
10:45 Development of Measures and Product Characteristics Screening Criteria (*breakout groups*)
*12:15 Lunch*
1:30 Review of Revised Risk Screening Framework
*3:00 Tea / Coffee break*
3:15 Assessing the Value of the Framework, Contributions & Implications, Next Steps
*4:00 Close of Workshop*

# APPENDIX B – Preliminary models and screening variables

*As a part of the SDM process, workshop participants collaborated on the development of preliminary nano toxicity and exposure models. While these are currently high level conceptual models, they provide a basis for further refinement utilizing recent literature and additional expert elicitation exercises.*

## Table B1 – Preliminary Nano Toxicity Model

The preliminary nano toxicity model developed by workshop participants utilized primary (intrinsic) physical and chemical properties to predict secondary (extrinsic) properties that become apparent (and may change) when introduced into different media. For example, intrinsic properties such as size and chemical composition determine the nanomaterials extrinsic properties such as tendency to agglomerate, reactivity etc. In turn, these properties are related to indicators of toxicity, including the potential for formation of ROS, ability to cross biological barriers, and other biological effects. Relationships between these properties were elicited using an influence diagram exercise.



## Table B2 – Preliminary Exposure Model

The preliminary exposure model also utilized primary (intrinsic) and secondary (extrinsic) properties as a basis of exposure estimation. Three main categories of concern for exposure were identified: persistence, mobility, and form of release. Each of these categories is influenced by intrinsic and extrinsic nanomaterial properties. For example, persistence was believed to be a function of nanomaterial size and solubility, which relate to reactivity, agglomeration potential, and sorption tendency. A full influence diagram elicitation exercise was not completed during the workshop.

| | **Primary / Intrinsic Properties**<br>**MEASUREABLE**<br>**MATERIAL** | **Behavioural / Extrinsic Properties**<br>**PREDICTIVE**<br>**ENVIRONMENT** | **Behavioural / Extrinsic Properties**<br>**PREDICTIVE**<br>**CELLULAR** |
|---|---|---|---|
| **PERSISTENCE**<br>- maintains its physical and chemical identity, e.g. surface properties<br>- encompasses form, function of nanoparticle | Size: Primary particles, Aggregates, Size distribution<br>Solubility | Reactivity<br>Agglomeration: size, structure, temporal<br>Sorption tendency onto organic material | |
| **MOBILITY**<br>- Dispersion of the material in the environment, both between compartments (e.g. air, water, soil, biota), and within the compartment<br>- How far a certain concentration will travel, over time | Surface properties: porosity, charge, surface defects, functionalization<br>Specific surface area<br>Shape: aspect ratio, sheaths | Agglomeration: size, structure, temporal<br>Sorption tendency onto organic material | |
| **FORM OF RELEASE**<br>- potentially modified via manufacturing process and along commercial life cycle, i.e. the form of release will vary along the life cycle | | | |

## Table B3 – Elicited Toxicity Measures

An exercise aimed at eliciting a set of common measures and scales was carried out with the aim of developing quantitative measures and defining standards for comparison. This table represents a preliminary list of measures and scales. Further refinement is planned for future work.

**TOXICITY MEASURES - Primary/Instrinsic/Measureable Properties**

PRIMARY QUALIFICATION: is it in powder, aqueous or organic phase?

| **SIZE** | | |
|---|---|---|
| property | measure | unit |
| Primary particles | average size<br>aspect ratio<br>sphericity | nm<br>width:height<br>0-1 |
| Aggregation | If suspended: poly-dispersity index (NOT for powders)<br>If solid: dustiness? | $M_w$ / $M_n$<br><br>? |
| Size distribution | 2 STD of size, relative to avg; qualifies uncertainty) | nm |

| **Shape** *qualitative information about shape* | | |
|---|---|---|
| property | measure | unit |
| shape category | enumeration | sphere, rod, sheet, irregular |
| aspect ratio | sphere: avg diameter<br>rod: avg width and length<br>sheet: length, width and height<br>irregular *(triggers more investigation)* | nm<br>nm:nm<br>yes/no<br>yes/no |

| **Density** | | |
|---|---|---|
| property | measure | unit |
| material<br>bulk (packing?) | mass/volume<br>mass/volume | g/mL<br>g/mL |

| **Specific surface area** | | |
|---|---|---|
| property | measure | unit |
| Specific surface area | BET (measured directly) | ? |

| **Surface properties** | | |
|---|---|---|
| property | measure | unit |
| Porosity | ? | ? |
| Charge | point of zero charge = isoelectric point ("IEP") | ? |
| Surface defects | ? | ? |
| Functionalization/Reactivity | Is it photoreactive?<br>Is it biologically reactive?<br>Is it redox reactive?<br>Does it display quantum confinement/quantum effects? | yes/no<br>yes/no<br>yes/no<br>yes/no |
| Additives *(e.g. nickel, cobalt. Clarify core versus other; doping to accentuate product, etc.)* | % of total mass | % |

| **Solubility (in water)** | | |
|---|---|---|
| property | measure | unit |
| solubility | KSP | ? |

## Table B4 – Elicited Toxicity Screening Questions

A number of screening questions were developed to help determine the form and use of nanomaterials in mixtures or products. These questions can provide a basis for rapid toxicity screening.

**TOXICITY SCREENING - Important Product Application Questions**

**1 What is the matrix of the product? Gas, Liquid, or Solid?**

**2 What are the characteristics of the nano material in its product matrix?**

- nano concentration within its phase (% by volume, mass/volume)
- phase processing of nanomaterial (to introduce into matrix)
  - none - direct application
  - liquid - surfactants (yes/no), acid (yes/no)
  - solid - polymer (yes/no)
- phase stability
  - air: nothing
  - liquid: boiling point, miscability
  - solid: degradability, hardness
- Are nano particles changed in matrix, or maintained?
  - size
  - charge
  - reactivity

**3 What is the carrier?**

- none = direct
- liquid
- solid/embedded
- phase processing

**4 What is/are the intended application(s)?**

## Table B5 – Elicited Exposure Screening Questions

A number of product characteristics were identified as contributing to potential exposure to nanomaterials from a product. These questions can provide a basis for rapid exposure screening.

**EXPOSURE SCREENING - Important Product Characteristics**

**Amount in product**

**Location of NP**

- Embedded in material
- In solution
- Surface bound
- Airborne free particles

# APPENDIX C – Nanomaterial case studies

## Table C1 – Nano-silver and CNT Case Studies

| | | | NANO SILVER | CARBON NANOTUBES |
|---|---|---|---|---|
| NANOMATERIAL TYPE | | | *NANO SILVER* | *CARBON NANOTUBES* |
| ATTRIBUTES<br>BASED ON | | | Disinfectant Spray<br>Hypothetical | Aircraft body composite<br>Hypothetical |
| Product Details | Description | | Silver nanoparticles suspended in solution, intended as a disinfectant spray | Carbon nanotubes used to create lighter and stronger aircraft body composites for new F-35 fighter jets. SW Carbon nanotubes used to reinforce standard epoxy polymers |
| | Intended Use / Benefits | | Spray disinfectant onto a surface and wipe clean | Strength, flexibility, low weight. 2x stronger than carbon fibre reinforced plastic, but 25-30% lighter |
| | Product Label | | Hypothetical product | In limited use in F-35 fighter jet wings |
| Technical Details | Location | | Nanoparticles suspended in solution (colloid) | Embedded within the wing composite material |
| | Amount Present | | Not indicated | Not indicated |
| | Properties | *Size Distribution* | 10nm | SWCNTs - length not specified |
| | | *Shape* | spherical | nanotube |
| | | *Surface characterstics* | no coating | not specified |
| | | *Chemical Composition* | Silver, some association with chlorine.<br>Other ingredients: 5% citric acid, 94% 'other' | not specified - assuming no functionalization |
| | | *Agglomeration* | Both free and agglomerated nAg in solution and in aerosol | Assumed to be well dispersed within the composite material, with a low degree of agglomeration |
| | | *Aerosol Size* | not indicated | N/A |
| | | *Concentration* | 100 ppm in solution. 1 mL per spray action. | Not specified |
| | | | | |

| | | | | |
|---|---|---|---|---|
| LC Scenario Variables | **SCENARIO DETAILS** | *PRODUCTION* | Nanomaterial production process not specified.<br><br>Colloid solution production process not specified. | CNTs produced using a large scale Chemical Vapour Deposition (CVD) process by bulk CNT manufacturer. Aircraft composite materials manufacturer then mixes CNTs with epoxy resin by before hardening to create bulk sheets of carbon fibre reinforced polymer that are ready for aircraft use. |
| | | *USE* | Solution sprayed directly onto a surface and wiped away with a cloth. Cloth then rinsed clean, same as any non-nano disinfectant | Wing materials are machined to specifications (cutting, grinding, drilling, etc), and fixed into place during aircraft manufacturing. Normal use during flight. Routine maintenance. |
| | | *END-OF-LIFE* | Spray container disposed (landfill/incinerator) or recycled. Some of the disinfectant nanosilver remains on the surface, some on the cloth, and the remainder rinsed down the drain during the use phase - only residuals left on the container | Disposal into municipal landfill or incinerator. Recycling not possible. |
| **OTHER INFORMATION** | ***Toxicity indications and studies*** | | N/A | |

http://www.flightglobal.com/news/articles/lockheed-martin-reveals-f-35-to-feature-nanocomposite-structures-357223/