

Lifecycle Management of Carbon Nanotube for Safer Innovation

Biotic and Biomimetic Degradation of CNTs
Our Scope for the Voluntary Lifecycle Management of CNTs in Production, Use and Waste

Objectives :

1. Accumulation and Sharing of Essential Knowledge for Lifecycle Management of CNT
2. Advocative Registration of the CNT for the Chemical Substances Management Systems as REACH and TSCA
3. Standardization of the Methodologies and Evaluation of CNT Degradation

Summary of Task :

1. SGCNT Is Biodegraded by Immune Cells Such as Macrophage in Lung and Kupffer Cell in Liver.
2. SGCNT Is Degraded by Commercial Chlorine Bleach
3. In Search of the Soil Bacteria which Capable of Degrade CNTs.

We Fulfill Social Responsibility as a SWCNT Manufacturer

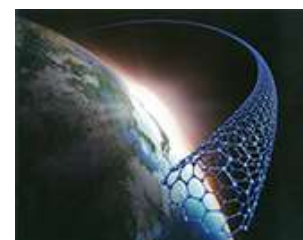
Joint Researches in Regulatory Science Area for Establishing ZEON's Voluntary Management System



1 ♡ = 2.3 g

2.3 g of SGCNT: Total Length Is ca. 100,000,000 km

It Takes 100 Years Driving a Car at 100 km/h !



Technical Issue: Dispersion of Aggregates (Bundle) to Derive the Potential of SGCNT

Risk Issue: Management of the Individual Tubes Are Impossible ⇒ Need of Risk Management

Collaboration Research for Voluntary Lifecycle Management of Our SWCNT

Inhalation Toxicity (OECD/WPMN Sponsorship Program) ☞ Risk Management Index NOAEL= 0.03 mg/m³

Long-term Inhalation Toxicity Test at GLP Testing Laboratory ☞ Not Carcinogenic

Carcinogenic Toxicity by Intra-peritoneal Administration of SGCNT ☞ Not Carcinogenic

Carcinogenic Toxicity by Intra-pulmonary Injection of CNTs Suspension ☞ Under Investigation

Mutagenicity Toxicity Test Using Mouse Mammalian Cells by GLP Testing Laboratory ☞ Not Mutagenic Toxicity

Biodegradation by Activated Sludge, (Including Bioassay Test and Adaptation Using Aromatic Hydrocarbon)
☞ No Negative Effect on Microbes but not Degradable

Biodegradation and Chemical Degradation of CNTs

☞ Degradable in Cultured Macrophage

☞ Degradable by Commercial Chlorine Bleach NaClO Treatment

Environmental Degradation of CNTs ☞ Degradable by Soil Bacteria

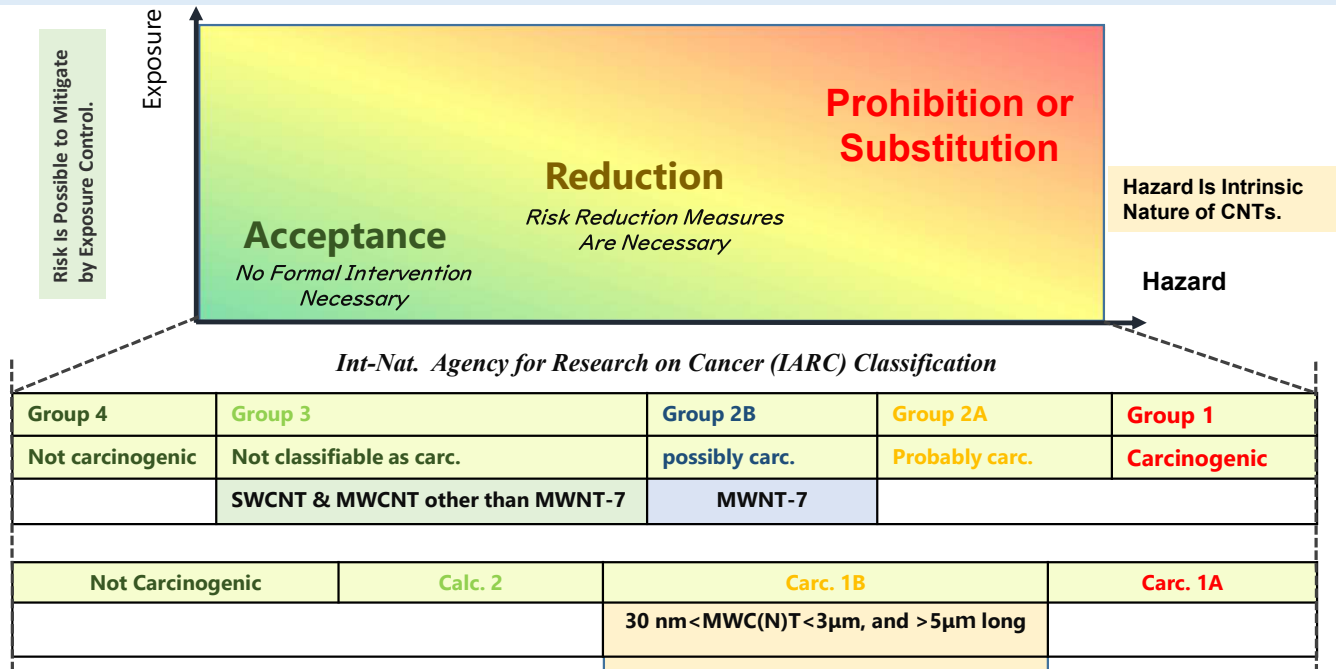
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Consistent, Fair and Objective Hazard Classification of CNTs Is Needed for Safer Innovation

Risk of Nanomaterials = Exposure x Hazard

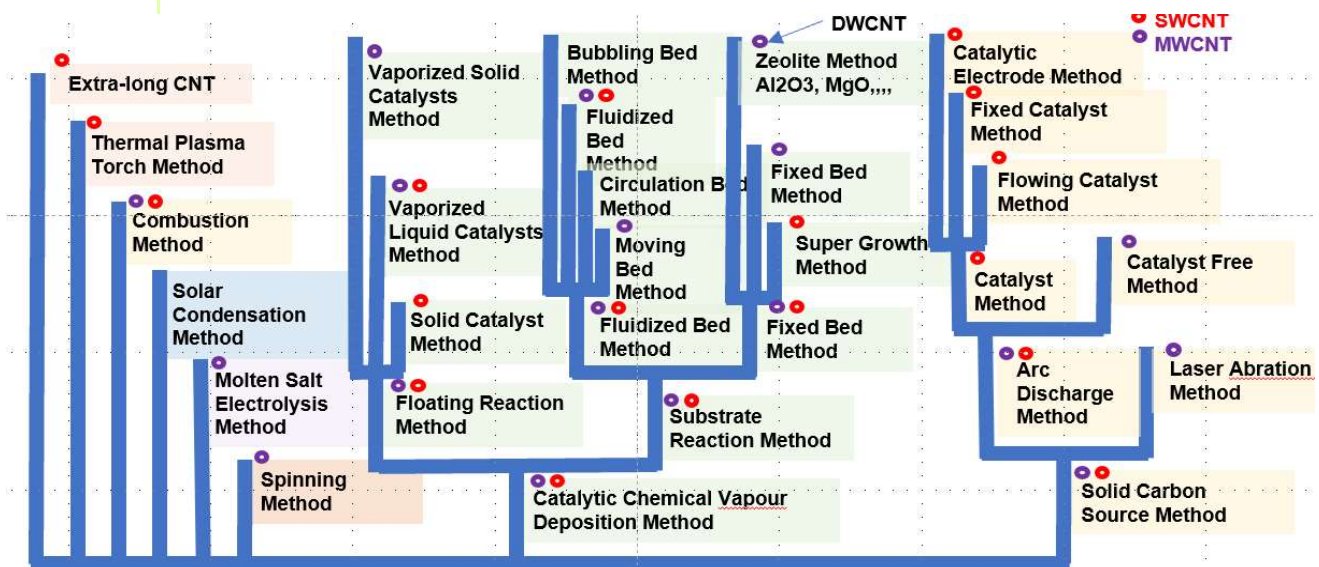


Multi-walled Carbon Tubes with a Geometric Tube Diameter Range ≥ 30 Nanometers (nm) to < 3 Micrometers (μm) and a Length $\geq 5 \mu\text{m}$ and Aspect Ratio $> 3:1$, Including Multi-walled Carbon Nanotubes (MWC(N)T).

Discussion in European Regulatory Environment

There Are Diverse Methodologies of CNT Production

Morphology, Thickness, Length, Surface Crystallinity, Surface Area, Rigidity, Dustiness, Metal Contents and So on Are Completely Different Depending on Process Parameters.



Various CNTs Made by Diverse Methodologies Are Available.
Source: NBCI Official Website

Our SWCNT Is Cleared from Lung in 60 Days after Administration

Clearance of Single-wall Carbon Nanotubes from the Mouse Lung: A Quantitative Evaluation by Minfang Zhang, et al., Nanoscale Adv., 2020, 2, 1551

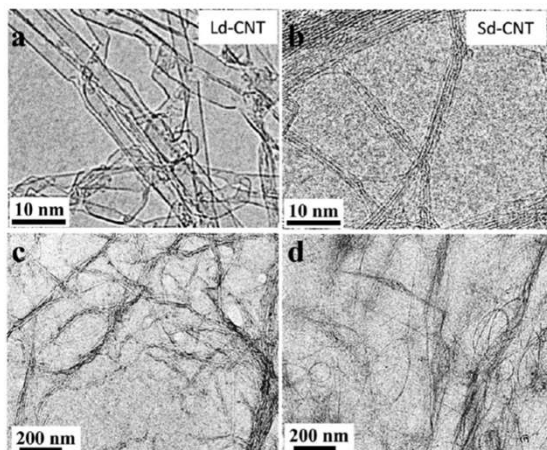
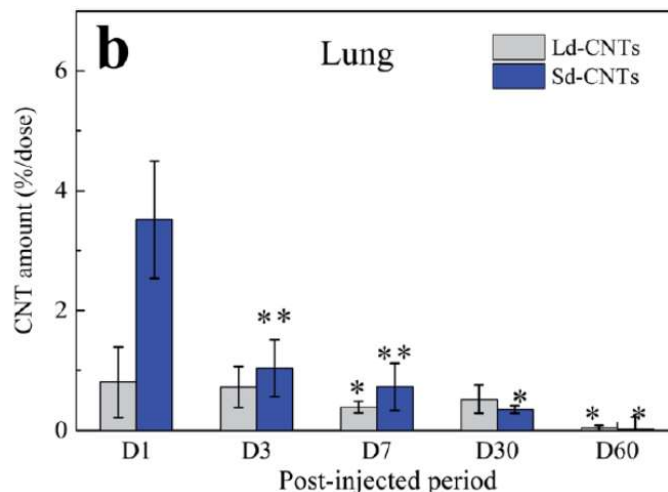


Fig. 1 Characteristics of large-diameter carbon nanotubes (Ld-CNTs) and small-diameter carbon nanotubes (Sd-CNTs). Transmission electron microscopy (TEM) images of Ld-CNTs (a), Sd-CNTs (b), and dispersions of Ld-CNTs (c) and Sd-CNTs (d) in BSA.

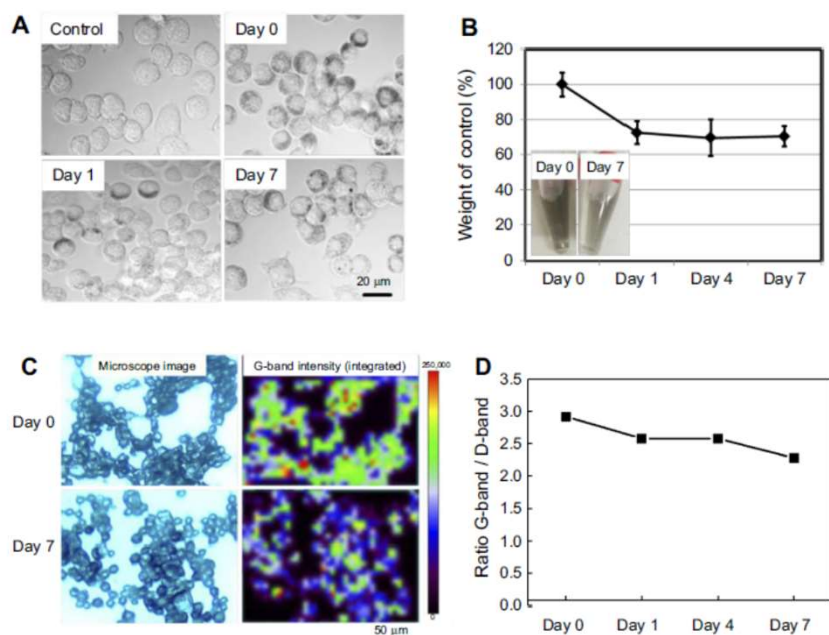
Changes in the Amounts of CNTs in the Lungs



Biodegradation of Super Growth CNT by Immune Cells

Minfang Zhang, et al., International Journal of Nanomedicine 2019;14 2797–2807

Degradation of SG-CNTs in RAW 264.7 Macrophages.



(A) DIC Images of Control RAW 264.7 Cells Incubated with SGCNTs for 24 h (Day 0), and Images Taken on Day 1 and Day 7, Obtained by Confocal Microscopy. CNTs Appear as Black Spots.

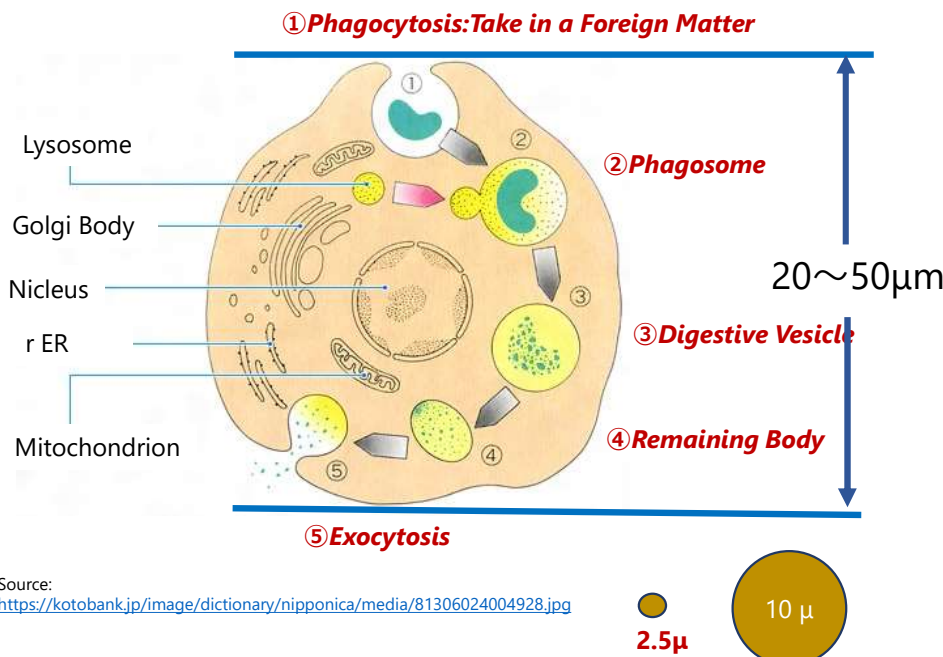
(B) The Intracellular SGCNT Levels in RAW 264.7 Cells at the Indicated Time Points Were Estimated from the Optical Absorbance of the Cell Lysate at 750 nm. Data Represent the Percentages of SGCNTs Relative to the Starting Concentration (Day 0) and Are Expressed as the Mean \pm SD of Three Independent Replicates. The Insets Show the Cell Lysates at Day 0 and Day 7.

(C) Microscopy Raman Mapping Images of G-band Intensities of SGCNTs in RAW 264.7 Cells Fixed with Glutaraldehyde at Day 0 and Day 7 (Right), Along with the Corresponding Microscopy Images (Left).

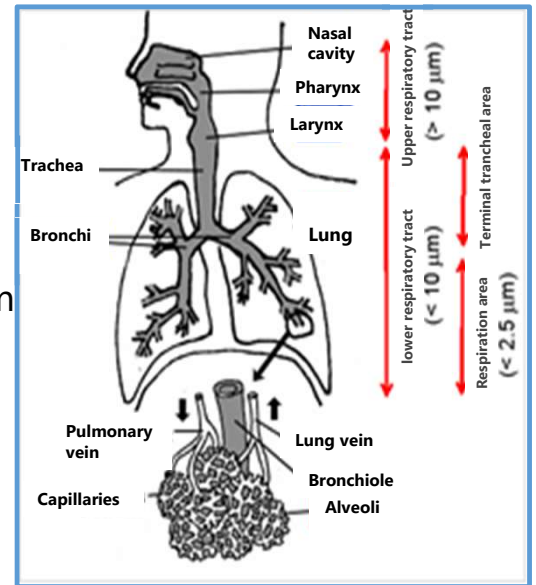
(D) The Ratio of G-band and D-band Intensities for Cell Lysates Obtained at Each Time Point.

https://www.aist.go.jp/aist_j/press_release/pr2017/pr20170912/pr20170912.html

Phagocytosis and Degradation of Foreign Matter by Phagocytic Cells



Source: <https://kotobank.jp/image/dictionary/nipponica/media/81306024004928.jpg>



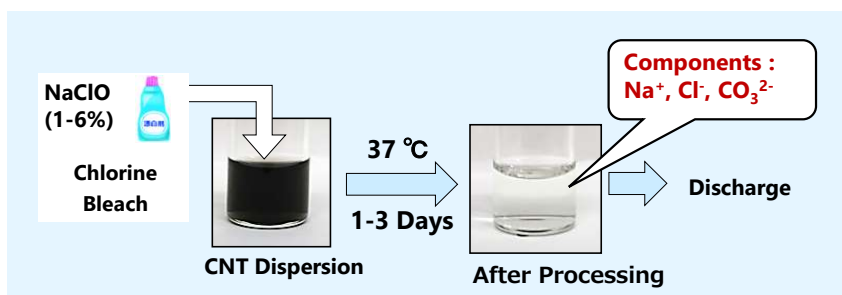
Source: HP of the National Institute of Environmental Studies (NIES)

PM2.5 and PM10 Comparing with Macrophage (35 μ)

Chemical Degradation of CNTs Using Commercially Available Chlorine Bleach

2019/02/04 AIST Press Release

https://www.aist.go.jp/aist_j/press_release/pr2019/pr20190204/pr20190204.html



Applications for Management of CNTs

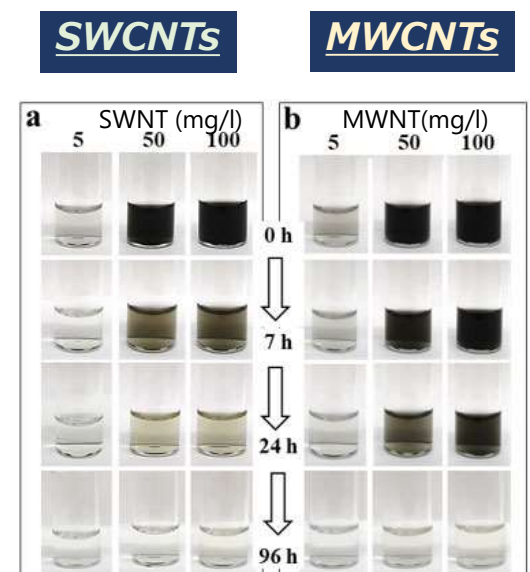
Possible Application in Occupational Field

Work Clothes :

Incineration ⇒ Bleaching

Wastewater Including CNT:

Filtration and Combustion ⇒ Bleaching



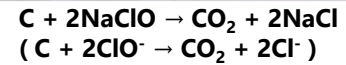
M. Zhang, et al.,
ACS Appl. Nano Mater. 2019, 2,7, 4293-4301

CNT Degradation by ClO⁻ Is "Biomimetic"

CNT Could Survive Even in Conc. H₂SO₄

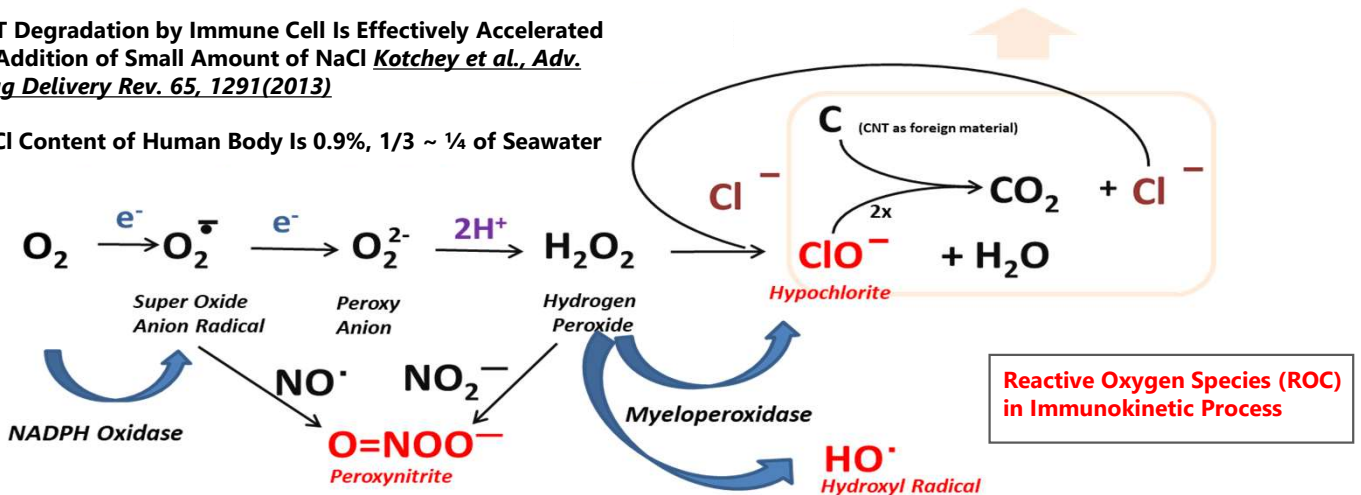


Possible to Degrade with a Few Drops of Chlorine Bleach → CO₂



- CNT Degradation by Immune Cell Is Effectively Accelerated by Addition of Small Amount of NaCl *Kotchey et al., Adv. Drug Delivery Rev. 65, 1291(2013)*

- NaCl Content of Human Body Is 0.9%, 1/3 ~ 1/4 of Seawater



Summary for the Risk Management of SGCNT

✓ SGCNT Is not Classifiable as to Its Carcinogenicity to Humans by International Agency for Research on Cancer (IARC)

We Also Confirmed It by Inhalation Exposure Test in a GLP Test Laboratory.

✓ SGCNT Is not Mutagenic*

We Confirmed It Using Mammalian Cell in a GLP Test Laboratory.

✓ SGCNT Is not Observed Reproductive Toxicity*

✓ SGCNT Is not Bioaccumulative*

✓ SGCNT Is Degradable (Possible to Manage)

SGCNT Is Degraded by Using Immune Cells and Chlorine Bleach.

SGCNT Could Be Degraded by Soil Bacteria .

* OECD/WPMN Sponsorship Program

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