Risk Management of Nanomaterials in the Workplace

Claude Ostiguy

IRSST

ostiguy.claude@irsst.qc.ca

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Why nanotechnologies ?

- ***Unique properties based on the size of the particles and with a different behaviour*** **of the same product at a larger dimension**
  - **Optical and electrical properties**
  - **Thermal conductivity**
  - **Flexibility, exceptional strengh, compressibility**
  - **Large surface area: catalysts, chemical reactivity**
  - **Resistance, lightness**
  - **Melting point**

Optical properties

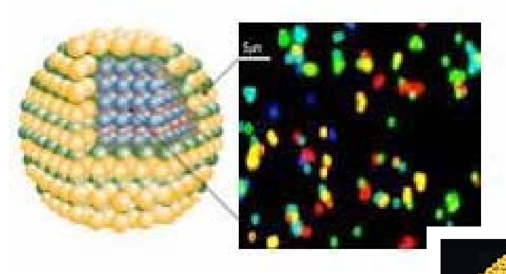
cm

mm - µm

nm

Diversity of nanoparticles

- **Creation of numerous new compounds**
  - **Carbon nanotubes, CNT**
  - **Fullerenes**
  - **Quantum dots**
  - **Dendrimers**
  - **Nanoshells …**



- **Nanometric dimensioning of existing products**
  - **Inorganic products (TiO_2, metals, metal oxides, …)**
  - **Organic products (PVC, …)**

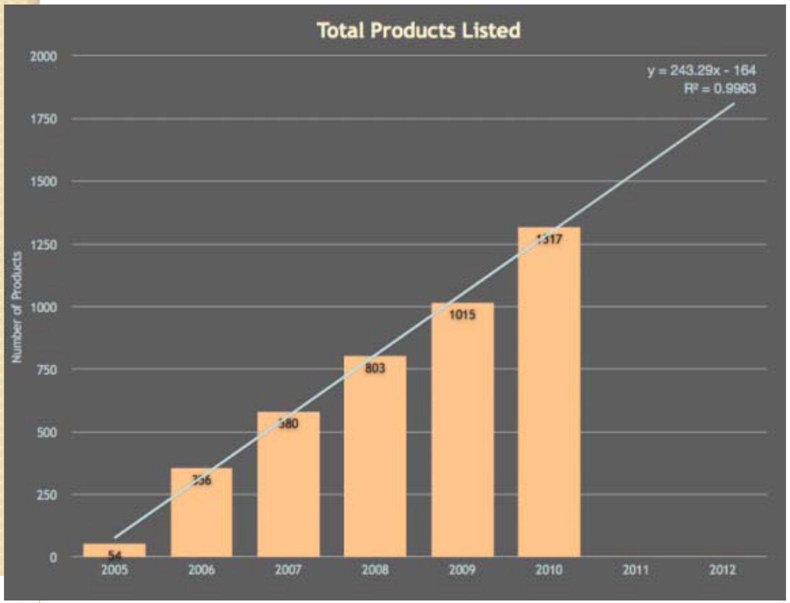
The nanotechnology value chain

➢ Investment in research in the United States (2009):

- $8.5 billion by the government
- $8.5 billion by companies
- $750 million in venture capital

➢ The 2009 world market:

- nanomaterials (e.g., CNTs): $1 billion
- nano-intermediates (e.g., catalysts, composites): $29 billion
- products containing nanos (e.g., electronics): $224 billion



➢ Consumer products

- 1317 products
- 587 companies
- 30 countries

From the Woodrow Wilson Center site, May 2011

A few examples of applications

- Cosmetics and skin products: ex. TiO2
- Paints
- Computer processors
- Antibacterial athletic garments
- Skis, tennis rackets, golf clubs
- Antibacterial household appliances with a silver coating
- Medical diagnostic tools and new therapies




Some companies involved in nanotechnology

3M
DUPONT
hp
TEKNA Plasma Systems inc.
Ford
Pfizer
Texas Instruments
Kodak
GM
intel.
Raytheon
Honeywell
Lucent Technologies
Bell Labs Innovations
Dow
IBM
BOEING
. . .
MONSANTO
Agilent Technologies
CORNING
THE DOCUMENT COMPANY
XEROX

Hazard anticipation

At the economic level

- Unique, unforeseeable properties and major commercial interest
  - Millions of jobs and hundreds of billions in revenues
  - More than 1300 products already on the market

At the OHS level

- Unique, unforeseeable properties and possibly representing new risks…
  - New behaviours?
  - New risks?

Unique OHS opportunity

First subject where prevention can be promoted BEFORE claims appear

An evolving workforce

⇒ **Trend: from the research laboratory to industry**

- Higher potential exposures
- Larger number of workers

- Nanotechnology is definitely moving towards the manufacturing sector, involving a still limited but growing and often poorly informed workforce

Potential emission of nanoparticles

- **In research laboratories**
  - Weighing
  - Drying
  - Manipulation
  - Contamination of tables and equipment
  - Waste…
- **In production plants**
  - Leaks from reactors (high T, colloids ...)
  - Product recovery
  - Post-production treatment
  - Packaging, storing, shipping
  - Equipment maintenance, spills…
- **Use and subsequent transformation**
  - Varied risks depending on uses and specific applications

Almost all research laboratories, as well as production and transformation processes, are likely to expose workers to NP if good work practices are not implemented

Approach to risk management

Need for knowledge

- Toxicology
- Safety
- Epidemiology and surveillance

Hazard identification

Is there reason to believe that a hazard exists?

Do nanoparticles represent a risk to exposed workers?

⇒ **Risk = *f* {hazard x contamination level}**

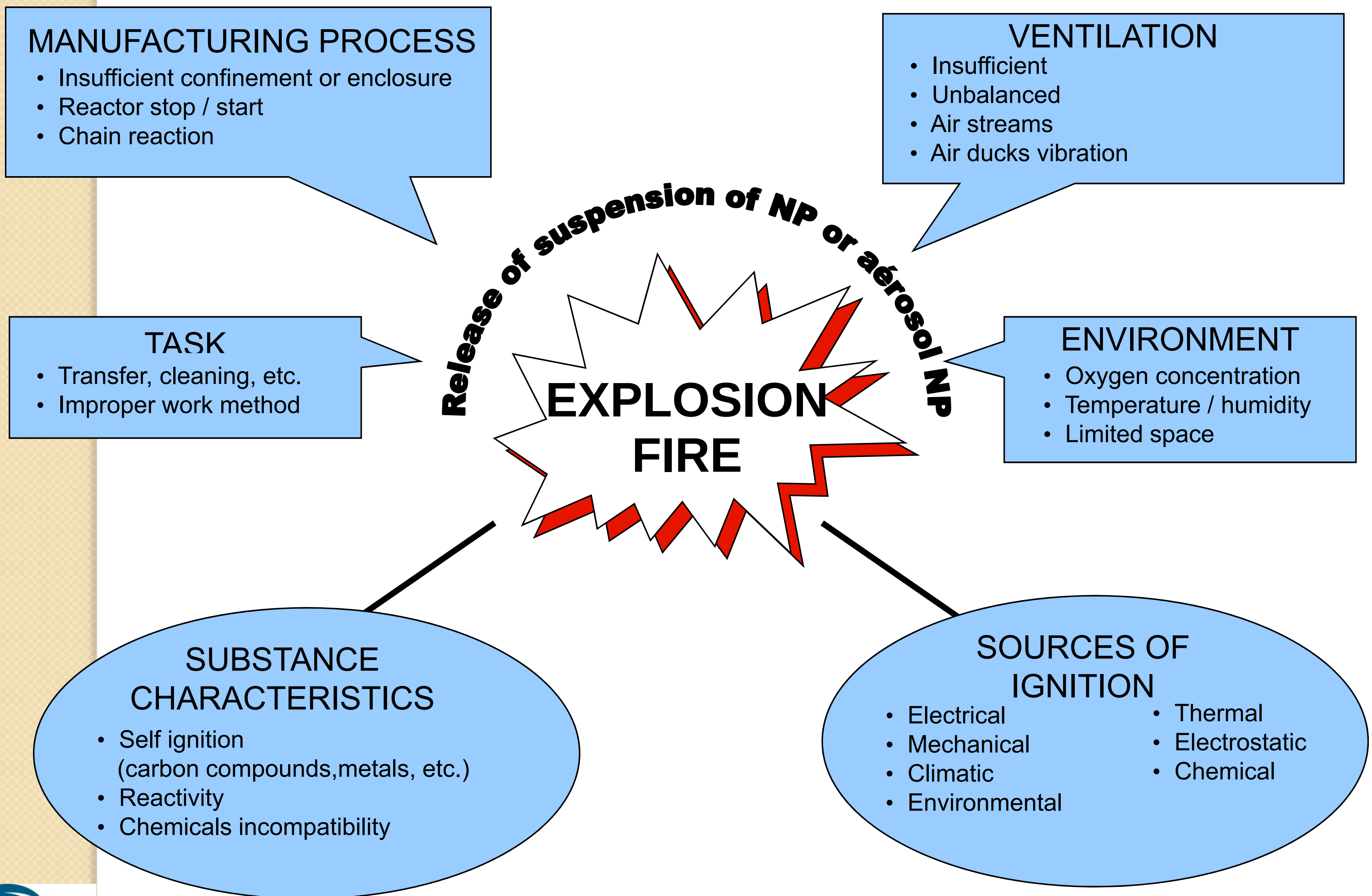
⇒ **Risk(t) = *f* {toxicity x exposure}**

In the presence of a hazardous agent, the risk is minimum if there is no contamination

Hazard identification: safety aspects

- **Explosion hazard :**
  - **High specific surface area, often involving reactive materials**
- **Fire hazard :**
  - **Nanometric metals and high chemical reactivity**

Conditions contributing to explosion/fires



Potential hazards from inhalation

- **Properties:**
  - NP developed for their unique chemical/physical properties
    ➡ could imply increased toxicity
- **Translocation :**
  - possibility to cross cell boundaries,
  - pass directly from the lung into the blood and be distributed to all organs in the body
  - Translocate to the brain following deposition in the nose
- **Size:**
  - Much higher surface area than larger particles
  - If surface is a driver for toxicity : increased toxic effects
- **Biopersistent high aspect ratio:**
  - CNT similar to asbestos?
- **Solubility**
  - Reduction in size increases solubility: ex. toxic metals

Documented hazards from inhalation

- **Toxicological studies: still limited but many effects reported**
  - Translocation and distribution in different organs
  - Pulmonary inflammation
  - Oxydative stress
  - Pulmonary granulomas, fibrosis, kidney disorders, cytotoxicity …

- **Toxicity varies from an NP to another**
  - On a mass basis, toxicity is normally more significant with insoluble or partly soluble nanoparticles than with microparticles (same chemical composition)

Dose - effect relationship: which metrics use?

- **Depending on the study, toxicity correlated to :**
  - **Surface area**
  - **Number of particles**
  - **Size distribution**
  - **Surface activity**
  - **Various characteristics of an NP**
  - **but not to the mass**

Too soon to come to a conclusion, but…

- **The results of current research suggest that if nanotubes are:**
  - Longer than 20 micrometres,
  - made of aggregates and
  - in sufficient quantity

- **Then we could expect the same types of effects as biopersistent mineral fibres**
  - Fibrosis
  - Cancer
  - Pleural changes
  - Mesothelioma

- **Is the situation the same as with asbestos?**

Approach to risk management

Need for knowledge

- **Toxicology**
- **Safety**
- **Epidemiology and surveillance**

- **Workplace evaluation**
- **Material and process characteristics**
- **Description of processes**
- **Work methods**

Hazard identification

Is there reason to believe that a hazard exists?

↓

Exposure assessment

Is there exposure in an actual situation?

Data collection

- **Mass concentration**
  - **Micro-orifice cascade impactors**
  - **Piezoelectric microbalances**
  - **TEOM, ELPI, SMPS…**
- **Surface area**
  - **Diffusion charger**
  - **Direct reading instruments**
  - **SMPS, TEM…**
- **Number concentrations**
  - **CPC, Electrometers, SMPS, ELPI, SEM, TEM…**
- **Granulometric distribution**
  - **SMPS, DEMS, cascade impactors, ELPI, SEM, TEM**
- **Chemical composition**
  - **Laboratory techniques (AA, ICP-MS…)**

- **ELPI: electrical low pressure impactor**
- **CPC: condensation particle counter**
- **TEM/SEM: transmission and scanning electron microscopes**
- **SMPS: Scanning mobility particle sizer**
- **TEOM: Tapered Element Oscillating Microbalance**
- **DEMS: Differential Electrical Mobility Sizer**

Personal monitors under development

Examples of available equipments

Approach to risk management

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- Risk assessment: dose and duration
- Dose modeling
- Exposure characterization

Hazard identification

Is there reason to believe that a hazard exists?

Exposure assessment

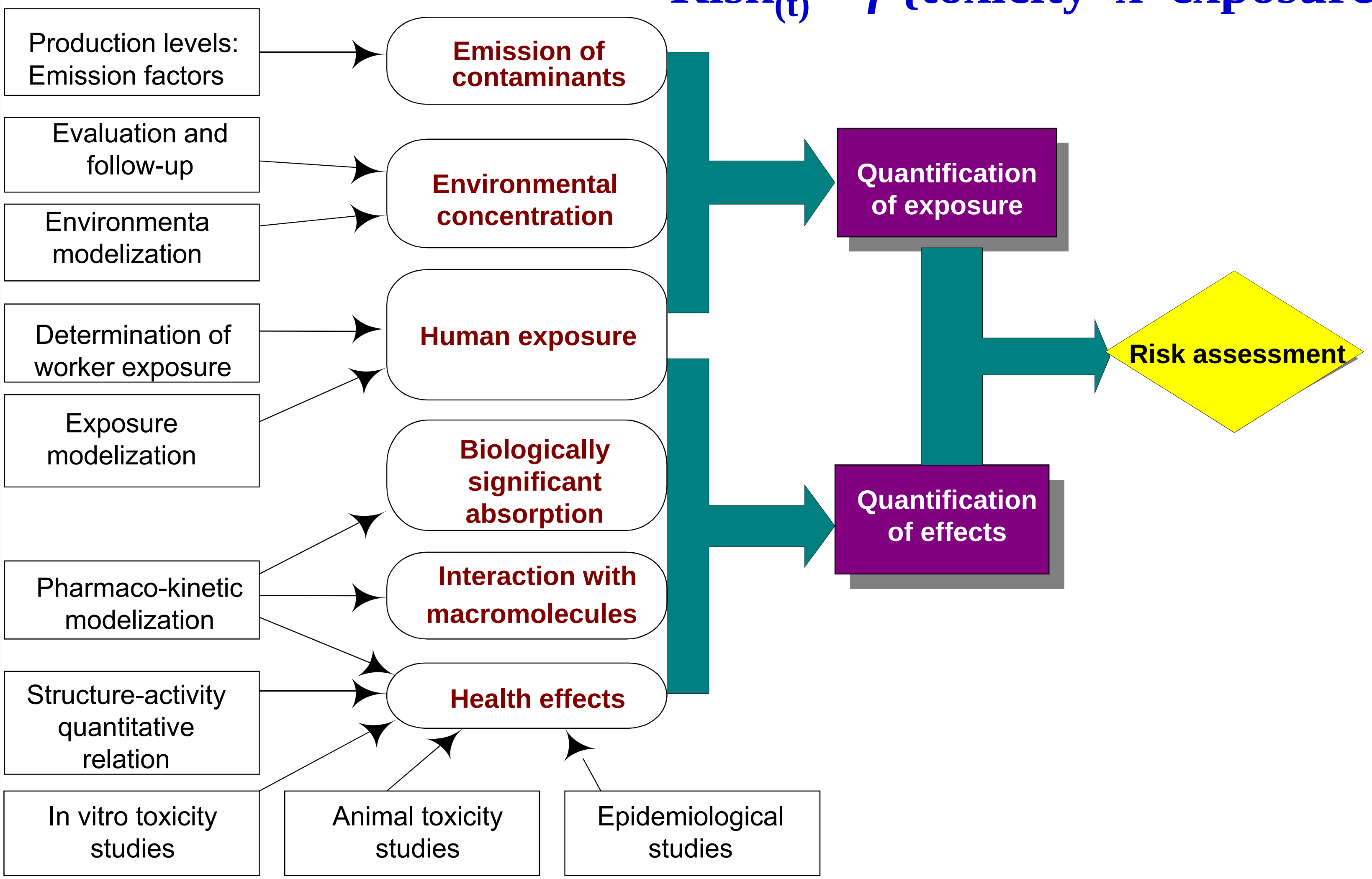
Is there exposure in an actual situation?

Risk characterization

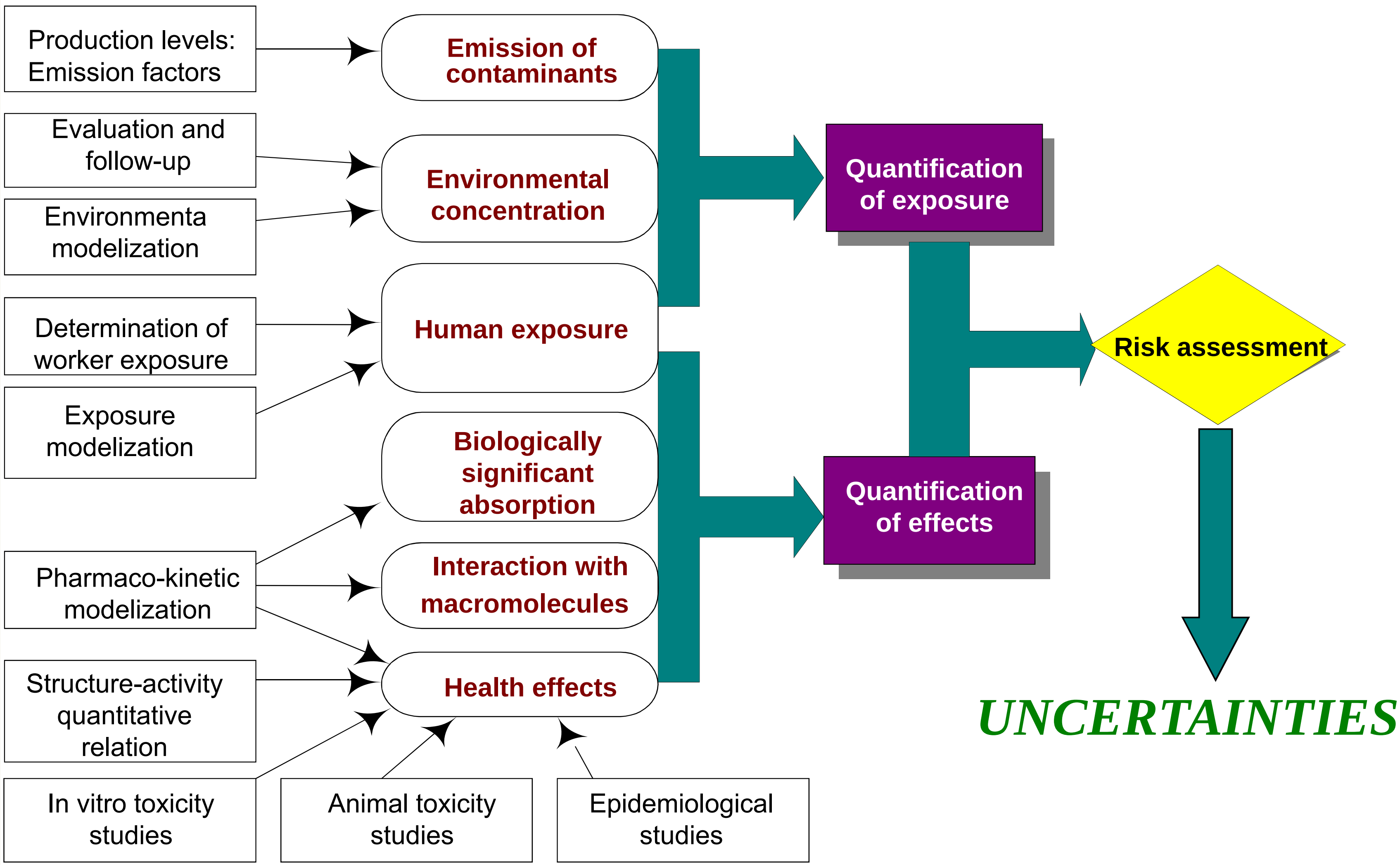
Is the substance hazardous AND will exposure occur?

Risk assessment procedure

$$Risk_{(t)} = f\{toxicity \times exposure\}$$



Uncertainty management



Control Banding

Control Banding

Qualitative
evaluation of chemical risks

Uncertainties

- New Materials
- Toxicological mechanisms
- Health and environmental effects
- Characterization of hazards and exposures
- …

progressive transition →

Quantitative
evaluation of chemical risks

Known Factors

- Type(s) of hazard
- Dose-response relation
- Handled quantities
- Exposure routes
- …

Definition of control levels

		Emission potential bands			
		EB 1	EB2	EB 3	EB 4
Hazard bands	A	CB 1	CB 1	CB 1	CB 2
	B	CB 1	CB 1	CB 2	CB 3
	C	CB 2	CB 3	CB 3	CB 4
	D	CB 3	CB 4	CB 4	CB 5
	E	CB 4	CB 5	CB 5	CB 5

CL 1: Natural or mechanical general ventilation

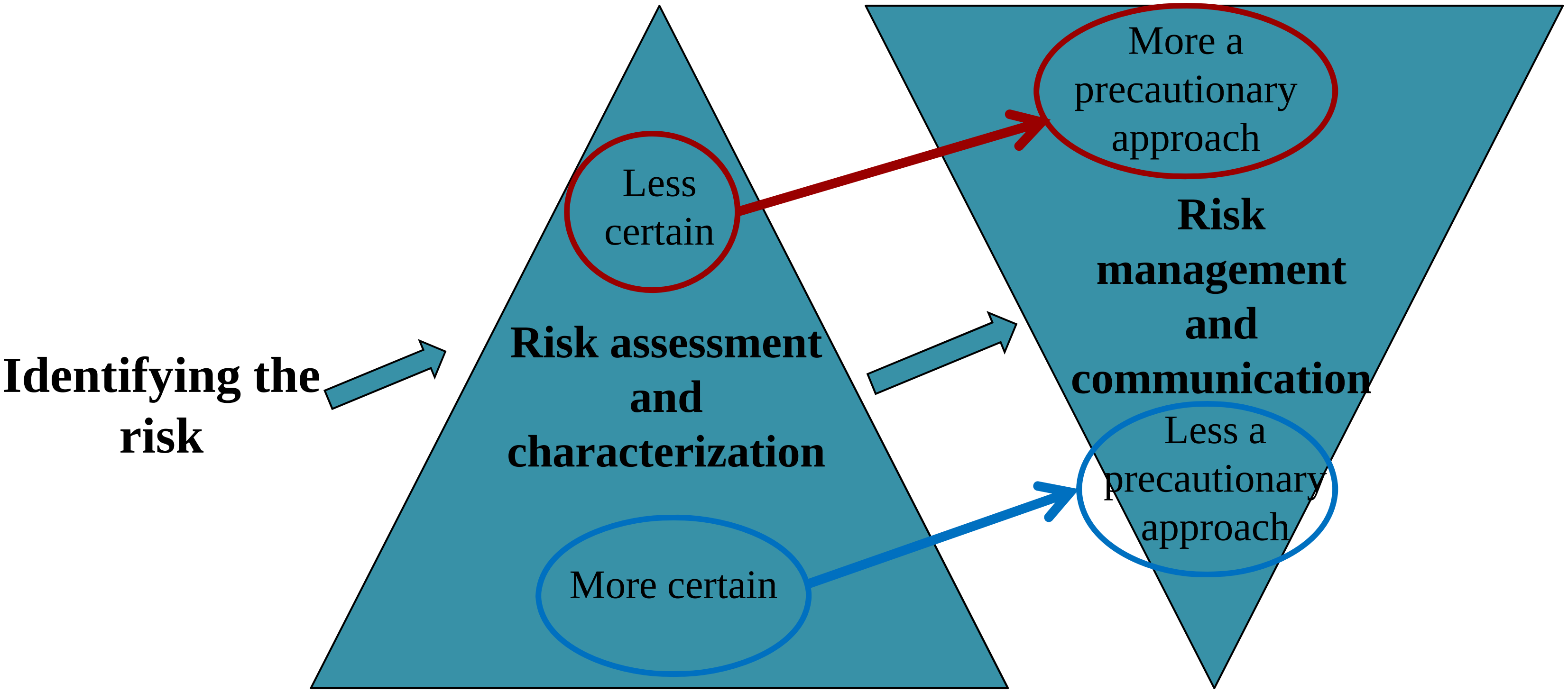
CL 2: Local ventilation: extractor hood, slot hood, arm hood, table hood, etc.

CL 3: Enclosed ventilation: ventilated booth, fume hood, closed reactor with regular opening.

CL 4: Full containment: continuously closed systems.

CL 5: Full containment and review by a specialist required: seek expert advice.

Management as a function of knowledge about the risk



Adapted from Dr. Kuempel, NIOSH

Approach to risk management

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- Risk assessment: dose and duration
- Dose modeling
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- Design, Elimination, substitution
- Engineering controls
- Communication about risk and training
- Administrative means
- Personal protective equipment
- Medical surveillance
- Dissemination of information

Hazard identification
Is there reason to believe that a hazard exists?

↓

Exposure assessment
Is there exposure in an actual situation?

↓

Risk characterization
Is the substance hazardous AND will exposure occur?

↓

Risk management
Develop procedures to minimize exposure

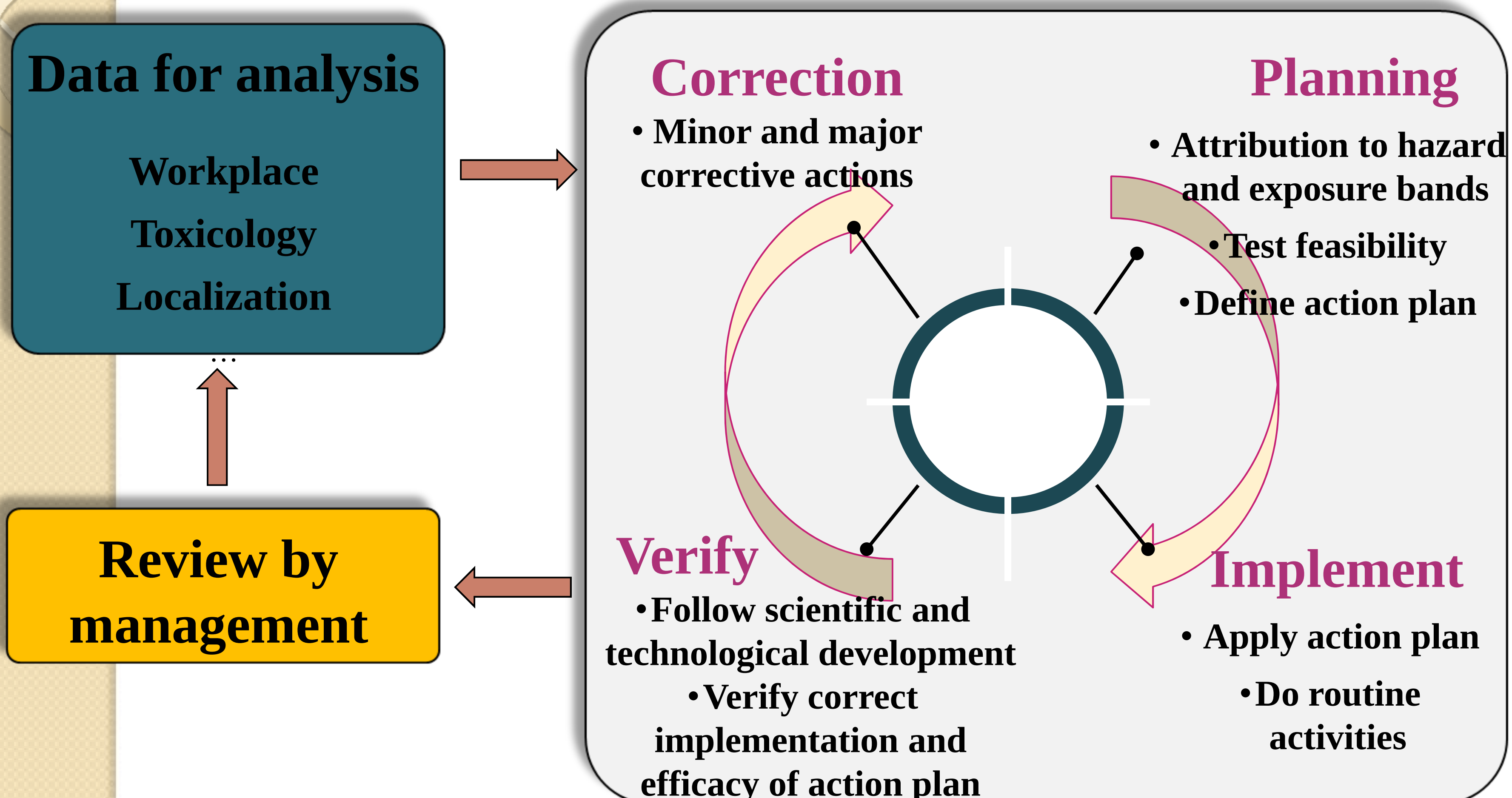
Control of exposure: good IH practices

Design

Effectiveness: + (most effective) to - (least effective)

- **Elimination, reduction**
- **Substitution**
- Engineering techniques
  - Isolation/ Closed circuits/ Enclosure
  - Ventilation
- Administrative procedures
  - Work schedules
  - Working procedures
  - Information / Training
  - Personal hygiene
  - Workplace and machine maintenance
- Individual protective equipment
  - Respiratory protection
  - Ocular, cutaneous… protection

Continuous improvement approach



Examples of implemented good work practices

- **Research laboratory :**
  - Dr. G. Soucy, Université de Sherbrooke, Qc
  - Synthesis of CNT

- **Industrial production plant:**
  - Tekna Advanced Materials, Qc
  - Production of nanometric metal, metal oxides and ceramics

Research Laboratory (CNT)

Characteristics:

- Negative pressure
- Central HEPA filtration
- Epoxy painting on the walls
- Two Nano-fume hoods
- One chemical fume hood
- Mobile and fixed ventilation/aspiration systems
- SAS (airlock room)
- Special personal equipment for handling of nano-powders:
  - Tyvek lab coat, powered air purifying respirator (PAPR) with HEPA filtration
- Controlled moisture content @ 40%
- Controlled temperature @ 20 C
- Glove-box cleaning room for synthesis system
- Glove-box for handling of nano-powders
- Emergency showers

Fully protected worker

- Tyvek suit
- Face shield
- Powered air purifying respirator (PAPR)
- HEPA filtration
- …

Homemade glove-box for instrumentation clean-up

- System fully adapted to the research needs

Laboratory nanohood and mobile local extraction system

Industrial Production plant

Tekna Advanced Materials, Sherbrooke, Québec

Design takes risk management into account

Objective: minimizing the absorbed dose by:

- Controlling the exposure level
- Minimizing the exposure time/frequency

Some possible avenues for minimizing exposure:

- Handling nanoparticles in an airtight enclosure (confinement)
- Using ventilation at the source if the product must be handled in an open atmosphere

Safety Barriers System - Examples

- **Hazard – Production of pyrophoric metals:**
  - **Hydrogen in-situ production rate follows its consumption – no stocking**
  - **Monitoring of residual oxygen concentration in processing vessels**
  - **Controlled passivation of pyrophoric products**
  - **Stocking of pyrophoric products under inert atmosphere**
  - **Equipment designed to withstand deflagration**
  - **Process off gas (already saturated with inerting water vapour) is exhausted to outside through the flash arrestor**

Safety Barriers System – Nanoparticles Leak

Barriers level 3 – leak of NP to an external production hall environment

- Building kept at negative pressure
- HEPA type filtration of air
- Wet off gas cleaning
- Air lock exit from working area

Barriers level 2 – exposition of operators to NP

- Local Ventilation
- Personal Protection Equipment
- Wet cleaning

Barriers level 1 - to prevent a leak of nanoparticles (NP) to the working atmosphere (few examples only)

- Processing unit sealed
- Pneumatic transport of raw material and products
- Deflagration containment design

Safety Barriers System

- **Air lock exit from production hall ⇒**
- **Personal Protective Equipment**

⇓

Motorized air blower unit equipped with splash protected gas, vapour & particulates (HEPA class) filtering unit

Local Ventilation System

Local Exhaust
- Articulated Arm
- 200 mm dia

Pre-Filter
- 3-ply type
- MERV 8 (>90 %)

Primary Filter
- Multi-wedge
- MERV 14 (>98 %)

Final Filter
- High capacity
- HEPA 99,97%

IRSST reports

- **Literature review on health risks related to NP:**
  - **R- 451 en français (R-558: deuxième édition, 2008)**
  - **R- 469 in English (R-589: second Edition, 2008)**
- **Literature review of NP health and safety aspects:**
  - **R- 455 en français (R-646: Seconde édition : 2009)**
  - **R- 470 in English (R-656: Second Edition: 2010)**
- **Guide of safe practices:**
  - **R- 586 en français (2008)**
  - **R- 599 in English (2009)**
  - **In Japanese (JNIOSH web site, 2009)**

State of current knowledge

• What do we know?	• What don't we know?
▪ Potential risks exist	▪ The nature and extent of the risk
▪ Exposure situations exist	▪ The nature and magnitude of the exposure
▪ NPs can be measured	▪ What parameter(s) should be measured
▪ NPs can be controlled: Filters and respirators should provide protection	▪ The limitations of the controls and the efficiency of the respiratory protection
▪ There is no permissible exposure limits	▪ Which standards would be appropriate
▪ There are no specific medical tests but it is prudent to carry out medical surveillance	▪ The content of a medical surveillance program

Our collective challenges

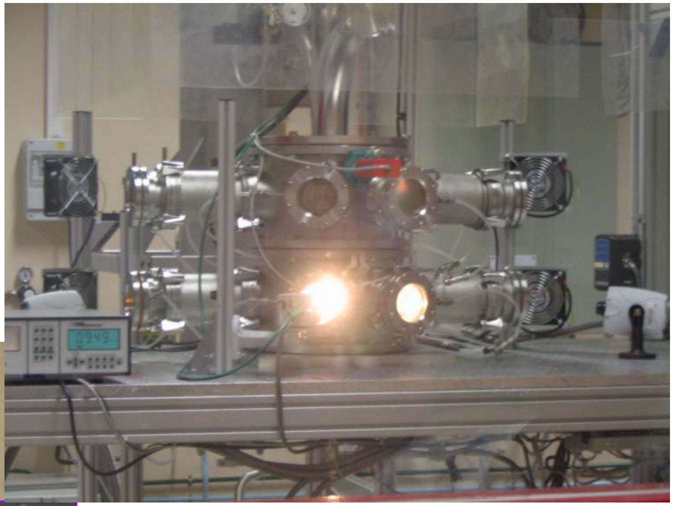
- **Maximize nanotechnology's benefits to society by minimizing or eliminating the environmental impacts and the risks of health and safety impacts for workers and the population**
- **Identify the workplaces that handle nanoparticles**
- **Support them in order to promote the establishment of working conditions for reducing or eliminating occupational exposure**
- **Disseminate the developed knowledge on a broad scale and share expertise**

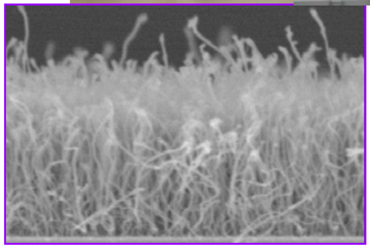
Conclusion

- Nanomaterials can represent specific OHS risks
- Toxicity and exposure are only partially documented
- Controlling exposure is possible by implementing good IH practices
- Keep exposure at a minimum level
- Researchers can play a role in prevention by:
  - Performing research
  - Translating research results to make them comprehensive for a wide audience
  - Diffusing and sharing results with the different stakeholders
  - Supporting the workplaces in the implementation of good practices

Preventionists, universities and companies must be involved in the safe, ethical and responsible development of nanotechnology

Questions?





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