Overview

- Particle nature and principles – current knowledge
  - Physical capture processes
  - Capturing devices
- What has changed now?
  - Aspect ratio
  - Fibre morphology (e.g. coil)
- CSIRO’s Carbon Nanotube Program
  - Carbon Nanotube (CNT) materials
  - Applications
  - OHS related activities
- Proposed Future Work
Particle Capture Processes

- **Interception**
  Particle contact while following streamline
- **Inertial Impaction**
  Particle leaves streamline
- **Diffusion**
  Brownian Motion
- **Electrostatic Deposition**
- **Gravitational Setting**

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Particle Capture Principles

- **Filter Medium**
- **Impactor**
  - Nozzle
  - Impaction Plate

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Baumgartner, H., Löffler, Umhauer. (1986)

Particle Sizing Devices

Cascade Impactor

Dynamic Mobility Analyser

Marple, V.A. Aerosol and Particle Measurement Short Course, 35th Offering, University of Minnesota, August 23-25 (2010)

CSIRO. Detection of Carbon Nanotubes - Nanotechnology Work Health and Safety Symposium, 9-10 September 2010

Particle Size Distributions

- Characteristics of one and the same particle size distribution:
  - Number count
  - Surface area
  - Mass

Distribution changes significantly by the way it is characterised!
What has changed now?

Dimensions of Carbon Nanotubes

12 nm → 0.6 m
Reach from Sea Level to Peak of Mount Everest

Aspect Ratio up to 40,000
What has changed now?
Carbon Nanotube Aerosols

- Filter efficiency for spherical particles or nano-particle agglomerates:
  - Plot:
    Minimum between 0.1 µm and 0.3 µm particle diameter
- “Fibrous Objects ?? (Carbon Nanotubes)
  - Large aspect ratio: L/D from 1,000 to 40,000
  - Mass and area scale differently
  - Variable morphologies: Coils, bundles, etc.

Baumgartner, Loeffler, Umhauer, 1986
IEEE Transactions on Electrical Insulation 21(3) : 477-486.

What has changed now?
Particles – Size, Material, Structure

Problem:
Some particles are more hazardous than others - even if they are of the same size!

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What has changed now?
Particles – Size, Material, Structure

Fibrous Particles Take On Different Shapes

CNT Coil

CNT Bundle

Aerosols sampled in workplaces (literature)

• Workplace Air Sampling:
  • Laboratory (General):
    • non-fibrous particles (cells, spores)
    • mineral fibres (insulation)
    • agglomerates (respirable dust particles)
  • Targeted CNT Sampling
    Images from Literature:
    • Top: coarse CNT fibres & agglomerates
    • Centre: fine CNT clumps from dispersions
    • Bottom: amorphous carbon agglomerates
  • CNT Yarn Spinning
    • Look for aerosol particles from single fine, spinnable CNT
    or small bundles of such CNT

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CSIRO's Carbon Nanotube Program

Structure of CSIRO Materials

• FINE Carbon Nanotubes (CNT)
  CVD - Catalyst Pre-Deposition
  • Spinnable CNT
    • Outer diameter: 8 - 11 nm
    • Typ. 100 – 600 µm long
    • 4-7 walls (TEM)
  • Short CNT
    • Outer diameter: ca. 10 nm
    • 2-3 µm long

• COARSE Carbon Nanotubes
  CVD - Catalyst Co-Injection
  • Long / Branched CNT
    • Outer diameter: 50-80nm
    • 2-3mm long
    • >60 walls

SEM by Chi Huynh and Stephen Hawkins, CSIRO
CSIRO’s Carbon Nanotube Program
Carbon Nanotube (CNT) Applications

• CNT Yarns
  • Diagnostics (filaments)
  • Medical (scaffolds)
• CNT Sheets
  • Conductive electrodes (displays, solar cell, electrochemistry)
  • Buckypaper membranes (membrane distillation)
• CNT as fluid pores
  • Isoporous CNT membranes, see image: (novel fluid transport phenomena)

SEM by K. Sears, CSIRO

CNT tips protruding from the surface Of an isoporous CNT membrane.

Carbon Nanotube OHS
Main Project Activities

Workplace Assessments & Policy Development

Equipment Evaluation & Research into CNT Aerosols
Carbon Nanotube OHS Workplace Assessments & Policy Development

- **Safe Work Australia**
  Contract on assessing workplace in CSIRO (Belmont) to CNT aerosols – published on SWA website:

- **Nanotechnology OHS Measurement Reference Group**
  - Members:
    Government (Fed/State), Australian Institute of Hygienists (AIIOH), several Universities and CSIRO
  - Input in policy development and standardisation

**Carbon Nanotube OHS Equipment Evaluation & Research**

Filter Testing

Hazardous Aerosol Evaluation

Nano-Aerosol Detection
Synthetic CNT Aerosols
Fine / Coarse Structure Differences (ELPI)

Plate 1
(44nm)

Plate 6
(516nm)

Proposed Future Work
Research Directions

General equipment evaluation
- Finish commissioning Hazardous Aerosol Test Duct
- Instrument set up and verification (Nano-ID)

Membrane sampling
SEM: no particles (?) – step-by-step verification

Aims

Assess equipment response to target particles background-free (using Test Duct)
Set up equipment for sampling tasks (Nano-ID, CPC)
Transfer knowledge to occupational hygienists for conducting workplace assessments

Nano-ID

- Designed to sample particle size over 4 (!) decades from 2nm to 30,000nm.
- Uses two principles in sequence:
  - Range 250nm – 30,000nm: Impactor
  - Range 2nm – 250nm: Diffusion battery (filter)

- Issues:
  - Greasing/not greasing of impactor plates:
    Suppression of particle bounce <-> SEM imaging of nanoparticles
  - Diffusion battery:
    Meshes (2nm end) <-> Nanofilament filter (250nm end)
    Reach sufficiently high particle concentration for SEM analysis

- Rule of thumb:
  - One instrument per particle size decade is required