

The background of the slide is a detailed 3D rendering of a carbon nanotube. It shows a hexagonal lattice of carbon atoms forming a cylindrical tube that curves across the frame. The atoms are represented as small spheres, and the bonds as connecting rods. The lighting creates highlights and shadows, giving the structure a three-dimensional appearance.

Exposure to carbon nanotubes

Occupational and
environmental health

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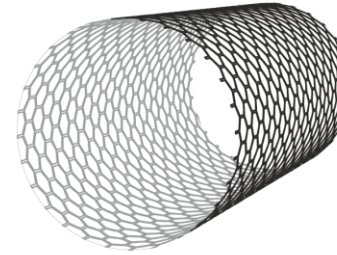
- Definition of carbon nanotubes
- Properties and application
- Exposure of carbon nanotubes
- Exposure routes
- Protective and aggravating factors
- Risk assessment
- Relevant regulations
- Recommendations

Background information

Definition

- Carbon nanotubes (CNTs) are **hollow tubes made of carbon atoms** (scale of nanometers).
- family of fullerene molecules, findings first reported in **1991**
- Very high **aspect ratio = length/diameter** (up to 10,000)
=> similar to fibers (minimum 3:1 ratio)
- low solubility
- These nanomaterials possess unique **properties** => high potential for use in **nanotechnologies**

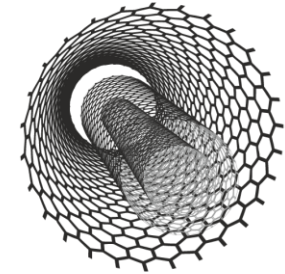
SWCNT



0.5–2.5 nm

Single-walled CNT

MWCNT

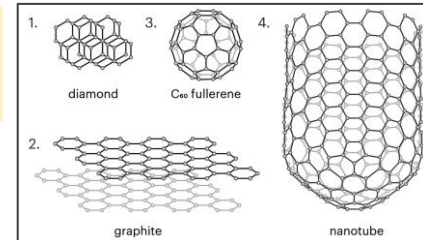


7–100 nm

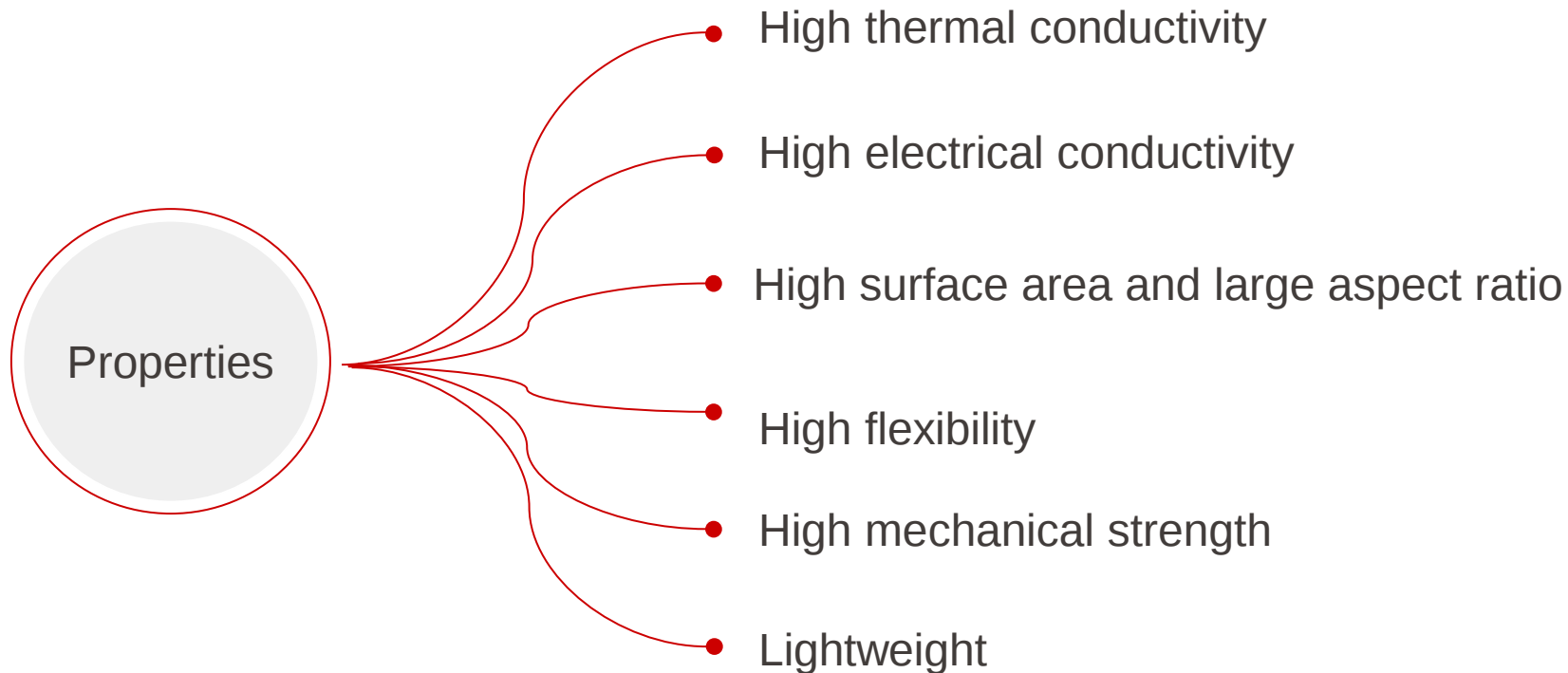
Multi-walled CNT

Every carbon atom is **covalently bound to three other carbon atoms**, forming a hexagonal network that forms the tube (rolled sheet of graphene).

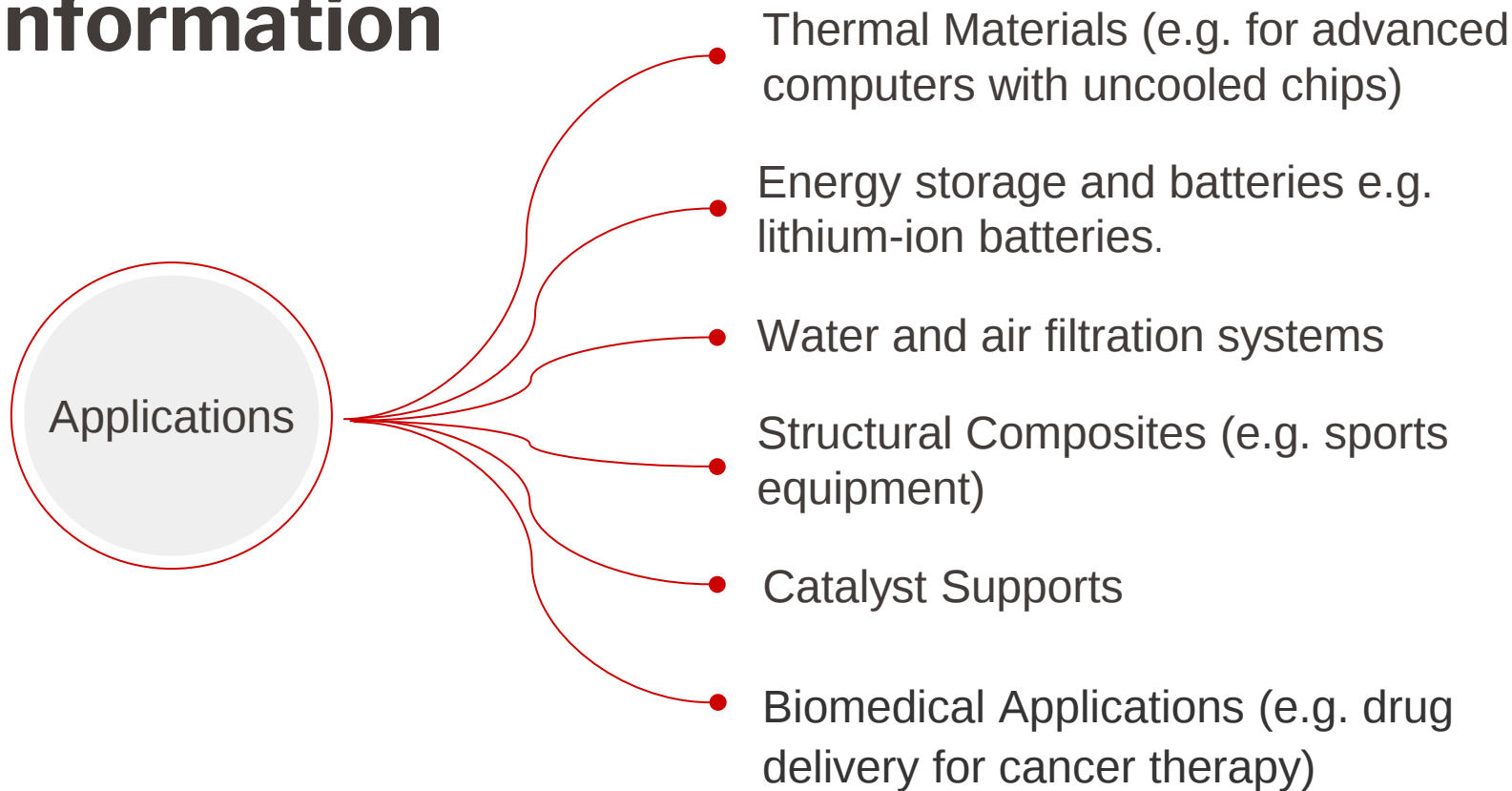
different forms of carbon materials:



Background information



Background information



Hazard identification

Hazards of exposure

Are we exposed ?

no evidence that CNTs present in materials or textiles present a toxicological risk when used

Carbon nanotubes are everywhere

textiles, sporting goods, electronics, cars, aeronautics and space, industrial engineering, nanomedicine and biotechnologies...



technicians > engineers > chemists

Occupational:

Work activities with the greatest mean CNT mass concentrations were **non-enclosed** and included sieving, harvesting, packaging, reactor cleaning, extrusion and pelletizing (forming granules).

(Guseva Canu *et al*, 2020)

Entry pathway = hand-to-mouth contact, inhalation of airborne nanoparticles, dermal exposure

Hazard identification

different CNTs have different physical and chemical properties => **different toxicological impacts**

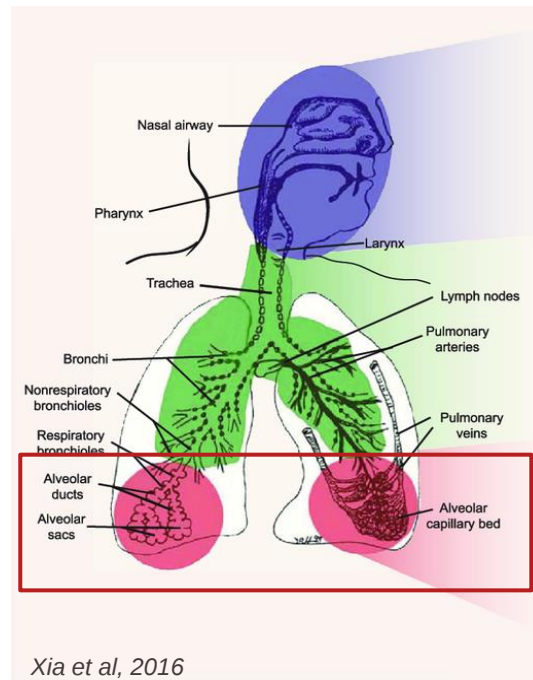
Risks for health

1. Inhalation

- nanosized particles (<0.1 mm in diameter) have a **higher deposition efficiency in the deep pulmonary region**

=> at significant amounts, induce oxidative stress and cause direct damage to cell membrane, inducing **cytotoxicity and immune responses (inflammation)**

=> enter the **bloodstream** = diverse systemic toxicity



Evidence: extensive research on nanoparticle deposition in respiratory system but **only studies in mice** for CNTs

→ Witaspl et al. Single-Walled Carbon Nanotubes Impair Human Macrophage Engulfment of Apoptotic Cell Corpses. *Inhalation Toxicology* 2009

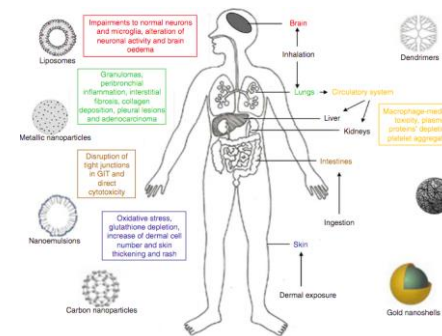
Hazard identification

Risks for health

2. Ingestion

- entry into the gastrointestinal tract (also through inhalation)
- **study in humans:** CNTs absorbed onto mucosa because of their smaller size but caused no significant adverse effects on the GIT histopathologically
- **study on mice:** Injection of CNTs in the GIT caused spotty necrosis, inflammatory cell infiltration, mitochondria swelling and lysis in hepatocytes

Evidence: only concerning studies are on mice and most adverse effects observed through intravenous injection



Lamberti M et al., Advantages and risks of nanotechnologies in cancer patients and occupationally exposed workers. Expert Opin Drug Deliv. 2014

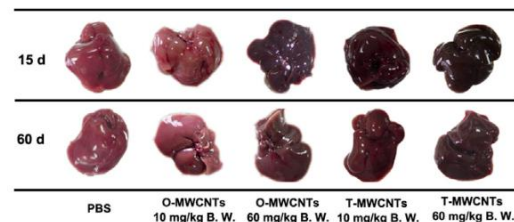


Figure 4. Photos of mouse livers treated with O-MWCNTs or T-MWCNTs.

Ji Z et al., The hepatotoxicity of multi-walled carbon nanotubes in mice. Nanotechnology. 2009

Hazard identification

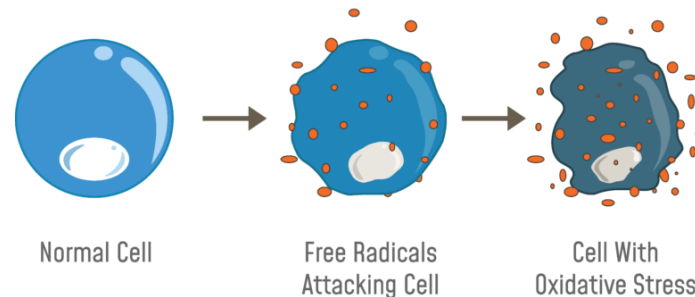
Risks for health

3. Dermal exposure

- inflammatory response
- dermal toxicity caused by accelerated oxidative stress by formation of free radicals in the skin of exposed workers
- aesthetic: loss of collagen and elastic fiber = skin ageing, wrinkling, dark spots
- function: reduced barrier function, increased sensitivity, and decreased moisture

Evidence: research done ex-vivo on a cell culture, no real-life study with workers

OXIDATIVE STRESS



Shvedova et al. Exposure to carbon nanotube material: assessment of nanotube cytotoxicity using human keratinocyte cells. J Toxicology Environment Health A. 2003

Factors affecting the risk

Protective factors

People:

- Enclosed processes
- Local exhaust ventilation
- Particulate filter (e.g. HEPA)
- Personal protective equipment (gloves, respiratory equipment, protecting clothing).
- Cleaning

Environment:

- Classified as hazardous waste

Aggravating factors

People

- Non-enclosed
- Poor/lack of ventilation
- Clogged filters
- Gloves and clothing not resistant to nanoparticles
- Cleaning wrong → risk of a dust explosion
- Poor hygiene practices

Is the risk high or low? Is there any data on accidents/illnesses in these situations?

Limits to the current data:

- Most conclusive research is on animals or ex vivo on human cell cultures
- results provided by a specific study, with specific samples, **can't be qualitatively or quantitatively extrapolated** to all types of CNTs

Speculated risks:

- structural characteristics resembling fibers and their extreme aspect ratio **suggest** toxic properties similar to those observed with asbestos
- **supporting evidence** that they exhibit asbestos-like behavior in **mice**
- **genotoxicity** = SWCNTs and mWCNTs can cause single-strand breaks in the genomic DNA - **in vitro and in vivo studies on human cells and animals**
- **carcinogenicity**: “ the promotion of lung tumors and mesothelioma is **anticipated** from the pulmonary exposure to CNTs”
- comparison with other fibers: SWCNTs were **more toxic than quartz** if inhaled chronically

Narei et al., 7- Toxicity and Safety Issues of Carbon Nanotubes, In Micro and Nano Technologies, Carbon Nanotube-Reinforced Polymers, Elsevier, 2018

Lam et al., A Review of Carbon Nanotube Toxicity and Assessment of Potential Occupational and Environmental Health Risks. Critical Reviews in Toxicology, 36(3), 189–217, 2006

Relevant regulations

- NIOSH (USA): Recommended exposure limit of 1 $\mu\text{g}/\text{m}^3$ as an 8-hour time-weighted average
- REACH Regulation (EU): As of January 1 2020, the EU requires companies that manufacture or import nanoforms (including nanotubes) to provide detailed information on:
 - Characterisation of nanoforms
 - Safety assessment
 - Etc.
- CNT waste: handled as nanomaterials or hazardous waste

Employers



Provide information allowing the workers to understand the places of exposure, routes of exposure, potential health risks etc.



Provide a medical screening for the workers (initial and periodic evaluation)



Establish exposure registries to track and monitor all workers with potential exposure to CNT.

Workers



Wear a respirator and other personal protective equipment made of the right materials.



Work with CNT in enclosed areas (e.g. glove box, process Chamber). When not possible, make sure to have local exhaust ventilation.



Clean work areas often in a correct way to avoid dust (e.g. vacuuming)



Avoid handling CNT in 'free particle' state (e.g., powder form) whenever possible.



Store CNT, whether in liquids or in powder form, in closed, tightly sealed containers whenever possible.



Do not store or consume food or beverage in workplace where CNT are handled.



**Thank you
for your
attention**

Hazard identification:

G. Ren, "carbon nanotube | Properties & Uses," *Encyclopedia Britannica*, Aug. 05, 2016. <https://www.britannica.com/science/carbon-nanotube>

"<https://tuball.cn/articles/multi-walled-carbon-nanotubes>," *tuball.cn*. <https://tuball.cn/articles/multi-walled-carbon-nanotubes> (accessed Oct. 02, 2023).

I. Guseva Canu, Kiattisak Batsungnoen, A. D. Maynard, and N. B. Hopf, "State of knowledge on the occupational exposure to carbon nanotubes," vol. 225, pp. 113472–113472, Apr. 2020, doi: <https://doi.org/10.1016/j.ijheh.2020.113472>.

R. Gupta and H. Xie, "Nanoparticles in Daily Life: Applications, Toxicity and Regulations," *Journal of environmental pathology, toxicology and oncology : official organ of the International Society for Environmental Toxicology and Cancer*, vol. 37, no. 3, pp. 209–230, 2018, doi: <https://doi.org/10.1615/JEnvironPatholToxicolOncol.2018026009>.

M. Kim *et al.*, "Human and environmental safety of carbon nanotubes across their life cycle," *Nature Reviews Materials*, Nov. 2023, doi: <https://doi.org/10.1038/s41578-023-00611-8>.

B. Wan, J. Hou, and L.-H. . Guo, "Safety of Carbon Nanotubes," Elsevier, 2016, pp. 405–431. doi: <https://doi.org/10.1016/B978-0-323-41481-4.00014-9>.

Background information:

"Applications of Carbon Nanotubes", AzoNano, Apr. 23, 2018. <https://www.azonano.com/article.aspx?ArticleID=4842> (accessed Dec. 07, 2024).

P. Gustavsson, M. Hedmer, and J. Rissler, "Carbon nanotubes – Exposure, toxicology and protective measures in the work environment", Arbetsmiljö Verket, 2011, <https://www.av.se/globalassets/filer/publikationer/kunskapssammanstallningar/carbon-nanotubes-knowledge-compilation-2011-1-eng.pdf?hl=CNT>

Risk assessment:

O. Akhavan, E. Ghaderi, and A. Akhavan, "Size-dependent genotoxicity of graphene nanoplatelets in human stem cells," *Biomaterials*, vol. 33, no. 32, pp. 8017–8025, Nov. 2012, doi: <https://doi.org/10.1016/j.biomaterials.2012.07.040>.

Relevant regulations:

"Occupational Exposure to Carbon Nanotubes and Nanofibers", Department of Health and Human Services, NIOSH, 2013. <https://www.cdc.gov/niosh/docs/2013-145/pdfs/2013-145.pdf?id=10.26616/NIOSH-PUB2013145>

"Nanomaterials", European Chemical Agency, <https://echa.europa.eu/regulations/nanomaterials> (accessed Dec. 07, 2024).

Recommendations:

"Occupational Exposure to Carbon Nanotubes and Nanofibers", Department of Health and Human Services, NIOSH, 2013. <https://www.cdc.gov/niosh/docs/2013-145/pdfs/2013-145.pdf?id=10.26616/NIOSH-PUB2013145>