Toxicological profile for

Activated carbon

This ingredient has been assessed to determine potential human health effects for the consumer. It was considered not to increase the inherent toxicity of the product and thus is acceptable under conditions of intended use.

1. Name of substance and physico-chemical properties

1.1. IUPAC systematic name

Carbon (PubChem)

1.2. Synonyms

FCM Substance 984 (EFSA, 2012a); Decolourizing carbon (FAO/JECFA, 2010); Acetylene black; Acticarbone; Actidose; Activated carbon; Activated charcoal; Adsorba; Adsorbit; AKOS015914131; Amoco PX 21; Animal bone charcoal; Anthrasorb; Aroflow; Arogen; Arotone; Arovel; Arrow; Atlantic; Black Kosmos 33; Black lead; Black pearls; Bone charcoal; C.I. Pigment Black 10; C.I. Pigment Black 6; C.I. Pigment Black 7; Calcotone Black; Cancarb; Canesorb; Canlub; Carbo activatus; Carbo vegetabilis; Carbodis; Carbolac; Carbomet; Carbomix; Carbon; Cecarbon; Ceylon Black Lead; Charcodote; Coke powder; Collocarb; Columbia LCK; Conductex; Continex; Croflex; Crolac; D&C Black No. 2; Delussa Black FW; DIAMOND; EINECS 215-609-9; EINECS 231-153-3; EINECS 231-953-2; EINECS 231-955-3; EINECS 264-846-4; Elftex; Essex; Excelsior; Farbruss; Fecto; Filtrasorb; Formocarbine; Fortafil 5Y; Furnal; Furnex; Gastex; Grafoil; Graphitic acid; Grosafe; Huber; Metanex; Micronex; Neotex; Niteron 55; Norit; Nuchar; Peach black; Pelikan C 11/1431a; Pelletex; Permablak 663; Raven; Rebonex; Regal; Schungite; Sevacarb; Seval; Shell carbon; Shungite; Silver graphite; Spheron; Statex; UNII-2P3VWU3H10; UNII-4QQN74LH4O; UNII-4XYU5U00C4 (PubChem)

1.3. Molecular formula

C (PubChem)

1.4. Structural Formula

C (PubChem)

1.5. Molecular weight (g/mol)

12.011 (PubChem)

1.6. CAS registration number

7440-44-0

1.7. Properties

1.7.1. Melting point

4440ºC (12.4 GPa) as diamond, 4489ºC triple point (10.3 Mpa) as graphite; 3650ºC, 3652ºC, 3727ºC (ChemSpider); -182.56ºC (EPISuite, 2017); ~3550ºC (PubChem)

1.7.2. Boiling point

3825ºC sublimation point graphite; sublimes at 3642ºC; triple point (graphite-liquid-gas), 4492ºC at a pressure of 101.325 kPa (HSDB, 2009); 5000ºC, 4200ºC (ChemSpider); -161.5ºC (EPISuite, 2017); >4000ºC, sublimates at 3650-3697ºC (PubChem)

1.7.3. Solubility

“Insoluble” (ChemSpider); 22 mg/L at 25ºC (EPISuite, 2017)

1.7.4. pKa

No data available to us at this time.

1.7.5. Flashpoint

>500ºC (PMCC)

1.7.6. Flammability limits (vol/vol%)

“Flammable solid; may ignite spontaneously in air” (PubChem)

1.7.7. (Auto)ignition temperature

900ºC (layer); 452-518ºC in flowing air, 316-399ºC or >500ºC (PubChem)

1.7.8. Decomposition temperature

No data available to us at this time.

1.7.9. Stability

Stable, in the form of powder reacts vigorously with a wide variety of materials; in the rod form is relatively inert; incompatible with strong oxidizing agents; highly flammable in powdered form, Combustible (ChemSpider); Freshly prepared material can heat and spontaneously ignite in air. The presence of water assists ignition, as do contaminants such as oils (PubChem)

1.7.10. Vapor pressure

1 mm Hg at 3586ºC or negligible at 20ºC (PubChem); approx. 0 mmHg (ChemSpider); 4.66×10^{5} mmHg at 25ºC (EPISuite, 2017)

1.7.11. log Kow

1.09 (EPISuite, 2017)

2. General information

2.1. Exposure

Natural Pollution Sources:

Abundance in earth's crust: approx 0.027%. Cosmic abundance: 6 atoms/atom Si. Occurs in 3 forms: (1) diamond; (2) graphite or black lead; (3) amorphous carbon such as coal, lampblack, and the various forms of artificial carbon. [O'Neil, M.J. (ed.). The Merck Index - An Encyclopedia of Chemicals, Drugs, and Biologicals. Whitehouse Station, NJ: Merck and Co., Inc., 2006.., p. 293] **PEER REVIEWED** (2009)

... very widely distributed in nature. It is found in abundance in the sun, stars, comets, and atmospheres of most planets. ... Without carbon, the basis for life would be impossible. [Lide, D.R. CRC Handbook of Chemistry and Physics 86TH Edition 2005-2006. CRC Press, Taylor & Francis, Boca Raton, FL 2005, p. 4-8] **PEER REVIEWED**

(14)C Isotope, continuously formed in earth's atmosphere by bombardment of nitrogen with cosmic neutrons. /(14)C/ [O'Neil, M.J. (ed.). The Merck Index - An Encyclopedia of Chemicals, Drugs, and Biologicals. Whitehouse Station, NJ: Merck and Co., Inc., 2006.., p. 293] **PEER REVIEWED** (2009)

Diamond, an allotropic form of carbon, crystallizes isometrically, consists of carbon atoms covalently bound by single bonds only in a predominantly octahedral structure. The purest diamonds used for gems are mined in South Africa, lower grades in Brazil, Venezuela, India, Borneo, Arkansas. /Diamond/ [Lewis, R.J. Sr.; Hawley's Condensed Chemical Dictionary 15th Edition. John Wiley & Sons, Inc. New York, NY 2007., p. 386] **PEER REVIEWED**

Artificial Pollution Sources:

A fourth form, known as "white" carbon**,** is now thought to exist. [Lide, D.R. CRC Handbook of Chemistry and Physics 86TH Edition 2005-2006. CRC Press, Taylor & Francis, Boca Raton, FL 2005, p. 4-8] **PEER REVIEWED**

Environmental Abiotic Degradation:

... is rapidly oxidized to carbon dioxide ... /which enters/ into animals and plants by photosynthesis and metabolism. /(14)C/ [O'Neil, M.J. (ed.). The Merck Index - An Encyclopedia of Chemicals, Drugs, and Biologicals. Whitehouse Station, NJ: Merck and Co., Inc., 2006.., p. 293] **PEER REVIEWED**

Major Uses:

Use in fuel industry ... /and in/ paints, lacquers and varnishes industry ... Use as absorbents and adsorbents. [European Chemicals Bureau; IUCLID Dataset, Carbon (7440-44-0) p.4 (2000 CD-ROM edition). Available from, as of July 18, 2008: http://esis.jrc.ec.europa.eu/ **PEER REVIEWED**

Decolorizing sugar, water and air purification, solvent recovery, waste treatment, removal of sulfur dioxide from stack gasses and "clean" rooms, deodorant, removal of jet fumes from airports, catalyst for natural gas purification, brewing, chromium electroplating, air conditioning. /Carbon, activated/ [Lewis, R.J. Sr.; Hawley's Condensed Chemical Dictionary 15th Edition. John Wiley & Sons, Inc. New York, NY 2007., p. 232] **PEER REVIEWED**

As strong reducing agent and is used as such in purifying metals; in electrodes, electrical devices ... and steel [Lewis, R.J. Sr.; Hawley's Condensed Chemical Dictionary 15th Edition. John Wiley & Sons, Inc. New York, NY 2007., p. 231] **PEER REVIEWED**

For carbon (USEPA/OPP Pesticide Code: 016001) ACTIVE products with label matches. /SRP: Registered for use in the U.S. but approved pesticide uses may change periodically and so federal, state and local authorities must be consulted for currently approved uses./ [National Pesticide Information Retrieval System's USEPA/OPP Chemical Ingredients Database on Carbon (7440-44-0). Available from, as of July 1, 2008: http://ppis.ceris.purdue.edu/htbin/epachem.com **PEER REVIEWED**

... One form of carbon, activated charcoal, is given orally as an adsorbent for treatment of accidental drug poisoning.

Human exposure is expected to be negligible for carbon when it is used as one component in gas-producing cartridges placed in animal burrows. Ignited cartridges are to be quickly placed into burrows which are then covered to entrap the generated fumes. Improperly covered burrows could result in inhalation exposure to the fumes if the applicator remains in close proximity to the burrow. [USEPA/Office of Pesticide Programs; Reregistration Eligibility Decision Document - Carbon and Carbon Dioxide p.6 (September 1991). Available from, as of July 19, 2008: http://www.epa.gov/pesticides/reregistration/status.htm] **PEER REVIEWED**

As taken from HSDB, 2009

Activated carbon (CAS RN 7440-44-0) is listed as an ingredient (at given concentrations, where specified) in auto (1-10%), inside the home (1-5%), “old” pesticide (9.3%) and pet care (10-30%) and personal care (0.5-1.5%) products by the CPID.

“CNT (carbon nanotubes) and CNF (carbon nanofibres) are currently used in many industrial and biomedical applications, including electronics, lithium-ion batteries, solar cells, super capacitors, thermoplastics, polymer composites, coatings, adhesives, biosensors, enhanced electron-scanning microscopy imaging techniques, inks, and in pharmaceutical/biomedical devices. CNT and CNF can be encountered in facilities ranging from research laboratories and production plants to operations where CNT and CNF are processed, used, disposed, or recycled. The data on worker personal exposures to CNT and CNF are extremely limited, but reported workplace airborne concentrations for CNT [Maynard et al. 2004; Han et al. 2008a; Bello et al. 2009, 2010; Tsai et al. 2009; Lee et al. 2010; Cena and Peters 2011; Dahm et al. 2011] and CNF [Methner et al. 2007; Evans et al. 2010; Birch 2011a; Birch et al. 2011b] indicate the potential for worker exposures in many tasks or processes and the reduction or elimination of exposures when measures to control exposure are used.

Occupational exposure to all types of CNT and CNF can be quantified using NIOSH Method 5040. A multi-tiered exposure measurement strategy is recommended for determining worker exposure to CNT and CNF [Section 6.1]. When exposure to other types of EC (e.g., diesel soot, carbon black) are absent or negligible, environmental background EC concentrations are typically < 1 µg/m3 including in facilities where CNT and CNF are produced and used [Evans et al. 2010; Birch 2011a, b; Dahm et al. 2011]. Thus, an elevated airborne EC concentration relative to background (environmental and in non-process areas in the workplace) is a reasonable indicator of CNT or CNF exposure. When exposure to other types of EC is possible, additional analytical techniques may be required to better characterize exposures. For example, analysis of airborne samples by transmission electron microscopy (TEM) equipped with energy dispersive x-ray spectroscopy (EDS) can help to verify the presence of CNT and CNF.

....NIOSH recommends that exposures to CNT and CNF be kept below the recommended exposure limit (REL) of 1 µg/m3 of respirable elemental carbon as an 8-hr TWA. Because there may be other sources of elemental carbon in the workplace that could interfere in the determination of CNT and CNF exposures, other analytical techniques such as transmission electron microscopy are described that could assist in characterizing exposures. Studies have shown that airborne background (environmental and in non-process areas in the workplace) concentrations to elemental carbon are typically less than 1 µg/m3 and that an elevated exposure to elemental carbon in the workplace is a reasonable indicator of CNT or CNF exposure [Evans et al. 2010; Birch 2011a, b; Dahm et al. 2011]. Studies have also shown in some manufacturing operations that exposures can be controlled below the REL when engineering controls are used [Dahm et al. 2011]. However, NIOSH has not assessed the extent to which exposures can be controlled during the life cycle of CNT/CNF product use, but since airborne CNT/CNF behave as classical aerosols, the control of worker exposures appears feasible with standard exposure control techniques (e.g., source enclosure, local-exhaust ventilation) [NIOSH 2009a]. Previously in a 2010 draft of this CIB for public comment, NIOSH indicated that the risks could occur with exposures less than 1 µg/m3 but that the analytic limit of quantification was 7 µg/m3. Based on subsequent improvements in sampling and analytic methods, NIOSH is now recommending an exposure limit at the current analytical limit of quantification of 1 µg/m3….The recommended exposure limit is in units of mass/unit volume of air, which is how the exposures in the animal studies were quantified and it is the exposure metric that generally is used in the practice of industrial hygiene. In the future, as more data are obtained, a recommended exposure limit might be based on a different exposure metric better correlated with toxicological effects, such as CNT/CNF number concentration [Schulte et al. 2012].

There are many uncertainties in assessing risks to workers exposed to CNT/CNF. These uncertainties, as described and evaluated in this document, do not lessen the concern or

diminish the recommendations. Other investigators and organizations have been concerned about the same effects and have recommended occupational exposure limits (OELs) for CNT within the range of 1–50 µg/m3 [Nanocyl 2009; Aschberger et al. 2010; Pauluhn 2010b; Nakanishi (ed) 2011a,b]. The relative consistency in these proposed OELs demonstrates the need to manage CNT/CNF as a new and more active form of carbon. To put this in perspective, since there is no Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for CNT/CNF, the PEL for graphite (5,000 µg/m3) or carbon black (3,500 µg/m3) [NIOSH 2007] might inappropriately be applied as a guide to control worker exposures to CNT/CNF. Based on the information presented in this document, the PELs for graphite or carbon black would not protect workers exposed to CNT/CNF.

In summary, the findings and recommendations in this Current Intelligence Bulletin are intended to minimize the potential health risks associated with occupational exposure to CNT and CNF by recommending a working lifetime exposure limit (1 µg/m3, 8-hr TWA, 45 years), a sampling and analytical method to detect CNT and CNF, medical surveillance and screening and other guidelines. The expanding use of CNT/CNF products in commerce and research warrants these protective actions."

As taken from NIOSH, 2013.

Summarised data on use levels of vegetable carbon in foodstuffs reported from industries.

Foodstuffs	**Data provided by**	**Reported range of typical use levels (lowest-highest) (mg/kg)**	**Maxiumun reported use levels (mg/kg)**
Desserts including flavoured milk products	NATCOL, 2007	100	2500
Confectionery	CIAA, 2009 NATCOL, 2007	5 – 2500 550	8000 2000
Decorations and coatings	CIAA, 2009	10000	10000
Fine Bakery Wares	CIAA, 2009	37	60
Mustard	CIAA, 2009	200	200
Sauces[1]	CIAA, 2009	60 – 230	540
Margarine	CIAA, 2009	290	410
Edible ices	CIAA, 2009 NATCOL, 2007	135 – 157 500	1185 1250

[1] The levels reported for "sauces" have also been applied to the whole food category "Sauces, seasonings (for example curry powder, tandoori), pickles, relishes, chutney and piccalilli" because the consumption data available do not allow to differentiate sauces from the other foods covered by this food category.

As taken from EFSA, 2012b

Charcoal powder (CAS RN 16291-96-6; 7440-44-0 (generic)) is used as an abrasive, absorbent and opacifying agent in cosmetics in the EU. Carbon (CAS RN 7440-44-0) is also listed as a cosmetic ingredient but has no reported functions. CI 77266 (CAS 1333-86-4, 7440-44-0) and CI 77268:1 (CAS 1339-82-8, 7440-44-0) are used as colorants. As taken from CosIng (Cosmetic

substances and ingredients database). available at https://ec.europa.eu/growth/tools-databases/cosing/

“Human Health Assessment

……. When used as an additive in plastics, the substance is expected to be manufactured in or imported into Canada encapsulated in a solid polymer matrix. The potential site of exposure to the substance is expected to be within industrial facilities. Therefore, direct exposure of the general population is expected to be low. No significant environmental release is anticipated due to the specialized use under this notification and therefore indirect exposure of the general population from environmental media is also expected to be low. However, if the substance is produced in different forms (e.g. liquid polymer form), applied in different formulations or used in any other potential applications, an increased direct or indirect exposure potential may exist. ……. The use of the substance in consumer products or in products intended for use by or for children may significantly alter the exposure of the general population resulting in the substance becoming harmful to human health. Similarly, the import or manufacture of the substance in quantities greater than 10 000 kg/yr may significantly increase the exposure levels of the general population resulting in the substance becoming harmful to human health. …..”

As taken from Environment Canada, 2015

“Used for high-temperature crucibles, as a lubricant and in "lead" pencils.”

As taken from PubChem.

Record for “graphite, synthetic” (no CAS RN provided):

ACGIH TLV: TWA – 2 mg/m^3 (respirable) (“all forms except graphite fibers”)

OSHA PEL: TWA – 15 mg/m^3 (total dust), 5 mg/m^3 (respirable fraction)

As taken from ACGIH, 2021.

Permissible exposure limits (PELs) for “graphite, synthetic” (no CAS RN listed):

Total dust – 10 mg/m^3

Respirable fraction – 5 mg/m^3

As taken from Cal/OSHA.

Vegetable carbon (CAS RN 7440-44-0) is used as a colour additive in non-medicinal natural health products (Health Canada, 2021).

2.2. Combustion products

No data available to us at this time

2.3. Ingredient(s) from which it originates

“A solid, porous, carbonaceous material prepared by carbonizing and activating organic substances. The raw materials, which include sawdust, peat, lignite, coal, cellulose residues, coconut shells, petroleum coke, etc., may be carbonized and activated at high temperature with or without the addition of inorganic salts in a stream of activating gases such as steam or carbon dioxide. Alternatively, carbonaceous matter may be treated with a chemical activating agent such as phosphoric acid or zinc chloride and the mixture carbonized at an elevated temperature, followed by removal of the chemical activating agent by water washing” (FAO/JECFA, 2010. Compendium of Food Additive Specifications). As taken from http://www.fao.org/3/a-i1782e.pdf

“Charcoal Powder [CAS RN 16291-96-6; 7440-44-0 (generic)] is the dried, carbonaceous material obtained from the heating of organic substances”.

“Carbon [CAS RN 7440-44-0] is an amorphous form of elemental carbon.”

“CI 77266 (CAS 1333-86-4, 7440-44-0) is composed of finely divided particles of elemental carbon obtained by the incomplete combustion of hydrocarbons”

“CI 77268:1 (CAS 1339-82-8, 7440-44-0) is classed chemically as an inorganic colour. It consists essentially of elemental carbon of plant origin.”

As taken from CosIng (Cosmetic substances and ingredients database). available at https://ec.europa.eu/growth/tools-databases/cosing/

3. Status in legislation and other official guidance

NIOSH Recommendations:

NIOSH concluded that the documentation cited by OSHA was inadequate to support the proposed PEL (as an 8-hour TWA) of 10 mg/cu m for graphite (synthetic). [NIOSH. NIOSH Pocket Guide to Chemical Hazards & Other Databases CD-ROM. Department of Health & Human Services, Centers for Disease Prevention & Control. National Institute for Occupational Safety & Health. DHHS (NIOSH) Publication No. 2005-151 (2005)] **PEER REVIEWED**

FIFRA Requirements:

As the federal pesticide law FIFRA directs, EPA is conducting a comprehensive review of older pesticides to consider their health and environmental effects and make decisions about their future use. Under this pesticide reregistration program, EPA examines health and safety data for pesticide active ingredients initially registered before November 1, 1984, and determines whether they are eligible for reregistration. In addition, all pesticides must meet the new safety standard of the Food Quality Protection Act of 1996. Pesticides for which EPA had not issued Registration Standards prior to the effective date of FIFRA, as amended in 1988, were divided into three lists based upon their potential for human exposure and other factors, with List B containing pesticides of greater concern and List D pesticides of less concern. Carbon is found on List D. Case No: 4019; Pesticide type: insecticide, rodenticide; Case Status: RED Approved 09/91; OPP has made a decision that some/all uses of the pesticide are eligible for reregistration, as reflected in a Reregistration Eligibility Decision (RED) document.; Active ingredient (AI): Carbon; AI Status: OPP has completed a Reregistration Eligibility Decision (RED) document for the case/AI. [United States Environmental Protection Agency/ Prevention, Pesticides and Toxic Substances; Status of Pesticides in Registration, Reregistration, and Special Review. (1998) EPA 738-R-98-002, p. 299] **PEER REVIEWED**

As taken from HSDB, 2009

“….This Account reviews the inhalation toxicity of manufactured nanomaterials and compares them with inhalation and intratracheal instillation studies of well-characterized fullerene and carbon nanotubes….The values of the acceptable exposure concentration in some countries were based on the data of subacute and subchronic inhalation and intratracheal instillation studies of well-characterized fullerene and carbon nanotubes. In Japan, the acceptable exposure concentration of fullerene is 0.39 mg/m³. In Europe, the proposal concentration is 44.4 μg/m³ for acute toxicity and 0.27 μg/m³ for chronic toxicity. The proposal acceptable exposure concentrations of carbon nanotubes are 0.03, 0.05, and 0.007 mg/m³ in Japan, Europe, and the United States, respectively.” As taken from Morimoto Y et al. 2013. Acc. Chem. Res. 46(3), 770-81. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/22574947

OSHA PEL 8-hour TWA	NIOSH REL Up to 10-hour	ACGIH TLV© 8-hour TWA	CAL/OSHA PEL 8-hour TWA

(ST) STEL (C) Ceiling Peak		TWA (ST) STEL (C) Ceiling		(ST) STEL (C) Ceiling		(ST) STEL (C) Ceiling Peak	
PEL-TWA	15 mg/m³ (total dust), 5 mg/m³ (respirable fraction)	**REL-TWA**		**TLV-TWA**	2 mg/m³ (respirable particulate matter) [1988]	**PEL-TWA**	10 mg/m³ (total dust), 5 mg/m³ (respirable fraction)
PEL-STEL		**REL-STEL**		**TLV-STEL**		**PEL-STEL**	
PEL-C		**REL-C**		**TLV-C**		**PEL-C**	
Skin notation	N	**Skin notation**	N	**Skin notation**	N	**Skin notation**	N
Notes: See 29 CFR 1910.1000 Table Z-1.		**Notes:** See Appendix D - Substances with No Established RELs.		**Notes:**		**Notes:** See footnote [n].	

As taken from OSHA, 2021UK 8-hr TWA for graphite (CAS RN 7440-44-0): 10 mg/m^3 (inhalable dust); 4 mg/m^3 (respirable dust) (HSE, 2020).

“Activated carbon should in addition comply with the same purity requirements as for Vegetable Carbon (E 153) set out by Commission Directive 95/45/EC with exception of ash content which can be up to 10 % (w/w)” (EFSA, 2012a, EFSA Journal 10(3):2643). As taken from http://www.efsa.europa.eu/en/efsajournal/doc/2643.pdf

E 153 Vegetable Carbon (EINECS 231-153-3) is authorised food additive in the EU in accordance with Annex II to Regulation (EC) No 1129/2011 of 11 November 2011 amending Annex II to Regulation EC No 1333/2008, and also Commission Regulation (EU) 738/2013 of 30/07/2013 amending Annex II to Regulation (EC) 1333/2008, on food additives. (European Commission, undated)The EFSA ANS Panel provides a scientific opinion re-evaluating the safety of vegetable carbon (E 153). Vegetable carbon has been evaluated previously by the SCF (1977, 1983) and by JECFA (1970, 1977, 1987). Neither Committee established an ADI for vegetable carbon, but the SCF concluded that vegetable carbon could be used in food The Panel considered the available toxicological data too limited to establish an ADI for vegetable carbon (EFSA 2012b).

Vegetable carbon (E 153) has been evaluated by JECFA in 1970, 1977 and 1987 (JECFA 1971, 1978,1987) and the SCF in 1977 and 1983 (SCF 1977, 1984). Both Committees did not establish an acceptable daily intake (ADI). However, “in view of its use as a traditional therapeutic agent”, the SCF recommended “the maintenance of the substance in the Directive for food use in general, despite the absence of extensive animal toxicological data” (SCF, 1977). In 1983, the Committee did not see any reason to change this evaluation (SCF, 1984). (EFSA 2012b)

There are REACH dossiers on “activated carbon – high density skeleton” (CAS RN 7440-44-0; EC no. 931-328-0) and “activated carbon – low density skeleton” (no CAS RN listed; EC no. 931-334-3) (ECHA, undated).

The following substances are not registered under REACH: “carbon” (CAS RN 7440-44-0) and “reaction mass of ACTIVATED CARBON and activated carbon” (no CAS RN listed; EC no. 924-991-2); “synthetic graphite” (CAS RN not listed; EC no. 928-923-2); (ECHA, undated).

“Carbon” (CAS RN 7440-44-0), “activated carbon – high density skeleton” (CAS RN 7440-44-0; EC no. 931-328-0), “activated carbon – low density skeleton” (no CAS RN listed; EC no. 931-334-3) and "carbon” (CAS 7440-44-0, EC 231-153-3) are not classified for packaging and labelling under Regulation (EC) No. 1272/2008 (ECHA, 2023).

Carbon (CAS RN 7440-44-0) is listed in the US EPA InertFinder Database (2023) as approved for food and non-food use pesticide products. For food use, it is regulated under 40 CFR Part 180.910 (Inert ingredients used pre- and post-harvest exemptions from the requirement of a tolerance) (US EPA, 2023).

Carbon (CAS RN 7440-44-0) is listed in the US EPA Toxic Substances Control Act (TSCA) inventory and also in the US EPA 2020 CDR list (Chemical Data Reporting Rule).The Chemical Data Reporting (CDR) Rule requires companies that manufacture (including import) certain chemicals at certain volumes in the U.S. to report to EPA every four years through its CDR. Carbon (CAS RN 7440-44-0) is 2020 CDR Partial Exempt. Manufacturers (including importers) of partially exempt chemicals are not required to report processing and use information, but are required to report basic identity and manufacturing information.

US EPA 2020 CDR List. US EPA 2020 CDR Partial Exempt List. US EPA TSCA inventory.

Activated carbon (CAS RN 64365-11-3) is included on the FDA’s inventory of “Substances Added to Food (formerly EAFUS) as a processing aid, and is included under 21 CFR 177.1210 (Indirect Food Additives: Polymers, Subpart B—Substances for Use as Basic Components of Single and Repeated Use Food Contact Surfaces, Closures with sealing gaskets for food containers) (FDA, 2022, 2023).

Evaluations of the Joint FAO/WHO Expert Committee on Food Additives (JECFA)

Activated carbon

Synonyms:	CARBON, ACTIVATED VEGETABLE (FOOD GRADE), DECOLOURIZING CARBON
Chemical Names:	CARBON
CAS number:	7440-44-0
Functional Class:	Food Additives ADSORBENT BLEACHING_AGENT
Evaluation year:	1987
ADI:	NOT LIMITED
Meeting:	31
Specs Code:	R (1990)

Report:	TRS 759-JECFA 31/25
Tox Monograph:	FAS 70.39/NMRS 48A-JECFA 14/79 (1970)
Specification:	COMPENDIUM ADDENDUM 11/FNP 52 Add. 11/89 (METALS LIMITS) (2003); FAO JECFA Monographs 1 vol.1/15
Previous Years:	1990, COMPENDIUM/21. R 1987, FNP 38-JECFA 31/43 1977, TRS 617-JECFA 21/28, NMRS 57-JECFA 21/4, FAS 70.39/NMRS 48A-JECFA 14/79 (1970). ADI NOT LIMITED. NL. R,T 1970, NMRS 48/TRS 462-JECFA 14/16, FAS 70.40/NMRS 48B-JECFA 14/39, FAS 70.39/NMRS 48A-JECFA

Vegetable carbon

Synonyms:	CARBON BLACK (VEGETABLE SOURCES), VEGETABLE BLACK
Chemical Names:	CARBON
CAS number:	7440-44-0; 1333-86-4 (CARBON BLACK)
INS:	153
Functional Class:	Food Additives COLOUR
Evaluation year:	1987
ADI:	NO ADI ALLOCATED
Meeting:	31
Specs Code:	R (1990)
Report:	TRS 759-JECFA 31/26
Tox Monograph:	NOT PREPARED
Specification:	COMPENDIUM ADDENDUM 10/FNP 52 Add.10/34 (METALS LIMITS) (2002). R; FAO JECFA Monographs 1 vol.3/587
Previous Years:	1990, COMPENDIUM/1579. R 1987, FNP 38-JECFA 31/47. R,T 1984, FNP 31/1-JECFA 28/43. R,T 1977, TRS 617-JECFA 21/17, NMRS VOL. II-IV/17 (1959). NOT PREPARED. DECISION POSTPONED. NO. S 1959, NMRS VOL. II-IV/17. N

As taken from JECFA, 2021.

Substance	Active carbon dust
CAS No.	64365-11-3

	Limit value - Eight hours		Limit value - Short term	
	ppm	mg/m³	ppm	mg/m³
People's Republic of China		5 (1)		

	Remarks
People's Republic of China	(1) Inhalable fraction

Substance	Carbon fibres			
CAS No.				
	Limit value - Eight hours		Limit value - Short term	
	ppm	mg/m³	ppm	mg/m³
Belgium	-	2 F/cm^3	-	-
People's Republic of China		3 (1)		

	Remarks
People's Republic of China	(1) Inhalable fraction

Substance	Dust, carbon (carbon black included), total dust			
CAS No.				
	Limit value - Eight hours		Limit value - Short term	
	ppm	mg/m³	ppm	mg/m³
Belgium		3,6		
Latvia		4		
Sweden		3		

As taken from GESTIS, 2021.

Carbon “poses no unreasonable risk to human health based on Tier I assessment under the NICNAS IMAP assessment framework” (AICIS, 2014).

Carbon (CAS RN 7440-44-0) is listed by the US EPA Office of Pesticide Programs (2021) and was first registered as an antimicrobial and “conventional chemical” pesticide on 27 September 1985. It is noted as being under registration review, as part of the group carbon and CO2.

INCI Name	CI 77266
Description	CI 77266 is a colorant composed of finely divided particles of elemental carbon obtained by the incomplete combustion of hydrocarbons.

CAS #	1333-86-4; 7440-44-0
EC #	215-609-9; 231-153-3; 931-328-0; 931-334-3
Cosmetics Regulation provisions	IV/126 IV/126a
Functions	•COLORANT
SCCS opinions	•1515/13 - Opinionon Carbon Black (nano-form) •1539/14 - Opinion for clarification of the meaning of the term "sprayable applications/products" for the nano forms of Carbon Black CI 77266, Titanium Oxide and Zinc Oxide
Identified INGREDIENTS or substances e.g.	
INCI Name	CI 77268:1
Description	CI 77268:1 is classed chemically as an inorganic colour. It consists essentially of elemental carbon of plant origin.
CAS #	1339-82-8; 7440-44-0
EC #	215-669-6; 231-153-3
Cosmetics Regulation provisions	IV/128
Functions	•COLORANT
SCCS opinions	
Identified INGREDIENTS or substances e.g.	•Coke black
Substance	Coke black
CAS #	7440-44-0; 1339-82-8
EC #	231-153-3; 215-669-6
Colour index Number / Name of Common Ingredients Glossary	CI 77268:1
INN/ISO/AN	
Regulation	(EC) 2009/1223
Regulated By	88/667/EEC
Other Directives/Regulations	

Annex/Ref #	IV/128
Colour	Black
Product Type, body parts	
Maximum concentration in ready for use preparation	
Other	
Wording of conditions of use and warnings	
SCCS opinions	
Chemical/IUPAC Name	Coke black
Identified INGREDIENTS or substances e.g.	•CI 77268:1
Note	
Current Version	v.1

As taken from CosIng (Cosmetic substances and ingredients database). Available at https://ec.europa.eu/growth/tools-databases/cosing/

Carbon black (CAS 1333-86-4, 7440-44-0) is an insoluble nanostructured material that is used as a colorant in many cosmetic products. There is a positive SCCS Opinion for its use in dermally-applied products. However, the opinion did not recommend applications that might lead to inhalation exposure of the consumer to carbon black nanoparticles due to the likelihood of harmful effects, including the potential to induce genotoxic effects. The Opinion also did not cover oral uses (such as tooth whitener) that are listed in the EC catalogue. Therefore, there is a safety concern over the use of carbon black in applications that may give rise exposure of the consumer to nanoparticles via oral or inhalation routes. As taken from SCCS, 2021.

Activated carbon (CAS 7440-44-0) is listed on Australian Inventory of Industrial Chemicals. (AICIS, formerly NICNAS). As taken from AICIS (Undated).

4. Metabolism/Pharmacokinetics

4.1. Metabolism/metabolites

“Carbon nanotubes (CNTs) consist of a family of carbon built nanoparticles, whose biological effects depend on their physical characteristics and other constitutive chemicals (impurities and functions attached)….Entrance into the body is physical, and usually few nanoparticles enter the body; however, once there, they are persistent due to their limited metabolisms, so their removal is slow….” As taken from Rodriguez-Yañez Y et al. 2013. Toxicol. Mech. Methods 23(3), 178-95. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23193995

4.2. Absorption, distribution and excretion

Exptl intravenous injection of pure carbon suspensions in rabbits produces no ocular inflammation, although carbon particles are deposited within the blood vessels. [Grant, W.M. Toxicology of the Eye. 3rd ed. Springfield, IL: Charles C. Thomas Publisher, 1986., p. 178] **PEER REVIEWED**

As taken from HSDB, 2009

“Further evidence for a correlation between geometric particle diameter and prolonged particle retention in airways was recently obtained from a study targeting 100 nm carbon particles to human airways by shallow aerosol bolus inhalation. In this study only 25% of the nanoparticles were removed by mucociliary clearance within 24 h, while 75% were retained for more than 48 h. Possible explanations for these findings are that the particles were no longer accessible to mucociliary clearance either because they penetrated through the mucus deep into the periciliary phase or that they were deposited in areas with reduced lung lining layer. In both cases, further interaction of particles with cells of the inner lung surface, i.e. macrophages, dendritic and epithelial cells is furthered and the probability for particle relocation beyond the epithelial barrier enhanced….There is evidence for translocation of gold…carbon nanoparticles in the size range of 5 - 100 nm across the air-blood barrier from animal experiments. Either, nanoparticles were found in the blood circulation and in secondary target organs, or thrombogenic effects were observed” (Geiser and Kreyling, 2010. Particle and Fibre Technology 7, 2). As taken from http://www.particleandfibretoxicology.com/content/pdf/1743-8977-7-2.pdf

“In this study, we prepared two-types of water-dispersible carbon nanotubes (CNTs) and investigated their biodistribution in mice as well as bio-/cyto-compatibility. After administration, their organs were excised at various post-injection times, then observed using both optical and transmission electron microscopy (TEM). The color of the liver and lung markedly darkened, suggesting that administered CNTs reached these organs. By TEM observation, the CNTs were found in the liver and lung. They were observed even in the kidney and spleen, though their distributions in those organs were very low compared with that in liver and lung. Therefore, most of the administered CNTs would be accumulated in the liver or lung. However, the time profile of the body weight of CNT-administered mice was close to that of control mice. In addition, we estimated the cytocompatibility of the water-dispersible CNTs for hepatocytes. According to a TNF-alpha assay of the cells cultured with CNTs, the expression level was almost the same as that of the control. These results suggested that the water-dispersible CNTs have good bio-/cyto-compatibility under this condition” (Abe et al., 2012. Journal of Nanoscience and Nanotechnology 12, 700-706). As taken from http://www.ncbi.nlm.nih.gov/pubmed/22524043

“Lim and co-workers (Lim et al. 2011a and Lim et al. 2011b) administered 0 (control), 40, 200 or

1000 mg multi-wall CNTs (MWCNTs)/kg bw/day orally by gavage to pregnant Sprague-Dawley rats (N=12/group) from gestation days 6 through 19. The MWCNTs used were commercially available with a nominal diameter of 10-15 nm and length around 20 µm. The purity was stated to be 95% carbon and approximately 5% iron. The authors did not embark on any physico-chemical characterization and did not determine if aggregation of the CNTs occurred following the only 3 minutes ultrasound treatment in 0.1% carboxymethylcellulose (stabilizer) solution in water…..Conclusion: This study was not designed to be an absorption study, but, the toxic effects seen at the highest oral dose (1000 mg/kg bw/day), might give some indirect indication that material related to the MWCNTs was absorbed.

Awasthi and co-workers (Awasthi et al. 2013) administered male Swiss albino mice (N=6/group) single doses of 0 (vehicle control, distilled water), 60, or 100 mg/kg bw) of MWCNTs and studied hepatotoxicity on post dosing days 7, 14, 21 and 28 using liver SOD and CAT activity and

microscopic examination as end-points. The tested MWCNTs, which were synthesised by chemical vapour deposition (CVD) technique, were purified and washed to remove metallic and carbonaceous impurities. Their size range was determined by SEM as 20–30 nm and length of 5–50 μm. The testing suspensions were made by physical mixing and ultrasonication of surface-oxidised material, but any further data on characterization or aggregation was missing…..Conclusion: The study does not support that any oral absorption of the test material occurred in mice.

Cicchetti and co-workers (Cicchetti et al. 2011) exposed human gingival fibroblasts in semiconfluent cultures to SWCNT concentrations between 50 and 150 μg SWCNTs/ml for 24 hours. The SWCNTs used were oxidized by treatment with a mixture of nitric and sulphuric acids. The surface area of was 407 m2/g, and the average external diameter was 1.58 nm ± 0.20 nm and the average length was 0.76 μm ± 0.70 μm. The SWCNTs were reported by the authors to have “a relatively high degree of crystallinity”….The effects seen in vitro indicated that SWCNT related material was absorbed into the cells, but did not prove the absorption of any intact nanomaterial.

Sachar and Saxena (Sachar and Saxena 2011) investigated the uptake of either SWCNTs or acid functionalized SWCNTs (AF-SWCNTs) in erythrocytes isolated from Swiss or C57BL76 female mice. The acid functionalized (AF)-SWCNTs were surface oxidized by a mixture of nitric and sulphuric acid under pressure at elevated temperature. The carboxylic acid moieties formed were derivatised by a fluorophor for imaging purposes, and were intensively purified to remove excess fluorescent dye. The particle size distribution and surface charge was not indicated. Particle size distribution and surface charge on AF-SWCNTs were reported before (Saxena et al. 2007 as cited in (Sachar and Saxena 2011)….Conclusion: This study suggested that some fluorescence related to exposure to fluorescence tagged AF-SWCNTs could enter erythrocytes, but no clear evidence about absorption of the intact NPs after oral exposure to SWCNT was provided.

In light of the occurrence of mainly negative data on absorption of CNT following oral exposure no evaluation of factors influencing their systemic absorption can be given.”

As taken from Binderup et al. 2013.

“Multiwalled carbon nanotubes (MWCNT) are one of the most commonly produced nanomaterials, and pulmonary exposure during production, use, and disposal is a concern for the developing nanotechnology field. The airway epithelium is the first line of defense against inhaled particles. In a mouse model, MWCNT were reported to reach the alveolar space of the lung after in vivo exposure, penetrate the epithelial lining, and result in inflammation and progressive fibrosis….” As taken from Snyder-Talkington BN et al. 2013a. Toxicol. Sci. 133(1), 79-89. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23377615

“BACKGROUND: SEVERAL PROPERTIES OF MULTI-WALLED CARBONNANOTUBES (MWCNT) HAVE THE POTENTIAL TO AFFECT THEIR BIOACTIVITY. THIS STUDY EXAMINED THE IN VITRO AND IN VIVO OUTCOMES OF THE INFLUENCE OF DIAMETER, LENGTH, PURIFICATION AND CARBOXYLATION (IN VITRO TESTING ONLY) OF MWCNT. METHODS: Three original 'as received' MWCNT that varied in size (diameter and length) were purified and functionalized by carboxylation. The resulting MWCNT were characterized and examined for cytotoxicity and inflammasome activation in vitro using THP-1 cells and primary alveolar macrophages from C57BL/6 mice. Oropharyngeal aspiration administration was used to deliver original MWCNT and in vivo bioactivity and lung retention was examined at 1 and 7 days. RESULTS:….Seven-day histology revealed that, consistent with the in vitro results, increasing width or length of MWCNT caused more severe pathology with the longest MWCNT causing the most severe inflammation. In addition, the same two larger MWCNT were retained more in the lung at 7 days….” As taken from Hamilton RF Jr et al. 2013. Part. Fibre Toxicol. 10(1), 57. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24225053

“The hallmark geometric feature of single-walled carbon nanotubes (SWCNT) and carbon nanofibers (CNF) - high length to width ratio - makes them similar to a hazardous agent - asbestos.

Very limited data are available concerning long-term effects of pulmonary exposure to SWCNT or CNF. Here we compared inflammatory, fibrogenic and genotoxic effects of CNF, SWCNT or asbestos in mice one year after pharyngeal aspiration. In addition, we compared pulmonary responses to SWCNT by bolus dosing through pharyngeal aspiration and inhalation 5h/day for 4 days, to evaluate the effect of dose rate. The aspiration studies showed that, these particles can be visualized in the lung at one year post-exposure, while some translocate to lymphatics…." As taken from Shvedova AA et al. 2014. Am. J. Physiol. Lung Cell. Mol. Physiol. 306(2), L170-82. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24213921

"Understanding the excretion pathway is one of the most important prerequisites for the safe use of nanoparticles in biomedicine. However, the excretion of nanoparticles in human remains largely unknown, except for some particles very small in size. Here we report a novel natural pathway for nanoparticle excretion, the intestinal goblet cell (GC) secretion pathway (IGCSP). Direct live observation of the behavior of 30-200nm activated carbonnanoparticles (ACNP) demonstrated that ACNP microinjected into the yolk sac of zebrafish can be excreted directly through intestinal tract without involving the hepato-biliary (hap-bile) system. Histopathological examination in mice after ligation of the common bile duct (CBD) demonstrated that the intravenously-injected ACNP were excreted into the gut lumen through the secretion of intestinal GCs. ACNP in various secretion phases were revealed by histopathological examination and transmission electron microscopy (TEM). IGCSP, in combination with renal and hap-bile pathways, constitutes a complete nanoparticle excretion mechanism." As taken from Zhao B et al. 2014. Nanomedicine 10(4), 839-49. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24183999

"Carbon nanotubes have shown broad potential in biomedical applications, given their unique mechanical, optical, and chemical properties. Functionalized carbon nanotubes not only can deliver drug into specific organs but also can inherently produce heating by near-infrared laser radiation for cancer therapy. However, the toxicological and pharmacological profile of such carbon nanotube system will have to be determined prior to any clinical study undertaken. For providing a guide to develop safe drug carriers, this review discusses the functionalization, toxicity and pharmacokinetics of carbon nanotubes. Lastly, the drug delivery and thermal ablation on carbon nanotubes are proposed." As taken from Luo E et al. 2013. Curr. Drug Metab. 14(8), 879-90. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24016108

"Because of their mechanical strength, chemical stability, and low molecular weight, carbon nanotubes (CNTs) are attractive biological implant materials. Biomaterials are typically implanted into subcutaneous tissue or bone; however, the long-term biopersistence of CNTs in these tissues is unknown. Here, tangled oxidized multi-walled CNTs (t-ox-MWCNTs) were implanted into rat subcutaneous tissues and structural changes in the t-ox-MWCNTs located inside and outside of macrophages were studied for 2 years post-implantation. The majority of the large agglomerates were present in the intercellular space, maintained a layered structure, and did not undergo degradation. By contrast, small agglomerates were found inside macrophages, where they were gradually degraded in lysosomes. None of the rats displayed symptoms of cancer or severe inflammatory reactions such as necrosis. These results indicate that t-ox-MWCNTs have high biopersistence and do not evoke adverse events in rat subcutaneous tissue in vivo, demonstrating their potential utility as implantable biomaterials." As taken from Sato Y et al. 2013. Sci. Rep. 3, 2516. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23981952

"In spite of the extreme rise to the knowledge of nanotechnology in pharmaceutical sciences, there are currently limited experimental works studying the interactions between nanoparticles (NPs) and the biological system. Adjustment of size and surface area plays the main role in the reaction between NPs and cells leading to their increased entrance into cells through skin, gastrointestinal and respiratory system. Moreover, change in physicochemical reactivity of NPs causes them to interact with circulatory and cellular proteins differentially leading to the altered parameters of their biokinetics, including adsorption, distribution, translocation, transformation, and elimination….Inhalation studies of some NPs have confirmed the translocation of inhaled materials

to extra pulmonary organs such as central nervous system (CNS) via olfactory neurons and induction of inflammatory response. Injectable uncoated NPs have a tendency to remain on the injection site while the poly ethanol glycol (PEG)-coated NPs can be notably drained from the injection site to get as far as the lymph nodes where they accumulate. This confirms the existence of channels within the extracellular matrix for NPs to move along…." As taken from Mostafalou S et al. 2013. Daru 21(1), 14. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23432813

"….Entrance into the body is physical, and usually few nanoparticles enter the body; however, once there, they are persistent due to their limited metabolisms, so their removal is slow, and chronic cumulative health effects are studied…." As taken from Rodriguez-Yañez Y et al. 2013. Toxicol. Mech. Methods 23(3), 178-95. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23193995

"We summarized the findings of in vivo toxicity studies of single-walled carbon nanotubes (SWCNTs) in laboratory animals. …... Injected SWCNTs were distributed throughout most of the organs including the brain, mainly retained in the lungs, liver, and spleen, and eliminated through the kidney and bile duct. Orally administered SWCNTs are suggested to be absorbed from the gastrointestinal tract to the blood circulation in mice and rats. …... Overall, the available data provides initial information on SWCNT toxicity. To further clarify their toxicity and risk assessment, studies should be conducted using well-characterized SWCNTs, standard protocols, and the relevant route and doses of human exposure." As taken from Ema M et al. 2016. Regul. Toxicol. Pharmacol. 74, 42-63. PubMed, 2016 available at http://www.ncbi.nlm.nih.gov/pubmed/26619783

4.3. Interactions

"Etoposide is a semisynthetic, chemotherapeutic drug widely recommended to treat an extensive range of human cancers. Our studies indicate that, while etoposide is capable of killing human cancer cells, exposure to single-walled carbon nanotubes (SWCNTs) and etoposide results in enhanced cell death that appears to be synergistic and not merely additive. In this study, we used high pressure liquid chromatography and mass spectrometry to quantify the internal effective dose of etoposide when the human pancreatic cancer cell (PANC-1) was exposed to the combination of these agents. Our results unequivocally indicate that SWCNTs improve etoposide uptake and increase its capacity to kill cancer cells. We suggest that a combination of SWCNTs and etoposide may prove to be a more efficient chemotherapeutic protocol, especially because of the potential to lower toxicdrug doses to levels that may be useful in decreasing adverse side effects, as well as in lowering the probability of inducing chemoresistance in exposed cancer cells." As taken from Mahmood M et al. 2013. Nanotechnology 24(4), 045102. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23291321

"In order to assess the in vivo efficacy of mycotoxin binders, specific toxicokinetic parameters should be measured according to European guidelines. For this purpose, an absorption model in pigs is described with emphasis on absorption kinetics. Pigs received a single oral bolus of the mycotoxin deoxynivalenol alone or in combination with active carbon (applied as mycotoxin binder). After administration of deoxynivalenol alone, significant plasma amounts of deoxynivalenol were detected and kinetic parameters were calculated using a one compartmental model. Activated carbon completely prevented the absorption of deoxynivalenol as no plasma amounts could be detected". As taken from Devreese M et al. 2014. Toxins (Basel) 6(10), 2998-3004. PubMed, 2015 available at http://www.ncbi.nlm.nih.gov/pubmed/25337799

"OBJECTIVES: Comparative in vivo studies were carried out to determine the adsorption characteristics of amitriptyline (AMT) on activated charcoal (AC) and sodium polystyrene sulfonate (SPS). AC has been long used as gastric decontamination agent for tricyclic antidepressants and SPS has showed to be highly effective on in-vitro drugs adsorption. MATERIALS AND METHODS: Sprague-Dawley male rats were divided into six groups. Group I: control, group II: AMT 200 mg/kg as single dose orally, group III and IV: AC 1g/kg as single dose orally 5 and 30 min after AMT

administration respectively, and group 5 and 6: SPS 1 g/kg as single dose orally 5 and 30 min after AMT administration, respectively. 60 min after oral administration of AMT (Tmax of AMT determined in rats), Cmax plasma levels were determined by a validated GC-Mass method. RESULTS: The Cmax values for groups II to IV were determined as 1.1, 0.5, 0.6, 0.1 and 0.3 µg/ml, respectively. CONCLUSION: AC and SPS could significantly reduce Cmax of AMT when administrated either 5 or 30 min after AMT overdose ($P<0.05$). However, SPS showed to be more effective than AC in reducing Cmax when was administrated immediately (5 min) after AMT overdose. The results suggest a more efficient alternative to AC for AMT and probably other TCA overdoses." As taken from Yousefi G et al. 2017. Iran. J. Basic Med. Sci. 20(1), 46-52. PubMed, 2018 available at https://www.ncbi.nlm.nih.gov/pubmed/28133524

5. Toxicity

5.1. Single dose toxicity

Organism	Test Type	Route	Reported Dose (Normalized Dose)	Effect	Source
dog	LD	intraperitoneal	> 5gm/kg (5000mg/kg)		Gekkan Yakuji. Pharmaceuticals Monthly. Vol. 34, Pg. 416, 1992.
dog	LD	oral	> 5gm/kg (5000mg/kg)		Gekkan Yakuji. Pharmaceuticals Monthly. Vol. 34, Pg. 416, 1992.
dog	LD	subcutaneous	> 5gm/kg (5000mg/kg)		Gekkan Yakuji. Pharmaceuticals Monthly. Vol. 34, Pg. 416, 1992.
mouse	LD	intraperitoneal	> 5gm/kg (5000mg/kg)		Gekkan Yakuji. Pharmaceuticals Monthly. Vol. 34, Pg. 416, 1992.
mouse	LD	oral	> 5gm/kg (5000mg/kg)		Gekkan Yakuji. Pharmaceuticals Monthly. Vol. 34, Pg. 416, 1992.
mouse	LD	subcutaneous	> 5gm/kg (5000mg/kg)		Gekkan Yakuji. Pharmaceuticals Monthly. Vol. 34, Pg. 416, 1992.
mouse	LD50	intravenous	440mg/kg (440mg/kg)		Toxicology and Applied Pharmacology. Vol. 24, Pg. 497, 1973.
rat	LD	intraperitoneal	> 5gm/kg (5000mg/kg)		Gekkan Yakuji. Pharmaceuticals Monthly. Vol. 34, Pg. 416, 1992.
rat	LD	oral	> 5gm/kg (5000mg/kg)		Gekkan Yakuji. Pharmaceuticals Monthly. Vol. 34, Pg. 416, 1992.
rat	LD	subcutaneous	> 5gm/kg (5000mg/kg)		Gekkan Yakuji. Pharmaceuticals Monthly. Vol. 34, Pg. 416, 1992.

As taken from PubChem

Species	Route	Dose data
Rat	Oral	LD_{50}: > 10000 mg/kg bw
Rat	Inhalation	LC_{50}: > 64.4 mg/L

As taken from IUCLID Dataset (2000), Carbon (7440-44-0).

“Probable oral lethal dose (human) > 15 g/kg; more than 1 quart (2.2 lb) for 70 kg person (150 lb).”

Mouse intravenous LD_{50}: 440 mg/kg bw

LD50 Rat oral > 10,000 mg/kg [European Chemicals Bureau; IUCLID Dataset, Carbon (7440-44-0) p.13 (2000 CD-ROM edition). Available from, as of July 18, 2008: http://ecb.jrc.it/esis/esis.php] **PEER REVIEWED**

LD50 Mouse iv 440 mg/kg [Lewis, R.J. Sr. (ed) Sax's Dangerous Properties of Industrial Materials. 11th Edition. Wiley-Interscience, Wiley & Sons, Inc. Hoboken, NJ. 2004., p. 704] **PEER REVIEWED**

As taken from HSDB, 2009

“Three female Crl:CD(SD) rats/group were dosed with single wall carbon nanotube (SWCNT) or multi wall carbon nanotube (MWCNT) four times by gavage at a total of 50 mg/kg bw or 200 mg/kg bw (four equally divided doses at one-hour intervals). Acute oral doses of SWCNT and MWCNT caused neither death nor toxicological effects, and thus the oral LD50 values for SWCNT and MWCNT were considered to be greater than 50 mg/kg bw and 200 mg/kg bw, in rats respectively…..It was suggested that SWCNT and MWCNT dosed by gavage reached the gastro-intestinal tract as agglomerates and were mostly excreted via feces”. (Matsumoto et al., 2012. Journal of Toxicological Sciences 37, 463-474). As taken from http://www.ncbi.nlm.nih.gov/pubmed/22687986

“The present study was conducted to assess the pulmonary and systemic responses in rats after intratracheal instillation of highly pure, well-dispersed, and well-characterized SWCNTs. Exposure to SWCNTs up to 2 mg/kg did not produce mortality, changes in clinical signs, or body weights during the observation period. Dose-dependent changes were observed in the lung weight, BALF inflammatory cells, and biochemical parameters such as LDH value, protein content, IL-1β and IL-6 activity, and histopathology. In the 0.04 mg/kg SWCNT-exposed group, almost no changes were observed during the observation period. In the 0.2 mg/kg SWCNT-exposed group, pulmonary inflammatory responses were observed after instillation. In the 1 mg/kg and 2 mg/kg SWCNT-exposed group, acute lung inflammation and subsequent granuloma accompanied by increased lung weights were observed. Furthermore, the histopathological findings in the lungs of rats exposed to SWCNTs showed inflammatory responses related with the vital reaction to the foreign substance that was instilled intratracheally, and there were no fibrosis, atypical lesion, or tumor-related findings even at the highest dose (2 mg/kg) of SWCNT-exposed groups up to 6 months after instillation. For all groups, histopathological changes due to the instillation exposure of SWCNTs were observed only in the lungs and lung-associated lymph nodes and not in the other tissues examined (i.e. the liver, kidney, spleen, and cerebrum)” (Kobayashi N et al., 2011. Inhalation Toxicology 23, 814-828). As taken from http://www.ncbi.nlm.nih.gov/pubmed/22004357

“Sachar and Saxena (Sachar and Saxena 2011) administered single doses (100 µg/animal) of either SWCNTs or acid functionalized SWCNTs (AF-SWCNTs) to inbred Swiss and C57BL76 female mice (6–12 week old, weighing 20-25 g; number per group not reported) by either intratracheal instillation, intravenous (i.v.) or intra-peritoneal (i.p.) injections, or orally by gavage. The acid functionalized (AF)-SWCNTs were surface oxidized by a mixture of nitric and sulphuric acid under pressure at elevated temperature. The carboxylic acid moieties formed were derivatised by a fluorophor for imaging purposes, and were intensively purified to remove excess fluorescent dye. The particle size distribution and surface charge was not indicated. A transient decrease was observed in the number of erythrocytes and levels of blood haemoglobin (from 3 to 48 hours but not after 72 hours) after i.v. injection and to a lesser extent after i.p. injections of AF-SWCNTs as compared to SWCNTs. Administration of AF-SWCNTs through oral gavage and the i.p. route did not reduce erythrocyte count (haemoglobin was apparently not measured for these routes of as no information is given in the paper).”

As taken from Binderup et al. 2013.

“BACKGROUND: Engineered nanomaterials (ENMs) have potential benefits, but they also present safety concerns for human health. Interlaboratory studies in rodents using standardized protocols are needed to assess ENM toxicity. METHODS: Four laboratories evaluated lung responses in C57BL/6 mice to ENMs delivered by oropharyngeal aspiration (OPA), and three labs evaluated Sprague-Dawley (SD) or Fisher 344 (F344) rats following intratracheal instillation (IT). ENMs tested included three forms of titanium dioxide (TiO2) [anatase/rutile spheres (TiO2-P25), anatase spheres (TiO2-A), and anatase nanobelts (TiO2-NBs)] and three forms of multiwalled carbonnanotubes (MWCNTs) [original (O), purified (P), and carboxylic acid "functionalized" (F)]. One day after treatment, bronchoalveolar lavage fluid was collected to determine differential cell counts, lactate dehydrogenase (LDH), and protein. Lungs were fixed for histopathology. Responses were also examined at 7 days (TiO2 forms) and 21 days (MWCNTs) after treatment. RESULTS:….All MWCNT types caused neutrophilia at 1 day in three of four mouse labs and in all rat labs. Three of four labs observed similar histopathology to O-MWCNTs and TiO2-NBs in mice. CONCLUSIONS: ENMs produced similar patterns of neutrophilia and pathology in rats and mice. Although interlaboratory variability was found in the degree of neutrophilia caused by the three types of TiO2 nanoparticles, similar findings of relative potency for the three types of MWCNTs were found across all laboratories, thus providing greater confidence in these interlaboratory comparisons.” As taken from Bonner JC et al. 2013. Environ. Health Perspect. 121(6), 676-82. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23649427

“With the development and application of carbon nanotubes (CNTs), the potential hazards of CNTs to biological systems and the environment are getting more and more attention. This review evaluated the effects of physicochemical properties of CNTs on toxicity and summarized the advances on the mechanism of CNTs toxicity. We also proposed the possible hazards associated with CNTs and harmful effects resulting from exposure of aquatic animals, bacteria and higher plants to CNTs in vitro and in vivo. The current knowledge and gaps on CNTs were outlined as a potential problem for the environment and human health. The current research gaps on CNTs toxicity were identified and the further studying focus was proposed, too. This essay concluded with a set of recommendations for the advancement of understanding of the role of CNTs and future challenges in environmental and ecotoxicological research.” As taken from Du J et al. 2013. Environ. Toxicol. Pharmacol. 36(2), 451-62. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23770455

“Background: several properties of multi-walled carbon nanotubes (mwcnt) have the potential to affect their bioactivity. this study examined the in vitro and in vivo outcomes of the influence of diameter, length, purification and carboxylation (in vitro testing only) of mwcnt. methods: three original 'as received' mwcnt that varied in size (diameter and length) were purified and functionalized by carboxylation. the resulting mwcnt were characterized and examined for cytotoxicity and inflammasome activation in vitro using thp-1 cells and primary alveolar macrophages from c57bl/6 mice. oropharyngeal aspiration administration was used to deliver original mwcnt and in vivo bioactivity and lung retention was examined at 1 and 7 days. results:…the in vivo studies demonstrated that all three original mwcnt caused similar neutrophil influx at one day, but increasing length or diameter resulted in the lavaged cells to release more inflammatory cytokines (il-6, tnf-alpha, and il-1beta) ex vivo. seven-day histology revealed that, consistent with the in vitro results, increasing width or length of mwcnt caused more severe pathology with the longest mwcnt causing the most severe inflammation. in addition, the same two larger mwcnt were retained more in the lung at 7 days. conclusions: taken together, the results indicated that in vitro and in vivo bioactivity of mwcnt increased with diameter and length. purification had no significant modifying effect from the original mwcnt. functionalization by carboxylation completely eliminated the bioactive potential of the mwcnt regardless of size in in vitro testing.” As taken from hamilton rf jr et al. 2013. part. fibre toxicol. 10(1), 57. pubmed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24225053

“Carbon nanotubes have shown broad potential in biomedical applications, given their unique mechanical, optical, and chemical properties. Functionalized carbon nanotubes not only can deliver drug into specific organs but also can inherently produce heating by near-infrared laser radiation for cancer therapy. However, the toxicological and pharmacological profile of such carbon nanotube system will have to be determined prior to any clinical study undertaken. For providing a guide to develop safe drug carriers, this review discusses the functionalization, toxicity and pharmacokinetics of carbon nanotubes. Lastly, the drug delivery and thermal ablation on carbon nanotubes are proposed.” As taken from Luo E et al. 2013. Curr. Drug Metab. 14(8), 879-90. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24016108

“Carbon nanotubes (CNTs) find their extensive application as a promising material in medicine due to unique characteristics. However, such materials have been accompanied with potentially hazardous effects on human health. The toxicity of CNTs may vary depending on their structural characteristics, surface properties and chemical composition. To gain insight into the toxicity of CNTs in vivo and in vitro, we summarize contributing factors for the toxic effects of CNTs in this review. In addition, we elaborate on the toxic effects and mechanisms in target sites at systemic, organic, cellular, and biomacromolecule levels. Various issues are reported to be effected when exposed to CNTs including (1) blood circulation, (2) lymph circulation, (3) lung, (4) heart, (5) kidney, (6) spleen, (7) bone marrow, and (8) blood brain barrier. Though there have been published reports on thetoxic effects of CNTs to date, more studies will still be needed to gain full understanding of their potential toxicity and underlying mechanisms.” As taken from Wang J et al. 2013a. Curr. Drug. Metab. 14(8), 891-9. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24016107

“We evaluated local inflammatory activity of oxidized multiwalled carbon nanotubes in rat experimental models of acute inflammation (paw edema and hyperalgesia) by analyzing their toxicity in non-mesoendothelial tissues. Subcutaneous injection of the nanotubes induced paw edema, that was maximal in the first 2 h after administration at 0.1 mg/kg (43.25 +/- 3.8 AUC) and 1 mg/kg (30.1 +/- 1.8 AUC) compared to saline (18.32 +/- 02.05 AUC). The histopathological analysis showed acute inflammation characterized by vasodilatation, edema formation, neutrophil infiltrate and tissue damage. The nanotubes also elicited hyperalgesic response, seen by the increase of animal paw withdrawal that was maximal in the first 3 hours. The data obtained at the 3rd h was: 75 +/- 9.3% (0.01 mg/kg), 58 +/- 8.3% (0.1 mg/kg) and 53 +/- 6.69% (1 mg/kg) in relation with saline (28 +/- 3.5%). In conclusion, the oxidized multiwalled carbon nanotubes elicit inflammatory and hyperalgesic effects associated to severe tissue damage in rats.” As taken from Pinto NV et al. 2013. J. Nanosci. Nanotechnol. 13(8), 5276-82. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23882754

“We summarized the findings of in vivo toxicity studies of single-walled carbon nanotubes (SWCNTs) in laboratory animals. The large majority addressed the pulmonary toxicity of SWCNTs in rodents. Inhalation, pharyngeal aspiration, and intratracheal instillation studies revealed that SWCNTs caused acute and chronic inflammation, granuloma formation, collagen deposition, fibrosis, …. in the lungs. Pulmonary toxicity of well-dispersed SWCNTs was more potent than less dispersed ones. ……. Oxidative stress was caused by the administration of SWCNTs. ….. Overall, the available data provides initial information on SWCNT toxicity. To further clarify their toxicity and risk assessment, studies should be conducted using well-characterized SWCNTs, standard protocols, and the relevant route and doses of human exposure.” As taken from Ema M et al. 2016. Regul. Toxicol. Pharmacol. 74, 42-63. PubMed, 2016 available at http://www.ncbi.nlm.nih.gov/pubmed/26619783

“Human Health Assessment

Based on the available hazard information on the substance [multi-walled carbon nanotube], the substance has a low potential for acute toxicity by the oral, dermal and inhalation routes of exposure (oral and dermal LD50 > 2000 mg/kg bw; inhalation LC50 > 1.3 mg/m3). …....”

As taken from Environment Canada, 2015

5.2. Repeated dose toxicity

"While environmental particles are associated with mortality and morbidity related to pulmonary and cardiovascular (CV) disease, the mechanisms involved in CV health effects are not known. Changes in systemic clotting factors have been associated with pulmonary inflammation. We hypothesized that inhaled ultrafine particles result in an inflammatory response which may stimulate systemic clotting factor release. Adult male Wistar rats were exposed to either fine or ultrafine carbon black (CB) for 7 h. The attained total suspended particle concentrations were 1.66 mg/m(3) for ultrafine CB and 1.40 mg/m(3) for fine CB. Particle concentration of ultrafine particles was more than 10 times greater than that of fine particles and the count median aerodynamic diameter averaged 114 nm for the ultrafine and 268 nm for the fine carbon particles. Data were collected immediately, 16 and 48 h following exposure. Only ultrafine CB caused an increase in total bronchoalveolar lavage (BAL) leukocytes, whereas both fine (2-fold) and ultrafine (4-fold) carbon particles caused an increase in BAL neutrophils at 16 h postexposure. Exposure to the ultrafine, but not fine, carbon was also associated with significant increases in the total numbers of blood leukocytes. Plasma fibrinogen, factor VII and von Willebrand factor (vWF) were unaffected by particle treatments as was plasma Trolox equivalent antioxidant status (TEAC). Macrophage inflammatory protein-2 mRNA was significantly increased in BAL cells 48 h following exposure to ultrafine CB. The data show that there is a small but consistent significant proinflammatory effect of this exposure to ultrafine particles that is greater than the effect of the same exposure to fine CB." As taken from Gilmour et al., (2004), Toxicol Appl Pharmacol. 2004 Feb 15;195(1):35-44, available at
http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?db=pubmed&cmd=Retrieve&dopt=AbstractPlus&list_uids=14962503&query_hl=26&itool=pubmed_docsum

"Five or ten Crl:CD(SD) rats/sex were dosed with SWCNT [single wall carbon nanotubes] once daily by gavage at a dose of 0 (control), 0.125, 1.25 or 12.5 mg/kg bw/day for 28 days with a 14-day recovery period (0 and 12.5 mg/kg bw/day groups). Six or twelve Crl:CD(SD) rats/sex were dosed with MWCNT [multi wall carbon nanotubes] once daily by gavage at a dose of 0 (control), 0.5, 5.0 or 50 mg/kg bw/day for 28 days with a 14-day recovery period (0 and 50 mg/kg bw/day groups). Based on no toxicological effects, the no observed adverse effect levels (NOAELs) of repeated dose toxicity of SWCNT and MWCNT were considered to be 12.5 mg/kg bw/day and 50 mg/kg bw/day (the highest dose tested), respectively. It was suggested that SWCNT and MWCNT dosed by gavage reached the gastro-intestinal tract as agglomerates and were mostly excreted via feces" (Matsumoto et al., 2012. Journal of Toxicological Sciences 37, 463-474). As taken from http://www.ncbi.nlm.nih.gov/pubmed/22687986

"….In this Organization for Economic Cooperation and Development (OECD) 413 guideline inhalation study with VGCF-H carbon nanofibers (CNFs), rats were exposed to 0, 0.54, 2.5 or 25 mg/m(3) CNF for 13 weeks. The standard toxicology experimental design was supplemented with bronchoalveolar lavage (BAL) and respiratory cell proliferation (CP) endpoints. BAL fluid (BALF) recovery of inflammatory cells and mediators (i.e., BALF- lactate dehydrogenase [LDH], microprotein [MTP], and alkaline phosphatase [ALKP] levels) were increased only at 25 mg/m(3), 1 day after exposure. No differences versus control values in were measured at 0.54 or 2.5 mg/m(3) exposure concentrations for any BAL fluid endpoints. Approximately 90% (2.5 and 25 mg/m(3)) of the BAL-recovered macrophages contained CNF. CP indices at 25 mg/m(3) were increased in the airways, lung parenchyma, and subpleural regions, but no increases in CP versus controls were measured at 0.54 or 2.5 mg/m(3). Based upon histopathology criteria, the NOAEL was set at 0.54 mg/m(3), because at 2.5 mg/m(3), "minimal cellular inflammation" of the airways/lung parenchyma was noted by the study pathologist; while the 25 mg/m(3) exposure concentration produced slight inflammation and occasional interstitial thickening. In contrast, none of the more sensitive pulmonary biomarkers such as BAL fluid inflammation/cytotoxicity biomarkers or CP turnover results at 2.5 mg/m(3) were different from air-exposed controls. Given the absence of convergence of the histopathological observations versus more quantitative measures at 2.5 mg/m(3), it is

recommended that more comprehensive guidance measures be implemented for setting adverse effect levels in (nano)particulate, subchronic inhalation studies including a WOE approach for establishing no adverse effect levels; and a suggestion that some findings should be viewed as normal physiological adaptations (e.g., normal macrophage phagocytic responses-minimal inflammation) to long-term particulate inhalation exposures." As taken from Warheit DB et al. 2013. Toxicol. Pathol. 41(2), 387-94. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23242579

"With the development and application of carbon nanotubes (CNTs), the potential hazards of CNTs to biological systems and the environment are getting more and more attention. This review evaluated the effects of physicochemical properties of CNTs on toxicity and summarized the advances on the mechanism of CNTs toxicity. We also proposed the possible hazards associated with CNTs and harmful effects resulting from exposure of aquatic animals, bacteria and higher plants to CNTs in vitro and in vivo. The current knowledge and gaps on CNTs were outlined as a potential problem for the environment and human health. The current research gaps on CNTs toxicity were identified and the further studying focus was proposed, too. This essay concluded with a set of recommendations for the advancement of understanding of the role of CNTs and future challenges in environmental and ecotoxicological research." As taken from Du J et al. 2013. Environ. Toxicol. Pharmacol. 36(2), 451-62. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23770455

"Carbon nanotubes have shown broad potential in biomedical applications, given their unique mechanical, optical, and chemical properties. Functionalized carbon nanotubes not only can deliver drug into specific organs but also can inherently produce heating by near-infrared laser radiation for cancer therapy. However, the toxicological and pharmacological profile of such carbon nanotube system will have to be determined prior to any clinical study undertaken. For providing a guide to develop safe drug carriers, this review discusses the functionalization, toxicity and pharmacokinetics of carbon nanotubes. Lastly, the drug delivery and thermal ablation on carbon nanotubes are proposed." As taken from Luo E et al. 2013. Curr. Drug Metab. 14(8), 879-90. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24016108

"Carbon nanotubes (CNTs) find their extensive application as a promising material in medicine due to unique characteristics. However, such materials have been accompanied with potentially hazardous effects on human health. The toxicity of CNTs may vary depending on their structural characteristics, surface properties and chemical composition. To gain insight into the toxicity of CNTs in vivo and in vitro, we summarize contributing factors for the toxic effects of CNTs in this review. In addition, we elaborate on the toxic effects and mechanisms in target sites at systemic, organic, cellular, and biomacromolecule levels. Various issues are reported to be effected when exposed to CNTs including (1) blood circulation, (2) lymph circulation, (3) lung, (4) heart, (5) kidney, (6) spleen, (7) bone marrow, and (8) blood brain barrier. Though there have been published reports on thetoxic effects of CNTs to date, more studies will still be needed to gain full understanding of their potential toxicity and underlying mechanisms." As taken from Wang J et al. 2013a. Curr. Drug. Metab. 14(8), 891-9. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24016107

"To date, NIOSH is not aware of any reports of adverse health effects in workers using or producing CNT (carbon nanotubes) or CNF (carbon nanofibres) . However, there are studies of animals exposed to CNT and CNF that are informative in predicting potential human health effects consistent with ways in which scientists traditionally have used such data in recommending risk management strategies. NIOSH systematically reviewed 54 laboratory animal studies, many of which indicated that CNT/CNF could cause adverse pulmonary effects including inflammation (44/54), granulomas (27/54), and pulmonary fibrosis (25/54). …

Critical effect levels for the noncancerous lung effects estimated from the animal dose-response data (e.g., BMD, benchmark dose and BMDL, the 95% lower confidence limit estimates of the BMD) have been extrapolated to humans by accounting for the factors influencing the lung dose in each animal species. The no observed adverse effect level (NOAEL) and lowest observed

adverse effect level (LOAEL) estimates reported in the subchronic inhalation studies were also evaluated as the critical effect levels. Working-lifetime exposure concentrations were calculated based on estimates of either the deposited or retained alveolar lung dose of CNT assuming an 8-hour time-weighted average (TWA) exposure during a 40-hour workweek, 50 weeks per year, for 45 years. Based on BMD modeling of the subchronic animal inhalation studies with MWCNT [Ma-Hock et al. 2009; Pauluhn 2010a], a working lifetime exposure of 0.2–2 µg/m3 (8-hour TWA concentration) was estimated to be associated with a 10% excess risk of early-stage adverse lung effects (95% lower confidence limit estimates) (Tables 5–1 and A–5). Risk estimates derived from short-term animal studies (Tables A–3 and A–4) were consistent with these estimates.

In addition to the BMD-based risk estimates, NOAEL or LOAEL values were used as the critical effect level in animals. As with the BMD(L) estimates, the human-equivalent working lifetime concentrations were estimated, although using dosimetric adjustment and uncertainty factors (Section A.6.3). The estimated human-equivalent working lifetime concentrations based on this approach were approximately 4–18 µg/m3 (8-hr TWA), depending on the subchronic study and the interspecies dose retention and normalization factors used. Dividing these estimates by data-suitable uncertainty factors (e.g., UFs of 20–60), and assuming a threshold model, the estimated zero risk levels were <1 µg/m3 as working lifetime 8-hr TWA concentrations. A recent subchronic inhalation (13-wk exposure plus 3 months follow-up) study of CNF in rats [DeLorme et al. 2012] showed qualitatively similar lung response as in a shorter-term (28-day) study of CNF administered by pharyngeal aspiration in mice [Murray et al. 2012] (Sections 3.5 and A.7). Using the NOAEL-based approach, the human-equivalent working lifetime concentration estimates were 1–4 µg/m3 (8-hr TWA), depending on the data and assumptions used to estimate the human-equivalent dose."

As taken from NIOSH, 2013.

"We summarized the findings of in vivo toxicity studies of single-walled carbon nanotubes (SWCNTs) in laboratory animals. The large majority addressed the pulmonary toxicity of SWCNTs in rodents. Inhalation, pharyngeal aspiration, and intratracheal instillation studies revealed that SWCNTs caused acute and chronic inflammation, granuloma formation, collagen deposition, fibrosis, …. in the lungs. Pulmonary toxicity of well-dispersed SWCNTs was more potent than less dispersed ones. ….. Oxidative stress was caused by the administration of SWCNTs. ……. Overall, the available data provides initial information on SWCNT toxicity. To further clarify their toxicity and risk assessment, studies should be conducted using well-characterized SWCNTs, standard protocols, and the relevant route and doses of human exposure." As taken from Ema M et al. 2016. Regul. Toxicol. Pharmacol. 74, 42-63. PubMed, 2016 available at http://www.ncbi.nlm.nih.gov/pubmed/26619783

5.3. Reproduction toxicity

This study was undertaken to test novel genetic polymorphisms involved in 1-carbon metabolism for a potential association with increased risk of developing pregnancy complications associated with uteroplacental insufficiency. STUDY DESIGN: This was a prospective cohort study consisting of 50 women at low risk and 93 women at high risk for having a pregnancy complication develop. Maternal and fetal DNA samples were genotyped for methionine synthase (MTR) A2756G, methionine synthase reductase (MTRR) A66G and methylenetetrahydrofolate dehydrogenase (MTHFD1) G1958A. A chi squared or chi(2) analysis was used to compare genotypes and pregnancy outcome, 1-way analysis of variance and linear regression were used to compare genotype with continuous variables. RESULTS: The fetal MTR 2756 G allele was associated with uteroplacental insufficiency (P = .022, likelihood ratio = 10.4) and maternal homocysteine (P = .017). The maternal MTR A2756G polymorphism was associated with uteroplacental insufficiency (P = .049, likelihood ratio = 6.0), but only in mothers not supplementing with high-dose B-vitamins. The maternal MTHFD1 AA genotype was associated with intrauterine growth restriction (P = .047,

likelihood ratio = 5.8). CONCLUSION: This study suggests the maternal and fetal MTR 2756 G allele is an important risk factor in the development of uteroplacental insufficiency. In addition, the maternal MTHFD1 1958 AA genotype may be associated with intrauterine growth restriction. As taken from Furness DL et al. Am J Obstet Gynecol. 2008, Sep; 199(3):276.e1-8. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=retrieve&db=pubmed&list_uids=18771981&dopt=AbstractPlus

Pregnant female C57BL/10JHir mice were irradiated whole-body at 9 days of gestation with a single acute dose of carbon-ion radiation. The average linear energy transfer (LET) of the carbon ions was 50 keV/microm within a spread-out Bragg peak (SOBP). The effects were studied by scoring changes in the postnatal development of the mice as well as in the pigmentation of the cutaneous coats and tail tips of their offspring 22 days after birth. The percentage of live births was reduced in mice exposed to carbon ions at doses greater than 0.5 Gy. The survival to day 22 was also reduced in mice exposed to carbon ions at doses greater than 0.75 Gy. Moreover, the body weight at day 22 was reduced in mice exposed to carbon ions at doses greater than 0.1 Gy. A comparison of the survival to day 22 after exposure to carbon ions with our previous results for 60Co gamma rays indicated that carbon ions were twice as effective as gamma rays. White spots were found in the mid-ventrum as well as in the tail tips of offspring exposed to carbon ions in utero. The frequency and the size of the white spots in the mid-ventrum and in the tail tips increased as the dose increased. Carbon ions appear to be slightly more effective than the gamma rays used in our previous study. In the ventral white spots, no melanocytes were observed in the epidermis, dermis and hair follicles. These results indicate that prenatal exposure to carbon ions has a greater effect on the postnatal development and survival of mice than does exposure to gamma rays, and that the relative biological effectiveness is greater than that for effects on melanocyte development. As taken from Hirobe T; Eguchi-Kasai K; Murakami M. Radiat Res. 2004, Nov; 162(5):580-4 available at http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=retrieve&db=pubmed&list_uids=15624313&dopt=AbstractPlus

In the present study, the effects of 290 Me V/u carbon-ion beams and X-rays on the development of rat brain were compared. Pregnant rats were exposed to carbon-ion beams of the 6-cm spread-out Bragg Peak (SOBP) at a single dose of 1.5 Gy on day 19.0 (midnight) of gestation. Three other groups of pregnant rats were exposed to X-rays on day 19.0 at single doses of 1.5, 2.0 and 2.5 Gy. Sham-exposed pregnant rats were used as controls. The offspring were deeply anesthetized at postnatal day 1, 7, 11, and 6 weeks of age, and perfused via the heart with 4% paraformaldehyde fixative. In rats with 6 weeks of age size of brain mantle exposed to 1.5 Gy carbon-ion beams was significantly smaller than that exposed to 1.5 Gy X-rays and larger than that exposed to 2.5 Gy. Local fiber distribution in the cerebral cortices of rats at 1, 7 and 11 postnatal days was examined using fluorescent dye, DiI. In rats exposed to carbon-ion beams, abnormal DiI-labeled fiber distribution was observed at three different postnatal stages. Similar but less irregular distribution of DiI-labeled fibers was observed in rats exposed to any dose of X-ray. Furthermore, in the control at postnatal day 11, DiI-labeled fibers in the cerebral cortex showed layer-dependent distribution. However, in rats exposed to carbon-ion beams or any dose of X-ray, the layer-dependent distribution of DiI-labeled fibers was not observed. Abnormal small clusters of DiI-labeled fibers were only observed in the cerebral cortex of rats exposed to 1.5 Gy carbon-ion beams. These findings suggest that the biological effects of 1.5 Gy carbon-ion beams on development of brain mantle are nearly equivalent to those of 2.0 Gy X-rays. However, subtle but more important abnormalities such as local fiber distribution in the cerebral cortex seemed to be more complicated. Funahashi A; Inouye M; Nakamura E; Takahashi S; Kubota Y. Teratology 1999 May;59(5):34A.

“OBJECTIVE: To investigate the effects of fetal nanoparticle exposure on reproductive function in male mice offspring.

ANIMAL(S): Forty pregnant ICR mice and 120 male offspring.

INTERVENTION(S): Two hundred microg of 14-nm carbon nanoparticles was administered intratracheally on days 7 and 14 of gestation, and reproductive function of male offspring was determined at ages 5, 10, and 15 weeks after birth.

MAIN OUTCOME MEASURE(S): Maternal and fetal growth, histologic changes in the testes, and daily sperm production (DSP).

RESULT(S): Histologic examination showed partial vacuolation of seminiferous tubules. and cellular adhesion of seminiferous epithelia was reduced at all three ages. In addition, DSP was significantly decreased in fetal carbon nanoparticle-exposed mice. The DSP in the fetal carbon nanoparticle-exposed mice decreased by 47% at the age of 5 weeks, by 34% at the age of 10 weeks, and by 32% at the age of 15 weeks. On the other hand, nanoparticle administration had no marked effect on body weight, testicle weight, epididymis weight, or serum testosterone concentration.

CONCLUSION(S): These findings suggest that fetal nanoparticle exposure affects the reproductive function of male offspring. In the future, it would be necessary to clarify the onset mechanisms of nanoparticle-induced male reproductive disorders" (Yoshida et al., 2010. Fertility and Sterility 93, 1695-1699). As taken from http://www.ncbi.nlm.nih.gov/pubmed/19446808

"A possible teratogenicity of multi-wall carbon nanotube (MWCNT) was assessed using ICR mice. MWCNTs were suspended in 2% carboxymethyl cellulose and given intraperitoneally or intra-tracheally to pregnant ICR mice on day 9 of the gestation. All fetuses were removed from the uterus on day 18 of the gestation, and were examined for external and skeletal anomalies. In the intraperitoneal study, various types of malformation were observed in all MWCNT-treated groups (2, 3, 4 and 5 mg/kg body weight, intraperitoneal). In contrast, such malformations were observed in groups given 4 or 5 mg/kg body weight, but not in that treated with 3 mg/kg in the intratracheal study. In either study, the number of litters having fetuses with external malformation and that of litters having fetuses with skeletal malformations were both increased in proportion to the doses of MWCNT. The present results are the first to report that MWCNT possesses the teratogenicity at least under the present experimental conditions. Mechanism(s) to result such malformations is yet unclear and further experiment is necessary" (Fujitani et al., 2012. Journal of Toxicological Sciences 37, 81-89). As taken from http://www.ncbi.nlm.nih.gov/pubmed/22293413

Type of Test	Route of Exposure	Species Observed	Dose Data	Sex/Duration	Toxic Effects	Reference
TDLo - Lowest published toxic dose	Subcutaneous	Rodent - rat	167 mg/kg	female 8 day(s) after conception	Reproductive - Fertility - post-implantation mortality (e.g. dead and/or resorbed implants per total number of implants)	TJADAB Teratology, The International Journal of Abnormal Development. (Alan R. Liss, Inc., 41 E. 11th St., New York, NY 10003) V.1- 1968- Volume(issue)/page/year: 4,327,1971

As taken from RTECS, 2018.

"Lim and co-workers (Lim et al. 2011a and Lim et al. 2011b) administered 0 (control), 40, 200 or 1000 mg multi-wall CNTs (MWCNTs)/kg bw/day orally by gavage to pregnant Sprague-Dawley rats (N=12/group) from gestation days 6 through 19. The MWCNTs used were commercially available with a nominal diameter of 10-15 nm and length around 20 µm. The purity was stated to be 95% carbon and approximately 5% iron. The authors did not embark on any physico-chemical characterization and did not determine if aggregation of the CNTs occurred following the only 3 minutes ultrasound treatment in 0.1% carboxymethylcellulose (stabilizer) solution in water.

According to the authors the no-observed–adverse-effect-level (NOAEL) was 200 mg MWCNTs/kg bw/day for maternal toxicity and 200 mg MWCNs/kg bw/day for developmental toxicity."

As taken from Binderup et al. 2013.

“Carbon nanoparticles, with their high biocompatibility and low toxicity, have recently been considered for biomedical applications, including antiangiogenic therapy. Critical to normal development and tumor formation, angiogenesis is the process of forming capillary blood vessels from preexisting vessels. In the present study, we evaluated the effects of diamond and graphite nanoparticles on the development of chicken embryos, as well as vascularization of the chorioallantoic membrane and heart at the morphological and molecular level. Nanoparticles did not affect either body/heart weight or serum indices of the embryos' health. However, vascularization of the heart and the density of branched vessels were significantly reduced after treatment with diamond nanoparticles and, to a lesser extent, graphite nanoparticles. Application of nanoparticles significantly downregulated gene and protein expression of the proangiogenic basic fibroblast growth factor, indicating that both diamond and graphite nanoparticles inhibit angiogenesis.” As taken from Wierzbicki M et al. 2013. Int. J. Nanomedicine 8, 3427-35. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24039425

“In order to investigate the effect of SWCNTs in the embryo, we examined the outcome of SWCNTs in avian embryo at an early stage of development. We found that SWCNTs-treatment inhibits the angiogenesis of the chorioallantoic membrane (CAM) and in the chicken embryo. Moreover, we showed that SWCNTs can harm the normal development of the embryo since all SWCNTs-exposed embryos are smaller in comparison with their matched controls. We also found that the majority of SWCNTs-exposed embryos die before 12days of incubation. Macroscopic examination did not reveal any anomalies in these embryos. However, RT-PCR analysis of eleven genes, which are important regulators of cell proliferation, apoptosis, survival and angiogenesis, shows that these genes are deregulated in brain and liver tissues from SWCNTs-treated embryos in comparison with their matched controls. This study suggests that SWCNTs could have a very toxic effect on the normal development of the embryo.”As taken from Roman D et al. 2013. Nanomedicine 9(7), 945-50. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23563045

5.4. Mutagenicity

“Mutagenicity of activated carbon adsorbate from drinking water collected in Niigata City was assayed by the Ames assay. Adsorbate was extracted from activated carbon with benzene, and then with ethanol. Although the benzene extract was not mutagenic, the ethanol one showed the mutagenic activity for Salmonella typhimurium strains TA98 and TA100 with and without S9 mix. The ethanol extract was much more mutagenic on TA100 than TA98 both with and without S9 mix. The mutagenic activity per liter of water was found to be the strongest in winter and the weakest in summer.” As taken from Shibuya et al., (1993), Tohoku J Exp Med. 1993 Sep;171(1):89-95, available at http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?db=pubmed&cmd=Retrieve&dopt=AbstractPlus&list_uids=8122259&query_hl=13&itool=pubmed_docsum

“There is evidence that carbon nanotubes may induce aneuploidy by interaction with the mitotic spindle apparatus” (COM, 2012. COM/12/S1).

“There is growing concern that gastrointestinal exposure to particles is associated with increased risk of toxicity to internal organs and carcinogenicity. The mechanism of action is related to particle-induced oxidative stress and oxidation of DNA. Observations from animal models indicate that gastrointestinal exposure to single-walled carbon nanotubes (SWCNT), fullerenes C60, carbon black, titanium dioxide and diesel exhaust particles generates oxidized DNA base lesions in organs such as the bone marrow, liver and lung. Oral exposure to nanosized carbon black has also been associated with increased level of lipid peroxidation derived exocyclic DNA adducts in the liver, suggesting multiple pathways of oxidative stress for particle-generated damage to DNA. At equal

dose, diesel exhaust particles (SRM2975) generated larger levels of 8-oxo-7,8-dihydro-2'-deoxyguanosine in rat liver than carbon black (Printex 90) did, whereas exposure to fullerenes C60 and SWCNT was the least potent. This ranking of samples was also observed for oxidatively damaged DNA in cultured cells. The extent of translocation from the gut is largely unresolved. However, there is evidence indicating that gastrointestinal exposure to particulate matter is associated with oxidative damage to DNA and this might be associated with increased risk of cancer" (Moller P et al. (2012). Current Molecular Medicine 12, 732-745. As taken from http://www.ncbi.nlm.nih.gov/pubmed/22292440

Nanomaterial	Nanoparticle Characteristics (Primary size)	Test System	Results
SWCNT	0.4-1.2 nm in diameter, 1-3μm in length.	Ames Salmonella assay using strains YG1024 and YG1029 without S9 mix.	-ve
MWCNT	Size unspecified.	Adenine phosphoribosyl-transferase (Aprt) mutation assay using Aprt-heterozygous mouse (C3H/Hej) embryonic stem cells.	+ve
SWCNT and MWCNTs	SWCNT (1.2-1.5 nm x 2.5μm) MWCNT (10-30 nm x 0.5-50μm).	Chromosome aberration assay in RAW264.7 cells (exposed for 24, 48, 72 h) to 1, 3 or 10 μg/ml.	+ve. Chromsome number in metaphases significantly different for both SWCNT and MWCNT. In addition chromosome breaks and irregularly condensed chromosomes were observed. Cytotoxicity was reported at concentrations of ≥50 μg/ml. ROS formation documented at 50 μg/ml..
SWCNT	0.4-1.2 nm in diameter, 1-3 μm in length composed of 99.7% carbon and 0.23% iron by weight.	Comet assay. Chinese hamster lung fibroblast V79 cells seeded into a medium containing 10% FCS.	After 3 h incubation, the highest concentration of SWCNT (96 μg/cm2) showed a 4.2-fold increase of Olive Tail Movement above the controls.
SWCNT	0.7-1.2 nm in diameter, 0.5-100 μm in length 96.7% carbon, 1.5% Co.	Alkaline murine assay in murine macrophage cell line RAW 264.7.	Comet +ve. Oxidized purines increased significantly, whereas pyrimidines showed a significant increase ($P<0.001$) only at the highest concentration (100 μg/ml)
SWCNT	1.1 nm in diameter, 50 μm in length composed of 96% carbon.	Alkaline comet assay in human peripheral blood lymphocytes cultured in a medium containing 15% FCS.	-ve.
SWCNT	Average diameter 1.4	Comet assay.Normal and	Exposure of NM cells to 25 or

	nm, 2-5 μm in length 70-90% purity.	malignant human mesothelial cells cultured in a medium containing 5% FCS exposed to 25 or 50 μg/cm2 SWCNTs for 24 h.	50 μg/cm2 SWCNTs resulted in a 5.2- and 6.6-fold increase in DNA tail length migration. Reactive oxygen species (ROS) scavengers only moderately reduced DNA damage.
SWCNT	1-4 nm in diameter, 1-3 μm in length composed of >99.7% carbon and 0.23% iron by weight.	Comet assay. Chinese hamster lung fibroblast V79 cells seeded into a medium containing 10% fetal calf serum (FCS).	After 24 h incubation, SWCNT (48 μg/cm2) showed a 3-fold increase of Olive Tail Movement above the controls.
SWCNT	2-5 μm in length composed of 72% carbon.	Comet assay. FE1 Muta™Mouse lung epithelial cells, cultured in a medium containing 2% FCS with and without FPG [a lesion-specific repair enzyme].	Comet -ve. Significantly increased the level of FPG sensitive sites/oxidized purines by 56%, respectively. No effect on mutant frequency in cII gene.
SWCNT and MWCNTs	SWCNT (1.2-1.5 nm x 2.5μm) MWCNT (10-30 nm x 0.5-50μm).	Comet assay using mouse macrophage RAW264.7 (in DMEM supplemented with 10% fetal bovine serum). Exposure for 24h. Intracellular ROS and uptake determined.	Comet +ve with SWCNT and MWCNT with concomitant ROS production
SWCNT and MWCNTs	SWCNT (<2nm x 5-15μm) (S4) MWCNT 20-60 nm x 5-15μm (M1) MWCNT 60-100 nmx 1-2 μm (M2) MWCNT <10 nm x 1-2 μm (M4).	Comet assay using A549 cells in DMEM supplemented with 10% FBS (3h exposure at 50 μg/ml).	Comet +ve for M1 and M2 but not M3 S4 (in-vivo studies showed M1 and M2 induced inflammation M3 and S4 did not). No effects on cell viability in this study. Authors concluded DNA damage was related to thickness of NT (characteristics of NTs in culture medium not reported).
MWCNT	MWCNT 1.5 nm x, 12 μm (purified and surface functionalised by carboxylation).	Comet assay in normal human dermal fibrblasts (48h exposure). DNA laddering and cytotoxicity determined.	Comet +ve at all doses used. Dose-dependent increase in cytotoxicity, and apoptosis reported. Increase DNA damage in laddering assay reported at highest dose level used.
MWCNT	MWCNT (average 81±5nm x 8.19±1.7 μm. (ultrasonication in RPMI 1640, 0.1% FBS. MWCNTs predominantly long loosely associated strands with small amounts of agglomeration.	Comet assay (24h) in normal meosthelial and malignat human mesothelial cells. ROS and cell viability measured.	Dose-dependent increase in DNA damage. Dose-related reduction in cell viability and increase in apoptosis reported. Small increase in ROS found. Activation of γ-H2AX (indicating double strand breasks) and Poly (ADP-ribose) polymerase (PARP) (indicating strand

			breaks) reported.
MWCNT	110-170 nm in diameter, 5-9 μm in length >98% carbon.	Alkaline comet assay in murine macrophage cell line RAW 264.7.	Comet positive. Increase in DNA migration due to the oxidative damage to purines was observed at a concentration of 1 and 10 μg/ml, whereas pyrimidines showed a significant increase only at the highest mass concentration tested (100 μg/ml).
SWCNT	0.4-1.2 nm in diameter, 1-3 μm in length composed of 99.7% carbon and 0.23% iron by weight.	Micronucleus assay in Chinese hamster lung fibroblast V79 cells incubated in a medium without fetal calf serum (FCS).	After 24 h incubation, the highest concentration of SWCNT (96 μg/cm^2) showed no significant increase in DNA damage.
SWCNT	0.7-1.2 nm in diameter, 0.5- 100 μm in length 96.7% carbon, 1.5% Co.	Micronucleus assay in murine macrophage cell line RAW 264.7 cultured in a medium containing 10% FCS with post-treatment with cytochalasin-B 20 h after the addition of MWCNT to culture.	Increase in number of micronuclei at doses above 0.1 μg/ml ($P<0.05$).
SWCNT	1-2 nm in diameter, 400-800 nm in length 98% purity and surface area of 585 m2/g.	Micronucleus assay in human bronchial epithelial BEAS-2B cells cultured in a medium containing either 2% or 10% FCS for 48 h and either post- or co-treatment, or absence of cytochalasin-B.	Increase in number of micronuclei at doses above 0.1 μg/ml ($P<0.05$).
SWCNT	1-4 nm in diameter, 1-3 μm in length composed of 99.7% carbon and 0.23% iron by weight.	Micronucleus assay in Chinese hamster lung fibroblast V79 cells incubated in a medium without both FCS and cytochalasin-B treatment.	After 24 h incubation, SWCNT (12 μg/cm2) showed significant (1.9-fold) micronucleus induction.
SWCNT	Dimensions not stated 70% purity functionalised with amides.	Micronucleus assay in human lymphocytes cultured in a medium containing 10% FCS treated with 24 h delayed co-treatment with cytochalasin-B. Enumeration of gamma H2AX foci as a measure of double strand breaks of the DNA in normal human dermal fibroblasts.	Increase in micronucleus induction in both cell types. In the fibroblasts there was a 2.7-fold increase in gamma H2AX foci above the control.
SWCNT and MWCNTs	SWCNT (1.2-1.5 nm x 2.5μm) MWCNT (10-30 nm x 0.5-50μm) suspended in	Cytokinesis-block micronucleus (CBMN) assay using mouse macrophage RAW264.7 cells. (48h	CBMN +ve (dose-related) for both SWCNT and MWCNT. Cellular ROS reported.

	serum free culture medium DMEM.	exposure).	
MWCNT	11.3 nm in diameter, 0.7 μm in length 98% carbon with traces of cobalt and iron catalysts.	Micronucleus assay in rat liver epithelial (RLE) cells suspended in a medium containing 5% FCS and MCF-7 breast cancer cells in medium containing 10% FCS were exposed separately. Post-treatment with cytochalasin-B.	There was a significant increase in micronuclei, up to 2-fold at the cytotoxic dose of 50 μg/ml, in RLE epithelial cells, and centromere-positive and negative micronuclei were produced in the MCF-7 cells.
MWCNT	20-40 nm in diameter, 1-5 μm in length 99% purity.	Human lymphocytes cultured in a medium containing 10% FCS treated with 24 h delayed co-treatment with cytochalasin-B. Enumeration of gamma H2AX foci as a measure of double strand breaks of the DNA in normal human dermal fibroblasts.	Induced lymphocyte micronuclei and anaphase bridges among nuclei in binucleated cells. Acted as a clastogen and aneugen simultaneously.
MWCNT	110-170 nm in diameter, 5-9 μm in length >98% carbon.	Murine macrophage cell line RAW 264.7 cultured in a medium containing 10% FCS with post-treatment with cytochalasin-B 20 h after the addition of MWCNT to culture.	Increase in number of micronuclei at doses above 1 μg/ml ($P<0.05$).
SWCNT	Diameter 1-4 nm, length 0.5-1 μm.	Primary human respiratory epithelial cells (SEAC) examined for chromosome gain/loss. Mitotic disruption investigated in immortalised human bronchial epithelial cells (BEAS 2B) (medium contained 10% serum). Doses of 0.024, 0.24, 2.4, 24 $\mu g/cm^2$ with an exposure period of 24h.	Dose-dependent increase in aneuploidy reported at all dose levels (and using vanadium pentoxide as a positive control) SWCNT interacted and sirupted the mitotic spindle and was also associated with DNA and centrosomes.
SWCNT	0.9-1.7 nm x ≤1μm. Analyses for size distribution in dosing solution not achieved due to complex morphology and bundling of SWCNTs.	Intratracheal dose of 54 μg given to apolipoprotein E knockout mice C57BL(ApoE-/-) suspended by sonication in 0.9% NaCl MilliQ water with 10% Bronchiolar lavage fluid (BAL). Animals sacrificed 3 h post dose. BAlfluid obtained for Comet assay.	+ve (% DNA in tail), also increased tail length ($p<0.001$) Data not presented Evidence for inflammation (increase in neurtophils and protein in BAL).

As taken from: Committee on Mutagenicity (COM) of Chemicals in Food, Consumer Products and the Environment (2012). Statement on genotoxicity assessment of nanomaterials and experimental considerations. COM/12/S1.

“Cicchetti and co-workers (Cicchetti et al. 2011) exposed human gingival fibroblasts in semiconfluent cultures to SWCNT concentrations between 50 and 150 µg SWCNTs/ml for 24 hours. The SWCNTs used were oxidized by treatment with a mixture of nitric and sulphuric acids. The surface area of was 407 m2/g, and the average external diameter was 1.58 nm ± 0.20 nm and the average length was 0.76 µm ± 0.70 µm. The SWCNTs were reported by the authors to have “a relatively high degree of crystallinity”. The authors reported a genotoxic effect ([DNA damage by the alkaline comet assay (from 75 µg/ml) and increase (at concentrations up to 100 µg/ml) or decrease (125 and 150 µg/ml) in the frequency of micronuclei]), decrease in cell proliferation and survival (125 and 150 µg/ml), increase in reactive oxygen species production (at all concentrations) and Hsp70 induction (at all concentrations).

Szendi and Varga (Szendi and Varga 2008) studied the possible genotoxicity of SWCNTs (<2nm x 4–15 µm, purity: 90%) and MWCNTs (10-30 nm x 1-2 µm; purity: 95% - 98%) dispersed in carbopol-based semiliquid gel. Urine samples obtained 24 hours after treatment by oral gavage of Fischer-344 male rats (N=3/group) with single doses of 0 (vehicle) or 50 mg/kg bw ofSWCNTs or MWCNTs, were 10x concentrated and were tested in bacterial mutation assay (Ames test) in Salmonella typhimurium TA98 and TA100 strains with and without metabolic activation. Oral exposure to the nanotubes did not increase urinary mutagenicity under the conditions of the assay. In addition, no genotoxic effects of SWCNTs or MWCNTs were found in the in vitro micronucleus and sister chromatid exchange assays using human lymphocytes.”

As taken from Binderup et al. 2013.

“The hallmark geometric feature of single-walled carbon nanotubes (SWCNT) and carbon nanofibers (CNF) - high length to width ratio - makes them similar to a hazardous agent - asbestos. …. Here we compared inflammatory, fibrogenic and genotoxic effects of CNF, SWCNT or asbestos in mice one year after pharyngeal aspiration. …….SWCNT induced cytogenetic alterations seen as micronuclei formation and nuclear protrusions in vivo. Importantly, inhalation exposure to SWCNT showed significantly greater inflammatory, fibrotic and genotoxic effects than bolus pharyngeal aspiration. Finally, SWCNT and CNF, but not asbestos exposures, increased the incidence of K-ras oncogene mutations in the lung….Overall, our data suggest that long-term pulmonary toxicity of SWCNT, CNF and asbestos - is defined not only by their chemical composition but also by the specific surface area and type of exposure.” As taken from Shvedova AA et al. 2014. Am. J. Physiol. Lung Cell. Mol. Physiol. 306(2), L170-82. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24213921

“In order to assess the safety of the carbon nanotubes to human health and the environment, we investigated the potential toxicity and ability of multi-walled carbon nanotubes (NT), to induce DNA damage by employing the Allium cepa genotoxicity/mutagenicity test and the Somatic Mutation and Recombination Test (SMART) in the fruitfly, Drosophila melanogaster. The results demonstrated that NT did not significantly induce genotoxic or mutagenic effects in the Allium cepa test. All concentrations evaluated in the SMART assay showed survival rates higher than 90 percent, indicating the absence of chronic toxicity for NT. Furthermore, the various treatments showed no significant increase in the NT mutation and recombination frequencies in mwh/flr(3) genotype compared to respective negative controls, demonstrating the absence of DNA damage caused by NT.” As taken from de Andrade LR et al. 2014. Ecotoxicol. Environ. Saf. 99, 92-7. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24189313

“Peroxidase enzyme digests of oxidized single-wall carbon nanotubes (SWCNT) were shown to damage DNA in potentially genotoxic reactions for the first time using an electro-optical array with and without metabolic activation.” As taken from Pan S et al. 2013. Toxicol. Res. 2(6), 375-378. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24159372

“….this study aims to evaluate the mutagenicity of multi-walled carbon nanotubes (MWCNTs) functionalized in somatic cells of Drosophila melanogaster, using the somatic mutation and recombination test (SMART). This assay detects the loss of heterozygosity of marker genes

expressed phenotypically on the wings of the fly. Larvae of three days were used, resulting from ST cross, with basal levels of the cytochrome P450 and larvae of high metabolic bioactivity capacity (HB cross). They were treated with different concentrations of MWCNTs functionalized. The MH descendants, analyzed in both ST and HB crosses, had no significant effects on the frequency of mutant. Based on the results and on the experimental conditions mentioned in this study, it was concluded that MWCNTs were not mutagenic in D. melanogaster." As taken from Machado NM et al. 2013. Food Chem. Toxicol. 62, 355-60. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23994091

"Multiple-walled carbon nanotubes (MWCNTs) may cause carcinogenesis. We found that long-term exposure to MWCNTs can induce irreversible oncogenic transformation of human bronchial epithelial cells and tumorigenicity in vivo. A genome-wide array-comparative genomic hybridization (aCGH) analysis revealed global chromosomal aberration in MWCNTs-treated clones, predominantly at chromosome 2q31-32, where the potential oncogenes HOXD9 and HOXD13 are located. Functional assays confirmed that this variation can modulate oncogenic signaling and plays a part in MWCNTs-induced tumorigenesis, suggesting that MWCNTs are carcinogens that act by altering genomic stability and oncogenic copy numbers." As taken from Wu P et al. 2013. Nano. Lett. 13(10), 4632-41. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23984819

"The present study explored the ecotoxicology of single-walled carbon nanotubes (SWCNTs) and their likely interaction with dissolved metals, with a focus on the effect of in vivo exposure in marine mussels….For the first time, the authors describe a potentiating toxicological effect, expressed as DNA strand breaks obtained using the comet assay, on divalent metals afforded by negatively charged SWCNT agglomerates in seawater at concentrations as low as 5 $\mu g\ L^{-1}$. This is supported by the observation that SWCNTs alone were only toxic at concentrations ≥100 $\mu g\ L^{-1}$ and that the SWCNT-induced DNA damage was correlated with oxidative stress only in the absence of metals. If these laboratory experiments are confirmed in the natural environment, the present results will have implications for the understanding of the role of carbon nanotubes in environmental metal dynamics, toxicology, and consequently, regulatory requirements." As taken from Al-Shaeri M et al. 2013. Environ. Toxicol. Chem. 32(12), 2701-10. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23982896

"Toxicological characterization of manufactured nanomaterials (NMs) is essential for safety assessment, while keeping pace with innovation from their development and application in consumer products. The specific physicochemical properties of NMs, including size and morphology, might influence their toxicity and have impact on human health. The present work aimed to evaluate the genotoxicity of nanosized titanium dioxide (TiO2), synthetic amorphous silica (SAS) and multiwalled carbon nanotubes (MWCNTs), in human lymphocytes. The morphology and size of those NMs were characterized by transmission electron microscopy, while the hydrodynamic particle size-distributions were determined by dynamic light scattering. Using a standardized procedure to ensure the dispersion of the NMs and the cytokinesis-block micronucleus assay (without metabolic activation), we observed significant increases in the frequencies of micronucleated binucleated cells (MNBCs) for some TiO2 NMs and for two MWCNTs, although no clear dose-response relationships could be disclosed. In contrast, all forms of SAS analyzed in this study were unable to induce micronuclei. The present findings increase the weight of evidence towards a genotoxic effect of some forms of TiO2 and some MWCNTs. Regarding safety assessment, the differential genotoxicity observed for closely related NMs highlights the importance of investigating the toxic potential of each NM individually, instead of assuming a common mechanism and equal genotoxic effects for a set of similar NMs." As taken from Tavares AM et al. 2014. Toxicol. In Vitro 28(1), 60-9. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23811260

"OBJECTIVE: To compare the cytotoxicity and DNA strand breakage induced by multi-walled carbon nanotubes (MWCNTs) with different lengths and different surface modifications in human alveolar type II cells (A549 cells). METHODS: Two different lengths (5-15 μm, 350-700 nm) of

MWCNTs and three different kinds of surface modified MWCNTs (COOH-MWCNTs, NH2-MWCNTs, and Tau-MWCNTs) were used in the experiments. The short MWCNTs were used as pristine MWCNTs to compare with the 3 surface modified MWCNTs. The cytotoxicity was determined by cell counting kit-8 (CCK-8) assay at the concentrations of 2, 8, and 32 mg/L at hours 12, 24, 36, and 48 respectively. Single cell gel electrophoresis (SCGE) assay was performed to evaluate DNA strand breakage in A549 cells after 24 h treatment of 8 mg/L of each tested material. RESULTS: Long multi-walled carbon nanotubes (Long-MWCNTs) and short multi-walled carbon nanotubes (Short-MWCNTs) showed a dose-dependent cytotoxicity within the exposure time 12-48 h. Especially, Long-MWCNTs showed greater cytotoxicity than Short-MWCNTs from 24 to 48 h at the same concentration. The relative cell viability of the 3 surface modified MWCNTs was higher than that of the pristine MWCNTs at h 12 at the concentration of 32 mg/L [COOH-MWCNTs (86.55±1.80)%, NH2-MWCNTs (84.67±1.32)%, Tau-MWCNTs (80.15±3.53)% and Pristine-MWCNTs (71.44±5.58)%], at h 24 at the concentration of 8 mg/L [COOH-MWCNTs (96.74±1.00)%, NH2-MWCNTs (96.74±3.35)%, Tau-MWCNTs (106.39±3.83)% and Pristine-MWCNTs (91.02±2.53)%], at h 24 at the concentration of 32 mg/L [COOH-MWCNTs (80.88±2.67)%, NH2-MWCNTs (82.90±3.25)%, Tau-MWCNTs (82.55±3.32)% and Pristine-MWCNTs (76.08±4.27)%] and at h 36 at the concentration of 8 mg/L [COOH-MWCNTs (96.87±1.05)%, NH2-MWCNTs (96.66±4.76)%, Tau-MWCNTs (100.23± 2.84)% and Pristine-MWCNTs (89.61±3.78)%], and the differences were statistically significant ($P<0.05$). Compared with the Pristine-MWCNTs, the relative cell viability of the 3 surface modified MWCNTs didn't demonstrate a statistically significant difference ($P>0.05$) at other observation time and exposure concentrations. The DNA strand breakage of the 3 surface modified MWCNTs: the Olive tail moment of COOH-MWCNTs was 1.56±0.22, the Olive tail moment of NH2-MWCNTs 2.25±1.62 and the Olive tail moment of Tau-MWCNTs 2.23±0.94; the tail DNA% of COOH-MWCNTs was (3.96± 0.60)%, the tail DNA% of NH2-MWCNTs (6.16±4.68)% and the tail DNA% of Tau-MWCNTs (6.05±2.31)%, which were lower than that of the pristine MWCNTs ($P<0.05$), whose Olive tail moment was 3.00±0.64 and tail DNA% (8.23±2.27)%. Moreover, the COOH-MWCNTs induced the lowest DNA damage among the three modified MWCNTs. CONCLUSION: Long-MWCNTs compared with Short-MWCNTs demonstrated a greater cytotoxicity and lower DNA strand breakage damage. The surface modifications of MWCNTs can reduce the cytotoxicity and DNA strand breakage in A549 cells." As taken from Pu J et al. 2013. Beijing Da Xue Xue Bao. 45(3), 405-11. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23774918

"Novel materials are often commercialized without a complete assessment of the risks they pose to human health because such assessments are costly and time-consuming; additionally, sometimes the methodology needed for such an assessment does not exist. Carbon nanotubes have the potential for widespread application in engineering, materials science and medicine. However, due to the needle-like shape and high durability of multiwalled carbon nanotubes (MWCNTs), concerns have been raised that they may induce asbestos-like pathogenicity when inhaled. Indeed, experiments in rodents supported this hypothesis. Notably, the genetic alterations in MWCNT-induced rat malignant mesothelioma were similar to those induced by asbestos. Single-walled CNTs (SWCNTs) cause mitotic disturbances in cultured cells, but thus far, there has been no report that SWCNTs are carcinogenic. This review summarizes the recent noteworthy publications on the genotoxicity and carcinogenicity of CNTs and explains the possible molecular mechanisms responsible for this carcinogenicity. The nanoscale size and needle-like rigid structure of CNTs appear to be associated with their pathogenicity in mammalian cells, where carbon atoms are major components in the backbone of many biomolecules. Publishing adverse events associated with novel materials is critically important for alerting people exposed to such materials. CNTs still have a bright future with superb economic and medical merits. However, appropriate regulation of the production, distribution and secondary manufacturing processes is required, at least to protect the workers." As taken from Toyokuni S. 2013. Adv. Drug Deliv. Rev. 65(15), 2098-110. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23751780

"…..... Due to the current lack of hazardous effect information on SWNCTs, a standardized genotoxicity battery test was conducted to clarify the genetic toxicity potential of SWCNTs (diameter: 1-1.2 nm, length: ~20 μm) according to Organization for Economic Cooperation and Development test guidelines 471 (bacterial reverse mutation test), 473 (in vitro chromosome aberration test), and 474 (in vivo micronuclei test) with a good laboratory practice system. The test results showed that the SWCNTs did not induce significant bacterial reverse mutations at 31.3-500 μg/plate in Salmonella typhimurium strains TA98, TA100, TA1535, and TA1537 or in Escherichia coli strain WP2uvrA, with and without a metabolic activation system. Furthermore, the in vitro chromosome aberration test showed no significant increase in structural or numerical chromosome aberration frequencies at SWCNT dose levels of 12.5-50 μg/ml in the presence and absence of metabolic activation. However, dose-dependent cell growth inhibition was found at all the SWCNT dose levels and statistically significant cytotoxic effects observed at certain concentrations in the presence and absence of metabolic activation. Finally, the SWCNTs did not evoke significant in vivo micronuclei frequencies in the polychromatic erythrocytes of an imprinting control region mice at 25-100 mg/kg. Thus, according to the results of the present study, the SWCNTs were not found to have a genotoxic effect on the in vitro and in vivo test systems." As taken from Kim JS et al. 2015a. Toxicol. Ind. Health 31(8), 747-757. PubMed, 2016 available at http://www.ncbi.nlm.nih.gov/pubmed/23552264

"Carbon nanotubes are unique one-dimensional macromolecules with promising application in biology and medicine. Since their toxicity is still under debate, here we describe an investigation of genotoxic properties of purified single-walled carbon nanotubes (SWCNT), multiwall carbon nanotubes (MWCNT), and amide-functionalized purified SWCNT. We used two different cell systems: cultured human lymphocytes where we employed cytokinesis-block micronucleus test and human fibroblasts where we investigate the induction of DNA double-strand breaks (DSBs) employing H2AX phosphorylation assay." As taken from Neškovi-ç O et al. 2013. Methods Mol. Biol. 991, 315-23. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23546681

"In order to study the effects of nanoparticles (NPs) with different physicochemical properties on cellular viability and structure, Saccharomyces cerevisiae were exposed to different concentrations of TiO2-NPs (1-3 nm), ZnO-NPs (<100 nm), CuO-NPs (<50 nm), their bulk forms, Ag-NPs (10 nm) and single-walled carbon nanotubes (SWCNTs). The GreenScreen assay was used to measure cyto- and genotoxicity, and transmission electron microscopy (TEM) used to assess ultrastructure….Two genotoxicity assays, GreenScreen and the comet assay, produced different results and the authors discuss the reasons for this discrepancy…." As taken from Bayat N et al. 2014. Nanotoxicology 8, 363-73. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23521755

"Single-wall carbon nanotubes (SWCNTs) and polyamidoamine dendrimers (PAMAM) have been proposed for a variety of biomedical applications. The combination of both molecules makes this new composite nanomaterial highly functionalizable and versatile to theranostic and drug-delivery systems. However, recent toxicological studies have shown that nanomaterials such as SWCNTs and PAMAM may have high toxicity in biological environments. Aiming to elucidate such behavior, in vitro studies with different cultured cells have been conducted in the past few years. This study focuses on the effects of SWCNT-PAMAM nanomaterials and their individual components on the C2C12 murine cell line, which is a mixed population of stem and progenitor cells. The interactions between the cells and the nanomaterials were studied with different techniques usually employed in toxicological analyses. The results showed that SWCNT-PAMAM and PAMAM inhibited the proliferation and caused DNA damage of C2C12 cells. Data from flow cytometry revealed a less toxicity in C2C12 cells exposed to SWCNT compared to the other nanomaterials. The results indicated that the toxicity of SWCNT, SWCNT-PAMAM and PAMAM in C2C12 cells can be strongly correlated with the charge of the nanomaterials." As taken from Cancino J et al. 2013. Toxicol. Lett. 219(1), 18-25. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23454831

“Although some types of carbon nanotubes (CNTs) have been described to induce mesothelioma in rodents and genotoxic effects in various cell systems, there are few previous studies on the genotoxicity of CNTs in mesothelial cells. Here, we examined in vitro DNA damage induction by short multi-wall CNTs (MWCNTs; 10-30 nm × 1-2 μm) and single-wall CNTs (SWCNTs; >50% SWCNTs, ~40% other CNTs; <2 nm × 1-5 μm) in human mesothelial (MeT-5A) cells and bronchial epithelial (BEAS 2B) cells, using the single cell gel electrophoresis (comet) assay and the immunoslot blot assay for the detection of malondialdehyde (M1dG) DNA adducts. In BEAS 2B cells, we also studied the induction of micronuclei (MN) by the CNTs using the cytokinesis-block method. The cells were exposed to the CNTs (5-200 μg/cm(2), corresponding to 19-760 μg/ml) for 24 and 48h in the comet assay and for 48 and 72 h in the MN and M1dG assays. Transmission electron microscopy (TEM) showed more MWCNT fibres and SWCNT clusters in BEAS 2B than MeT-5A cells, but no significant differences were seen in intracellular dose expressed as area of SWCNT clusters between TEM sections of the cell lines. In MeT-5A cells, both CNTs caused a dose-dependent induction of DNA damage (% DNA in comet tail) in the 48-h treatment and SWCNTs additionally in the 24-h treatment, with a statistically significant increase at 40 μg/cm(2) of SWCNTs and (after 48 h) 80 μg/cm(2) of both CNTs. SWCNTs also elevated the level of M1dG DNA adducts at 1, 5, 10 and 40 μg/cm(2) after the 48-h treatment, but both CNTs decreased M1dG adduct level at several doses after the 72-h treatment. In BEAS 2B cells, SWCNTs induced a statistically significant increase in DNA damage at 80 and 120 μg/cm(2) after the 24-h treatment and in M1dG adduct level at 5 μg/cm(2) after 48 h and 10 and 40 μg/cm(2) after 72 h; MWCNTs did not affect the level of DNA damage but produced a decrease in M1dG adducts in the 72-h treatment. The CNTs did not affect the level of MN. In conclusion, MWCNTs and SWCNTs induced DNA damage in MeT-5A cells but showed a lower (SWCNTs) or no (MWCNTs) effect in BEAS 2B cells, suggesting that MeT-5A cells were more sensitive to the DNA-damaging effect of CNTs than BEAS 2B cells, despite the fact that more CNT fibres or clusters were seen in BEAS 2B than MeT-5A cells. M1dG DNA adducts were induced by SWCNTs but decreased after a 3-day exposure to MWCNTs and (in MeT-5A cells) SWCNTs, indicating that CNTs may lead to alterations in oxidative effects within the cells. Neither of the CNTs was able to produce chromosomal damage (MN).” As taken from Lindberg HK et al. 2013. Toxicology 313(1), 24-37. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23266321

“The genotoxicity of single-walled carbon nanotubes (SWCNTs) was determined using a battery of genotoxicity assays, comprising a bacterial reverse mutation test, an in vitro mammalian chromosomal aberration test and a mammalian erythrocytes micronucleus test. SWCNTs had no mutagenicityin S. typhimurium TA98, TA100, TA1535 or TA1537, or in E. coli WP2uvrA, in the absence or presence of metabolic activation. SWCNTs did not increase the number of structural or numerical chromosomal aberrations after short-term or continuous exposure. In the micronucleus test using CD-1 mice, SWCNTs did not affect the proportion of immature erythrocytes, the total proportion of erythrocytes or the number of micronuclei in immature erythrocytes. SWCNTs appear not to pose a genotoxic risk.” As taken from Ema M et al. 2013a. J. Appl. Toxicol. 33(9), 933-9. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/22763644

“The genotoxicity of multi-walled carbon nanotubes (MWCNTs) was evaluated in vivo with comet assays using the lung cells of rats given MWCNTs. The MWCNTs were intratracheally instilled as a single dose at 0.2 or 1.0 mg kg(-1) or a repeated dose at 0.04 or 0.2 mg kg(-1) , once a week for 5 weeks, to male rats. The rats were sacrificed 3 or 24 h after the single instillation and were sacrificed 3 h after the last instillation in the repeated instillation groups. Histopathological examinations of the lungs revealed that MWCNTs caused inflammatory changes including the infiltration of macrophages and neutrophils after a single instillation and repeated instillation at both doses. In comet assays using rat lung cells, no changes in % Tail DNA were found in any group given MWCNTs. These findings indicate that MWCNTs do not have the potential to cause DNA damage in comet assays using the lung cells of rats given MWCNTs at doses causing inflammatory responses.” As taken from Ema M et al. 2013b. J. Appl. Toxicol. 33(10), 1053-60. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/22936419

“The genotoxic effects of multi-walled carbon nanotubes (MWCNTs) were examined by using in vitro and in vivo assays. MWCNTs significantly induced micronuclei in A549 cells and enhanced the frequency of sister chromatid exchange (SCE) in CHO AA8 cells. When ICR mice were intratracheally instilled with a single dose (0.05 or 0.2 mg/animal) of MWCNTs, DNA damage of the lungs, analysed by comet assay, increased in a dose-dependent manner. Moreover, DNA oxidative damage, indicated by 8-oxo-7,8-dihydro-2'-deoxyguanosine and heptanone etheno-deoxyribonucleosides, occurred in the lungs of MWCNT-exposed mice. The gpt mutation frequencies significantly increased in the lungs of MWCNT-treated gpt delta transgenic mice. Transversions were predominant, and G:C to C:G was clearly increased by MWCNTs. Moreover, many regions immunohistochemically stained for inducible NO synthase and nitrotyrosine were observed in the lungs of MWCNT-exposed mice. Overall, MWCNTs were shown to be genotoxic both in in vitro and in vivo tests; the mechanisms probably involve oxidative stress and inflammatory responses.” As taken from Kato T et al. 2013. Nanotoxicology 7(4), 452-61. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/22397533

“Single-walled carbon nanotubes (SWCNTs) have recently attracted great attention because of their fibrous structure and high aspect ratio. Here the genotoxic potential of 400-800 nm, 1-3 μm and 5-30 μm SWCNT with respect to their geometry and surface characteristics was studied. Following thorough physico-chemical characterisation, human bronchial epithelial (BEAS-2B) and lymphoblastoid (MCL-5) cells were treated with SWCNT for 24 or 48 h. This showed significant increases in micronucleus frequency in a time- and dose-dependent manner in both cell types in the absence of cytotoxicity. Over the same dose range, only 1-3 μm SWCNT gave rise to significant increases in hprt point mutations at doses ≥25 μg/ml. Cellular 2,7-dichlorodihydrofluoresceindiacetate (DCFH-DA) fluorescence assay and RT-PCR for oxidative pathway gene profiling revealed a possible oxidative mechanism for the genotoxicity observed in the 1-3 μm SWCNT. Consequently, this study has demonstrated that SWCNT genotoxicity is dependent on its secondary structure under experimental conditions and oxidative stress alone cannot account for the observed damage.” As taken from Manshian BB et al. 2013. Nanotoxicology 7(2), 144-56. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/22263934

“Single walled carbon nanotubes were studied with respect to cytotoxic and genotoxic properties in cells of the gastrointestinal tract as exemplified for the human colon carcinoma cell line HT29….in subcytotoxic concentrations substantial DNA damaging effects were found in the alkaline comet assay, which were not associated with enhanced formation of formamidopyrimidine-DNA-glycosylase-sensitive sites. In addition, an increase of kinetochore-negative micronuclei (V79) and phosphorylation of the tumour suppressor protein p53 (HT29) underlined the genotoxic potential of these nanostructures.” As taken from Pelka J et al. 2013. Nanotoxicology 7(1), 2-20. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/22007624

“In addition to the early-stage non-cancer lung effects in animals, some studies in cells or animals have shown genotoxic or carcinogenic effects. In vitro studies with human lung cells have shown that single-walled carbon nanotubes (SWCNT) can cause genotoxicity and abnormal chromosome number by interfering with mitosis (cell division) [Muller et al. 2008b; Sargent et al. 2009, 2011; Kisin et al. 2011]. Other in vitro studies did not show evidence of genotoxicity of some MWCNT [Wirnitzer et al. 2009; Kim et al. 2011].”

As taken from NIOSH, 2013.

Mutagenicity Studies:

Test System:	Chinese hamster V79 lung fibroblast cells
End Point:	In vitro chromosomal aberrations
Metabolic Activation:	None

Dose:	0; 2.5; 5; 10 ug/ml (Test material solvent: water)
Dose Regimen:	4 hr treatment, 18 hr recovery
Results:	Negative. Positive response at 10 ug/ml was considered not relevant by authors because it was within range of historical controls. Material tested was baytubes, multi-walled carbon-nanotubes.
Reference:	[WIRNITZER,U, HERBOLD,B, VOETZ,M, RAGOT,J; STUDIES ON THE IN VITRO GENOTOXICITY OF BAYTUBES AGGLOMERATES OF ENGINEERED MULTI-WALLED CARBON-NANOTUBES (MWCNT). TOXICOL. LETT. 186(3): 160-165, 2009]
Test System:	Chinese hamster V79 lung fibroblast cells
End Point:	In vitro chromosomal aberrations
Metabolic Activation:	None
Dose:	0; 2.5; 5; 10 ug/ml (Test material solvent: water)
Dose Regimen:	18 hr continuous treatment
Results:	Negative. Material tested was baytubes, multi-walled carbon-nanotubes.
Reference:	[WIRNITZER,U, HERBOLD,B, VOETZ,M, RAGOT,J; STUDIES ON THE IN VITRO GENOTOXICITY OF BAYTUBES AGGLOMERATES OF ENGINEERED MULTI-WALLED CARBON-NANOTUBES (MWCNT). TOXICOL. LETT. 186(3): 160-165, 2009]
Test System:	Chinese hamster V79 lung fibroblast cells
End Point:	In vitro chromosomal aberrations
Metabolic Activation:	Rat, Liver, S9, Aroclor 1254
Dose:	0; 2.5; 5; 10 ug/ml (Test material solvent: water)
Dose Regimen:	4 hr treatment, 18 hr recovery
Results:	Negative. Material tested was baytubes, multi-walled carbon-nanotubes.
Reference:	[WIRNITZER,U, HERBOLD,B, VOETZ,M, RAGOT,J; STUDIES ON THE IN VITRO GENOTOXICITY OF BAYTUBES AGGLOMERATES OF ENGINEERED MULTI-WALLED CARBON-NANOTUBES (MWCNT). TOXICOL. LETT. 186(3): 160-165, 2009]
Test System:	Ames Salmonella typhimurium
Strain Indicator:	TA98
Metabolic Activation:	Rat, Liver, S9, Aroclor 1254
Method:	Preincubation

Dose:	0; 50; 158; 500; 1581; 5000 ug/tube
Results:	Negative. Material tested was baytubes, multi-walled carbon-nanotubes.
Reference:	[WIRNITZER,U, HERBOLD,B, VOETZ,M, RAGOT,J; STUDIES ON THE IN VITRO GENOTOXICITY OF BAYTUBES AGGLOMERATES OF ENGINEERED MULTI-WALLED CARBON-NANOTUBES (MWCNT). TOXICOL. LETT. 186(3): 160-165, 2009]
Test System:	Ames Salmonella typhimurium
Strain Indicator:	TA100
Metabolic Activation:	Rat, Liver, S9, Aroclor 1254
Method:	Preincubation
Dose:	0; 50; 158; 500; 1581; 5000 ug/tube
Results:	Negative. Material tested was baytubes, multi-walled carbon-nanotubes.
Reference:	[WIRNITZER,U, HERBOLD,B, VOETZ,M, RAGOT,J; STUDIES ON THE IN VITRO GENOTOXICITY OF BAYTUBES AGGLOMERATES OF ENGINEERED MULTI-WALLED CARBON-NANOTUBES (MWCNT). TOXICOL. LETT. 186(3): 160-165, 2009]
Test System:	Ames Salmonella typhimurium
Strain Indicator:	TA102
Metabolic Activation:	Rat, Liver, S9, Aroclor 1254
Method:	Preincubation
Dose:	0; 50; 158; 500; 1581; 5000 ug/tube
Results:	Negative. Material tested was baytubes, multi-walled carbon-nanotubes.
Reference:	[WIRNITZER,U, HERBOLD,B, VOETZ,M, RAGOT,J; STUDIES ON THE IN VITRO GENOTOXICITY OF BAYTUBES AGGLOMERATES OF ENGINEERED MULTI-WALLED CARBON-NANOTUBES (MWCNT). TOXICOL. LETT. 186(3): 160-165, 2009]
Test System:	Ames Salmonella typhimurium
Strain Indicator:	TA1535
Metabolic Activation:	Rat, Liver, S9, Aroclor 1254
Method:	Preincubation
Dose:	0; 50; 158; 500; 1581; 5000 ug/tube
Results:	Negative. Material tested was baytubes, multi-walled carbon-nanotubes.

Reference:	[WIRNITZER,U, HERBOLD,B, VOETZ,M, RAGOT,J; STUDIES ON THE IN VITRO GENOTOXICITY OF BAYTUBES AGGLOMERATES OF ENGINEERED MULTI-WALLED CARBON-NANOTUBES (MWCNT). TOXICOL. LETT. 186(3): 160-165, 2009]
Test System:	Ames Salmonella typhimurium
Strain Indicator:	TA1537
Metabolic Activation:	Rat, Liver, S9, Aroclor 1254
Method:	Preincubation
Dose:	0; 50; 158; 500; 1581; 5000 ug/tube
Results:	Negative. Material tested was baytubes, multi-walled carbon-nanotubes.
Reference:	[WIRNITZER,U, HERBOLD,B, VOETZ,M, RAGOT,J; STUDIES ON THE IN VITRO GENOTOXICITY OF BAYTUBES AGGLOMERATES OF ENGINEERED MULTI-WALLED CARBON-NANOTUBES (MWCNT). TOXICOL. LETT. 186(3): 160-165, 2009]
Test System:	Ames Salmonella typhimurium
Strain Indicator:	TA1537
Metabolic Activation:	None
Method:	Preincubation
Dose:	0; 50; 158; 500; 1581; 5000 ug/tube
Results:	Negative. Material tested was baytubes, multi-walled carbon-nanotubes.
Reference:	[WIRNITZER,U, HERBOLD,B, VOETZ,M, RAGOT,J; STUDIES ON THE IN VITRO GENOTOXICITY OF BAYTUBES AGGLOMERATES OF ENGINEERED MULTI-WALLED CARBON-NANOTUBES (MWCNT). TOXICOL. LETT. 186(3): 160-165, 2009]
Test System:	Ames Salmonella typhimurium
Strain Indicator:	TA1535
Metabolic Activation:	None
Method:	Preincubation
Dose:	0; 50; 158; 500; 1581; 5000 ug/tube
Results:	Negative. Material tested was baytubes, multi-walled carbon-nanotubes.
Reference:	[WIRNITZER,U, HERBOLD,B, VOETZ,M, RAGOT,J; STUDIES ON THE IN VITRO GENOTOXICITY OF BAYTUBES AGGLOMERATES OF ENGINEERED MULTI-WALLED CARBON-NANOTUBES (MWCNT). TOXICOL. LETT. 186(3): 160-165, 2009]

Test System:	Ames Salmonella typhimurium
Strain Indicator:	TA102
Metabolic Activation:	None
Method:	Preincubation
Dose:	0; 50; 158; 500; 1581; 5000 ug/tube
Results:	Negative. Material tested was baytubes, multi-walled carbon-nanotubes.
Reference:	[WIRNITZER,U, HERBOLD,B, VOETZ,M, RAGOT,J; STUDIES ON THE IN VITRO GENOTOXICITY OF BAYTUBES AGGLOMERATES OF ENGINEERED MULTI-WALLED CARBON-NANOTUBES (MWCNT). TOXICOL. LETT. 186(3): 160-165, 2009]
Test System:	Ames Salmonella typhimurium
Strain Indicator:	TA100
Metabolic Activation:	None
Method:	Preincubation
Dose:	0; 50; 158; 500; 1581; 5000 ug/tube
Results:	Negative. Material tested was baytubes, multi-walled carbon-nanotubes.
Reference:	[WIRNITZER,U, HERBOLD,B, VOETZ,M, RAGOT,J; STUDIES ON THE IN VITRO GENOTOXICITY OF BAYTUBES AGGLOMERATES OF ENGINEERED MULTI-WALLED CARBON-NANOTUBES (MWCNT). TOXICOL. LETT. 186(3): 160-165, 2009]
Test System:	Ames Salmonella typhimurium
Strain Indicator:	TA98
Metabolic Activation:	None
Method:	Preincubation
Dose:	0; 50; 158; 500; 1581; 5000 ug/tube
Results:	Negative. Material tested was baytubes, multi-walled carbon-nanotubes.
Reference:	[WIRNITZER,U, HERBOLD,B, VOETZ,M, RAGOT,J; STUDIES ON THE IN VITRO GENOTOXICITY OF BAYTUBES AGGLOMERATES OF ENGINEERED MULTI-WALLED CARBON-NANOTUBES (MWCNT). TOXICOL. LETT. 186(3): 160-165, 2009]
Test System:	Human bronchial epithelial BEAS 2B cells
End Point:	In vitro micronucleus

Metabolic Activation:	None
Dose:	0; 1; 5; 10; 20; 40; 60; 80; 100 ug/sq cm (chamber slide surface) corresponding to 0; 3.6; 18; 36; 72; 144; 216; 288; and 360 ug/ml
Dose Regimen:	24 hr continuous treatment; cytochalasin B added simultaneously with the particles
Results:	Negative. Test material was single-walled carbon nanotubes (>50%, ~40% other CNTs; 1.1 nm x 0.05-100 um).
Reference:	[LINDBERG,HK, FALCK,GC, SUHONEN,S, VIPPOLA,M, VANHALA,E, CATALAN,J, SAVOLAINEN,K, NORPPA,H; GENOTOXICITY OF NANOMATERIALS: DNA DAMAGE AND MICRONUCLEI INDUCED BY CARBON NANOTUBES AND GRAPHITE NANOFIBRES IN HUMAN BRONCHIAL EPITHELIAL CELLS IN VITRO. TOXICOL. LETT. 186(3): 166-173, 2009]
Test System:	Human bronchial epithelial BEAS 2B cells
End Point:	In vitro micronucleus
Metabolic Activation:	None
Dose:	0; 1; 5; 10; 20; 40; 60; 80; 100 ug/sq cm (chamber slide surface) corresponding to 0; 3.6; 18; 36; 72; 144; 216; 288; and 360 ug/ml
Dose Regimen:	72 hr continuous treatment; cytochalasin B added simultaneously with the particles
Results:	Negative. Test material was single-walled carbon nanotubes (>50%, ~40% other CNTs; 1.1 nm x 0.05-100 um).
Reference:	[LINDBERG,HK, FALCK,GC, SUHONEN,S, VIPPOLA,M, VANHALA,E, CATALAN,J, SAVOLAINEN,K, NORPPA,H; GENOTOXICITY OF NANOMATERIALS: DNA DAMAGE AND MICRONUCLEI INDUCED BY CARBON NANOTUBES AND GRAPHITE NANOFIBRES IN HUMAN BRONCHIAL EPITHELIAL CELLS IN VITRO. TOXICOL. LETT. 186(3): 166-173, 2009]
Test System:	Human bronchial epithelial BEAS 2B cells
End Point:	In vitro micronucleus
Metabolic Activation:	None
Dose:	0; 1; 5; 10; 20; 40; 60; 80; 100 ug/sq cm (chamber slide surface) corresponding to 0; 3.6; 18; 36; 72; 144; 216; 288; and 360 ug/ml
Dose Regimen:	48 hr continuous treatment; cytochalasin B added simultaneously with the particles
Results:	Positive. Test material was single-walled carbon nanotubes (>50%, ~40% other CNTs; 1.1 nm x 0.05-100 um)
Reference:	[LINDBERG,HK, FALCK,GC, SUHONEN,S, VIPPOLA,M, VANHALA,E, CATALAN,J, SAVOLAINEN,K, NORPPA,H; GENOTOXICITY OF NANOMATERIALS: DNA DAMAGE AND

	MICRONUCLEI INDUCED BY CARBON NANOTUBES AND GRAPHITE NANOFIBRES IN HUMAN BRONCHIAL EPITHELIAL CELLS IN VITRO. TOXICOL. LETT. 186(3): 166-173, 2009]

As taken from CCRIS, 2010.

The Panel concluded that, altogether, tests with carbon black particles do not indicate a genotoxic hazard. However, the positive results obtained in tests in vitro with carbon black solvent extracts point to the presence of genotoxic compounds, mainly PAHs and nitro and sulphur containing PAHs (IARC, 2010), absorbed onto the surface of the particles. The Panel noted that the PAHs extracted by solvent are tightly bound to carbon particles, and may have limited bioavailability in physiological condition. (EFSA 2012b)

“Graphene and its derivatives are promising candidates for important biomedical applications because of their versatility. The prospective use of graphene-based materials in a biological context requires a detailed comprehension of the toxicity of these materials. Moreover, due to the expanding applications of nanotechnology, human and environmental exposures to graphene-based nanomaterials are likely to increase in the future. Because of the potential risk factors associated with the manufacture and use of graphene-related materials, the number of nanotoxicological studies of these compounds has been increasing rapidly in the past decade. These studies have researched the effects of the nanostructural/biological interactions on different organizational levels of the living system, from biomolecules to animals. This review discusses recent results based on in vitro and in vivo cytotoxicity and genotoxicity studies of graphene-related materials and critically examines the methodologies employed to evaluate their toxicities. ……..” As taken from Seabra AB et al. 2014. Chem. Res. Toxicol. 27(2), 159-168. PubMed, 2015 available at http://www.ncbi.nlm.nih.gov/pubmed/24422439

“Carbon-based nanomaterials have attracted great interest in biomedical applications such as advanced imaging, tissue regeneration, and drug or gene delivery. The toxicity of the carbon nanotubes and graphene remains a debated issue although many toxicological studies have been reported in the scientific community. In this review, we summarize the biological effects of carbon nanotubes and graphene in terms of in vitro and in vivo toxicity, genotoxicity and toxicokinetics. .....”. As taken from Zhang Y et al. 2014. Drug Metab. Rev. 46(2), 232-46. PubMed, 2015 available at http://www.ncbi.nlm.nih.gov/pubmed/24506522

“Long carbon nanotubes (CNTs) resemble asbestos fibers due to their high length to diameter ratio and they thus have genotoxic effects. Another parameter that might explain their genotoxic effects is contamination with heavy metal ions. On the other hand, short (1-2 μm) CNTs do not resemble asbestos fibers, and, once purified from contaminations, they might be suitable for medical applications. To identify the role of fiber thickness and surface properties on genotoxicity, well-characterized short pristine and carboxylated single-walled (SCNTs) and multi-walled (MCNTs) CNTs of different diameters were studied for cytotoxicity, the cell's response to oxidative stress (immunoreactivity against hemoxygenase 1 and glutathione levels), and in a hypoxanthine guanine phosphoribosyltransferase (HPRT) assay using V79 chinese hamster fibroblasts and human lung adenocarcinoma A549 cells. DNA repair was demonstrated by measuring immunoreactivity against activated histone H2AX protein. The number of micronuclei as well as the number of multinucleated cells was determined. CNTs acted more cytotoxic in V79 than in A549 cells. Plain and carboxylated thin (<8 nm) SCNTs and MCNTs showed greater cytotoxic potential and carboxylated CNTs showed indication for generating oxidative stress. Multi-walled CNTs did not cause HPRT mutation, micronucleus formation, DNA damage, interference with cell division, and oxidative stress. Carboxylated, but not plain, SCNTs showed indication for in vitro DNA damage according to increase of H2AX-immunoreactive cells and HPRT mutation. Although short CNTs presented a low in vitro genotoxicity, functionalization of short SCNTs can render these particles genotoxic.” As taken from Mrakovcic M et al. 2015. Toxicol. Sci. 144(1), 114-27. PubMed, 2016 available at http://www.ncbi.nlm.nih.gov/pubmed/25505129

“We summarized the findings of in vivo toxicity studies of single-walled carbon nanotubes (SWCNTs) in laboratory animals. The large majority addressed the pulmonary toxicity of SWCNTs in rodents. Inhalation, pharyngeal aspiration, and intratracheal instillation studies revealed that SWCNTs caused ….. genotoxic effects in the lungs. ….. Overall, the available data provides initial information on SWCNT toxicity. To further clarify their toxicity and risk assessment, studies should be conducted using well-characterized SWCNTs, standard protocols, and the relevant route and doses of human exposure.” As taken from Ema M et al. 2016. Regul. Toxicol. Pharmacol. 74, 42-63. PubMed, 2016 available at http://www.ncbi.nlm.nih.gov/pubmed/26619783

“Human Health Assessment

….. It is not an in vitro mutagen (negative in a mammalian cell gene mutation test and in a mammalian chromosome aberration test). Therefore the substance is unlikely to cause genetic damage. ….."

As taken from Environment Canada, 2015

Carbon nanotubes (CNTs) were the first nanomaterials to be evaluated by the International Agency for Research on Cancer (IARC). The categorization as possibly carcinogenic agent to humans was only applicable to multi-walled carbon nanotubes called MWCNT-7. Other types of CNTs were not classifiable because of missing data and it was not possible to pinpoint unique CNT characteristics that cause cancer. Importantly, the European Commission’s Joint Research Centre (JRC) has established a repository of industrially manufactured nanomaterials that encompasses at least four well-characterized MWCNTs called NM-400 to NM-403 (original JRC code). This review summarizes the genotoxic effects of these JRC materials and MWCNT-7. The review consists of 36 publications with results on cell culture experiments (22 publications), animal models (9 publications) or both (5 publications). As compared to the publications in the IARC monograph on CNTs, the current database represents a significant increase as there is only an overlap of 8 publications. However, the results come mainly from cell cultures and/or measurements of DNA strand breaks by the comet assay and the micronucleus assay (82 out of 97 outcomes). A meta-analysis of cell culture studies on DNA strand breaks showed a genotoxic response by MWCNT-7, less consistent effect by NM-400 and NM-402, and least consistent effect by NM-401 and NM-403. Results from other *in vitro* tests indicate strongest evidence of genotoxicity for MWCNT-7. There are too few observations from animal models and humans to make general conclusions about genotoxicity. As taken from Moller P et al. 2021. Available at https://www.sciencedirect.com/science/article/pii/S1383574221000302

5.5. Cytotoxicity

This study investigated the cytotoxic potential of novel activated carbon adsorbents (MAST Carbon International Ltd.) developed for medical applications such as extracorporeal therapies. Carbon adsorbents were assessed for their in vitro cytotoxicity against a V79 cell line using a material extraction method in combination with a colony formation assay. Results were compared to those from a commercially available cellulose-coated carbon adsorbent, developed for direct haemoperfusion. Initial findings demonstrated an inhibition of colony formation and an apparent cytotoxic effect. However, it was found that this inhibition occurred as a result of protein and ion adsorption by carbon materials possessing large surface area and highly developed porous structure. Consequently, these essential nutrients were unavailable to the cells during colony formation. Modifications to the cytotoxicity assessment methods were required in order to take into account nutrient loss. Subsequently it was determined that the carbon materials do not show a cytotoxic response towards the V79 cell line under the modified conditions employed. The suggested approach may be useful in the assessment of other biomaterials such as carbon nanotubes and other nanoparticles which possess large surface area. The preliminary data support the ongoing investigation of these adsorbents as candidates for use in extracorporeal therapies.

BARNES Lara-Marie et al. Carbon ISSN 0008-6223 CODEN CRBNAH. 2009, vol. 47, nº8, pp. 1887-1895 [9 page(s) (article)] (33 ref.)

The success or failure of medical implants often depends on the cell-surface behavior after implantation of the device. This study investigated the use of woven carbon fabric, which had been sonoelectrochemically coated with calcium phosphate, to enhance bone cell attachment and proliferation in vitro. Human osteoblast-like cells, MG63, were used to study the interactions between cells and the material and assess the cytotoxicity of the substrates. The cytotoxicity of the materials was assessed using an MTS ((3-(4,5-dimethylthiazol-2-yl)-5-(3-carboxymethoxyphenyl)-2-(4-sulfophenyl)-2H-tetrazolium, inner salt)) assay to determine the viability of the osteoblast-like MG63 cells in direct contact with the carbon fabric or calcium phosphate coated carbon fabrics, and to assess the cytotoxicity of extracts from these materials. The morphology of the surface adherent cells was assessed by scanning electron microscopy (SEM). Results showed that neither carbon fabrics nor calcium phosphate coated materials were cytotoxic. Furthermore, cell attachment and proliferation were enhanced by coating carbon fabrics with calcium phosphate. SEM showed that the cells had a normal morphology and were well spread similar to those seen in the tissue culture plate control. These flexible calcium phosphate coated fabrics could, therefore, have uses in the reconstruction of bone in orthopaedic and dental surgery. New Carbon Materials, Volume 23, Issue 2, June 2008, Pages 139-143. Hong-mei HAN et al.

“Engineered nanomaterials offer numerous and tantalizing opportunities in many sectors of society, including medicine. Needless to say, attention should also be paid to the potential for unexpected hazardous effects of these novel materials. To date, much of the nanotoxicology literature has focused on the assessment of cell viability or cell death using primitive assays for the detection of plasma membrane integrity or mitochondrial function or assessment of cellular morphology. However, when assessing the cytotoxic effects of engineered nanomaterials, researchers need not only to consider whether cells are dead or alive but also to assess which of the numerous, highly specific pathways of cell death might be involved. Moreover, it is important to diagnose cell death based not only on morphological markers but on the assessment and quantification of biochemical alterations specific to each form of cell death. In this Account, we provide a description of the three major forms of programmed cell death in mammalian cells: apoptosis, autophagic cell death, and regulated necrosis, sometimes referred to as necroptosis. Apoptosis can be activated via the extrinsic (death receptor-dependent) or via the intrinsic (mitochondria-dependent) route. Apoptotic cell death may or may not require the activation of cytosolic proteases known as caspases. Autophagy (self-eating) has an important homeostatic role in the cell, mediating the removal of dysfunctional or damaged organelles thereby allowing the recycling of cellular building blocks. However, unrestrained autophagy can kill cells. Studies in recent years have revealed that necrosis that depends on activation of the kinases RIP1 and RIP3 is a major form of programmed cell death with roles in development and immunity. We also discuss recent examples of the impact of engineered nanoparticles on the three different pathways of programmed cell death. For example, acute exposure of cells to carbon nanotubes (CNTs) can induce apoptosis whereas chronic exposure to CNTs may yield an apoptosis-resistant and tumorigenic phenotype in lung epithelial cells. Several reports show that nanoparticles, including polystyrene particles, are routed to the lysosomal compartment and trigger cell death through the destabilization of lysosomal membranes with engagement of the intrinsic apoptosis pathway. In addition, a number of studies have demonstrated that nanomaterials such as CNTs, quantum dots, and gold nanoparticles can affect cellular autophagy. An improved understanding of the complexities of the nanomaterial-induced perturbation of different cell death pathways may allow for a better prediction of the consequences of human exposure” (Andón and Fadeel, 2013. Accounts of Chemical Research 46(3), 733-42. As taken from http://www.ncbi.nlm.nih.gov/pubmed/22720979

“The present study aimed to evaluate the potential toxicity and the general mechanism involved in multi-walled carbon nanotubes (MWCNT)-induced cytotoxicity in C6 rat glioma cell line. Two kinds of MWCNT, which were coded as MWCNT1 (measured 10-20nm in diameter and 2μm in average length) and MWCNT2 (measured 40-100nm in diameter and 10μm in average length), were used in

this study. To elucidate the possible mechanisms of cytotoxicity induced by MWCNT, MTT assay and flow cytometry analysis for apoptosis and cell cycle, MDA and SOD assays for oxidative stress were quantitatively assessed. The exposure of C6 rat glioma cells to different sizes of two kinds of carbon nanotubes at concentrations between 25 and 400μg/ml decreased the cell viability in a concentration- and time-dependent manner. The exposure of C6 rat glioma cells to MWCNT (200-400μg/ml) resulted in a concentration dependent cell apoptosis and G1 cell cycle arrest, and increased the level of oxidative stress. Results demonstrate that smaller size of MWCNT seems to be more toxic than that of larger one. MWCNT-induced cytotoxicity in C6 cells is probably due to the increased oxidative stress. " (Han YG et al., 2012. Neurotoxicology 33(5), 1128-34. As taken from http://www.ncbi.nlm.nih.gov/pubmed/22728153

"Sachar and Saxena (Sachar and Saxena 2011) investigated the uptake of either SWCNTs or acid functionalized SWCNTs (AF-SWCNTs) in erythrocytes isolated from Swiss or C57BL76 female mice. The acid functionalized (AF)-SWCNTs were surface oxidized by a mixture of nitric and sulphuric acid under pressure at elevated temperature. The carboxylic acid moieties formed were derivatised by a fluorophor for imaging purposes, and were intensively purified to remove excess fluorescent dye. The particle size distribution and surface charge was not indicated. Particle size distribution and surface charge on AF-SWCNTs were reported before (Saxena et al. 2007 as cited in (Sachar and Saxena 2011). A dose and time dependent decline (70 to 90%) in erythrocyte recovery was recorded in cultures treated with AF-SWCNTs (concentrations of 10, 25 or 50 μg/ml), while treatment with SWCNTs (50 μg/ml) had no effect on erythrocyte recovery as compared to the untreated control groups. Furthermore, the authors reported an increase in the binding of 8-anilino naphthalene sulfonic acid to erythrocytes treated with AF-SWCNTs, which according to the authors indicated a significant damage of the erythrocyte membrane after exposure to the AF-SWCNT NPs.

Cicchetti and co-workers (Cicchetti et al. 2011) exposed human gingival fibroblasts in semiconfluent cultures to SWCNT concentrations between 50 and 150 μg SWCNTs/ml for 24 hours. The SWCNTs used were oxidized by treatment with a mixture of nitric and sulphuric acids. The surface area of was 407 m2/g, and the average external diameter was 1.58 nm ± 0.20 nm and the average length was 0.76 μm ± 0.70 μm. The SWCNTs were reported by the authors to have "a relatively high degree of crystallinity". The authors reported a….decrease in cell proliferation and survival (125 and 150 μg/ml), increase in reactive oxygen species production (at all concentrations) and Hsp70 induction (at all concentrations)."

As taken from Binderup et al. 2013.

/ALTERNATIVE and IN VITRO TESTS/ ... The impact of /carbon/ single-walled nanotubes (SWNT) on rat aortic smooth muscle cells (SMC) was examined for SWNT (0.0-0.1 mg/mL) over a 3.5-day time-course. Cell culture medium was filtered to remove the aggregate material and both nanomaterial (un-filtered) and filtered SWNT media were used to examine cell growth. In general, the removal of SWNT aggregates from cell culture test medium by filtration increased the SMC number in comparison to unfiltered medium at pre-filtered SWNT dosages below 0.1 mg/mL. However, at 0.1 mg/mL, both filtered and unfiltered media exhibited a similar decrease in cell number relative to the control medium. The filtered medium was characterized and contained both suspended nanoparticles as well as a small quantity of SWNT, which may have contributed to the observed cell growth inhibition. As a comparison to the SWNT, activated carbon (0.1 mg/mL), a nanoporous, microparticulate carbon material, was found to be less inhibitory to SMC growth than the SWNT at the same dosage, implying an inverse proportionality between carbon nanomaterial size regimes and cell growth inhibition. [Raja PM et al; Toxicol Lett 169 (1): 51-63 (2007)] **PEER REVIEWED**

As taken from HSDB, 2009

"Carbon nanotubes (CNTs) have been used in orthopaedic applications because of their exceptional mechanical properties. However, the influence of CNTs on the behaviour of bone-forming cells and on the ability of these cells to respond to growth factors, such as bone

morphogenetic proteins (BMPs), remains poorly known. Therefore, in the present study, single-walled CNTs (SWCNTs) were synthesised using an induction thermal plasma process and purified using a multistep procedure. The impact of these purified SWCNTs on the Smad activation, cell proliferation and differentiation, with or without BMP-2 and BMP-9 (1.92 nM), was also studied using western blot, mitochondrial enzymatic activity, TUNEL, RT-PCR and alkaline phosphatase activity analyses. Pre-treatment of MC3T3-E1 preosteoblasts with SWCNTs accelerated the Smad1/5/8 activation, induced by both BMP-2 and BMP-9, within 15 min. It also slightly affected their proliferation at 48 h without apoptosis. Interestingly, at 72 h, BMP-9 favoured the differentiation of MC3T3-E1 preosteoblasts pretreated with SWCNTs to a larger extent than BMP-2 did. Therefore, the combination of BMP-9 with SWCNTs appears to be a promising avenue for bone applications." As taken from Alinejad Y et al. 2013. J. Biomed. Nanotechnol. 9(11), 1904-13. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24059089?dopt=AbstractPlus

"BACKGROUND: Differences in interlaboratory research protocols contribute to the conflicting data in the literature regarding engineered nanomaterial (ENM) bioactivity. OBJECTIVES: Grantees of a National Institute of Health Sciences (NIEHS)-funded consortium program performed two phases of in vitro testing with selected ENMs in an effort to identify and minimize sources of variability. METHODS: Consortium program participants (CPPs) conducted ENM bioactivity evaluations on zinc oxide (ZnO), three forms of titanium dioxide (TiO2), and three forms of multiwalled carbon nanotubes (MWCNTs). In addition, CPPs performed bioassays using three mammalian cell lines (BEAS-2B, RLE-6TN, and THP-1) selected in order to cover two different species (rat and human), two different lung epithelial cells (alveolar type II and bronchial epithelial cells), and two different cell types (epithelial cells and macrophages). CPPs also measured cytotoxicity in all cell types while measuring inflammasome activation [interleukin-1β (IL-1β) release] using only THP-1 cells. RESULTS:….MWCNTs did not produce cytotoxicity, but stimulated lower levels of IL-1β production in THP-1 cells, with the original MWCNT producing the most IL-1β. CONCLUSIONS: The results provide justification for the inclusion of mechanism-linked bioactivity assays along with traditional cytotoxicity assays for in vitro screening. In addition, the results suggest that conducting studies with multiple relevant cell types to avoid false-negative outcomes is critical for accurate evaluation of ENM bioactivity." As taken from Xia T et al. 2013. Environ. Health Perspect. 121(6), 683-90. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23649538

"The applicability of rat precision-cut lung slices (PCLuS) in detecting nanomaterial (NM) toxicity to the respiratory tract was investigated evaluating sixteen OECD reference NMs (TiO_2, ZnO, CeO_2, SiO_2, Ag, multi-walled carbon nanotubes (MWCNTs)). Upon 24-hour test substance exposure, the PCLuS system was able to detect early events of NM toxicity: total protein, reduction in mitochondrial activity, caspase-3/-7 activation, glutathione depletion/increase, cytokine induction, and histopathological evaluation. Ion shedding NMS (ZnO and Ag) induced severe tissue destruction detected by the loss of total protein. Two anatase TiO_2 NMs, CeO_2 NMs, and two MWCNT caused significant (determined by trend analysis) cytotoxicity in the WST-1 assay. At non-cytotoxic concentrations, different TiO_2 NMs and one MWCNT increased GSH levels, presumably a defense response to reactive oxygen species, and these substances further induced a variety of cytokines. One of the SiO_2 NMs increased caspase-3/-7 activities at non-cytotoxic levels, and one rutile TiO_2 only induced cytokines. Investigating these effects is, however, not sufficient to predict apical effects found in vivo. Reproducibility of test substance measurements was not fully satisfactory, especially in the GSH and cytokine assays. Effects were frequently observed in negative controls pointing to tissue slice vulnerability even though prepared and handled with utmost care. Comparisons of the effects observed in the PCLuS to in vivo effects reveal some concordances for the metal oxide NMs, but less so for the MWCNT. The highest effective dosages, however, exceeded those reported for rat short-term inhalation studies." As taken from Sauer UG et al. 2014. Toxicol. Appl. Pharmacol. 276(1), 1-20. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24382512

"BACKGROUND: SEVERAL PROPERTIES OF MULTI-WALLED CARBONNANOTUBES (MWCNT) HAVE THE POTENTIAL TO AFFECT THEIR BIOACTIVITY. This study examined the in

vitro and in vivo outcomes of the influence of diameter, length, purification and carboxylation (in vitro testing only) of MWCNT. METHODS: Three original 'as received' MWCNT that varied in size (diameter and length) were purified and functionalized by carboxylation. The resulting MWCNT were characterized and examined for cytotoxicity and inflammasome activation in vitro using THP-1 cells and primary alveolar macrophages from C57BL/6 mice. Oropharyngeal aspiration administration was used to deliver original MWCNT and in vivo bioactivity and lung retention was examined at 1 and 7 days. RESULTS: Studies with THP-1 macrophages demonstrated that increased length or diameter corresponded with increased bioactivity as measured by inflammasome activation. Purification had little effect on the original MWCNT, and functionalization completely eliminated bioactivity. Similar results were obtained using alveolar macrophages isolated from C57BL/6 mice…." As taken from Hamilton RF Jr et al. 2013. Part. Fibre Toxicol. 10(1), 57. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24225053

"Double-walled carbon nanotubes (DWCNT) are a rather new and unexplored variety of carbon nanotubes. Previously conducted studies established that exposure to a variety of carbon nanotubes produced lung inflammation and fibrosis in mice after pharyngeal aspiration. However, the bioactivity of double-walled carbon nanotubes (DWCNT) has not been determined. In this study, the hypothesis that DWCNT would induce pulmonary toxicity was explored by analyzing the pulmonary bioactivity of DWCNT. To test this hypothesis, C57Bl/6 mice were exposed to DWCNT by pharyngeal aspiration. Mice underwent whole-lung lavage (WLL) to assess pulmonary inflammation and injury, and lung tissue was examined histologically for development of pulmonary disease as a function of dose and time…DWCNT exposure also produced a dose-dependent rise in lactate dehydrogenase (LDH) activity, as well as albumin levels, in WLL fluid, indicating that DWCNT exposure promoted cytotoxicity as well as decreases in the integrity of the blood-gas barrier in the lung, respectively…." As taken from Sager TM et al. 2013. J. Toxicol. Environ. Health A. 76(15), 922-36. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24156695

"The intranasal drug delivery route provides exciting expectations regarding the application of engineered nanomaterials as nano-medicines or drug-delivery vectors into the brain. Among nanomaterials, multiwalled CNTs (MWCNTs) are some of the best candidates for brain cancer therapy since they are well known to go across cellular barriers and display an intrinsic ability to block cancer cell proliferation triggering apoptosis. This study reveals that microglial cells, the brain macrophages and putative vehicles for MWCNTs into the brain, undergo a dose-dependent cell division arrest and apoptosis when treated with MWCNTs. Moreover, it is shown that MWCNTs severely interfere with both cell migration and phagocytosis in live microglia. These results lead to a re-evaluation of the safety of inhaled airborne CNTs and provide strategic clues of how to biocompatibilize MWCNTs to reduce brain macrophage damage and to develop new nanodrugs." As taken from Villegas JC et al. 2014. Adv. Healthc. Mater. 3(3), 424-32. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23950018

"Background: nanotechnology, particularly the use of multi-walled carbon nanotubes (mwcnt), is a rapidly growing discipline with implications for advancement in a variety of fields. A major route of exposure to MWCNT during both occupational and environmental contact is inhalation. While many studies showed adverse effects to the vascular endothelium upon MWCNT exposure, in vitro results often do not correlate with in vivo effects. This study aimed to determine if an alveolar-capillary co-culture model could determine changes in the vascular endothelium after epithelial exposure to MWCNT. METHODS: A co-culture system in which both human small airway epithelial cells and human microvascular endothelial cells were separated by a Transwell membrane so as to resemble an alveolar-capillary interaction was used. Following exposure of the epithelial layer to MWCNT, the effects to the endothelial barrier were determined. RESULTS: Exposure of the epithelial layer to MWCNT induced multiple changes in the endothelial cell barrier, including an increase in reactive oxygen species, actin rearrangement, loss of VE-cadherin at the cell surface, and an increase in endothelial angiogenic ability. Overall increases in secreted VEGFA, sICAM-1, and sVCAM-1 protein levels, as well as increases in intracellular phospho-NF-κB, phospho-Stat3, and phospho-p38 MAPK, were also noted in HMVEC after epithelial exposure. CONCLUSION: The

co-culture system identified that alveolar-capillary exposure to MWCNT induced multiple changes to the underlying endothelium, potentially through cell signaling mediators derived from MWCNT-exposed epithelial cells. Therefore, the co-culture system appears to be a relevant in vitro method to study the pulmonary toxicityof MWCNT." As taken from Snyder-Talkington BN et al. 2013b. Part. Fibre Toxicol. 10, 35. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23903001

"OBJECTIVE: To compare the cytotoxicity and dna strand breakage induced by multi-walled carbonnanotubes (mwcnts) with different lengths and different surface modifications in human alveolar type ii cells (A549 CELLS). METHODS: TWO DIFFERENT LENGTHS (5-15 μm, 350-700 nm) of MWCNTs and three different kinds of surface modified MWCNTs (COOH-MWCNTs, NH2-MWCNTs, and Tau-MWCNTs) were used in the experiments. The short MWCNTs were used as pristine MWCNTs to compare with the 3 surface modified MWCNTs. The cytotoxicity was determined by cell counting kit-8 (CCK-8) assay at the concentrations of 2, 8, and 32 mg/L at hours 12, 24, 36, and 48 respectively. Single cell gel electrophoresis (SCGE) assay was performed to evaluate DNA strand breakage in A549 cells after 24 h treatment of 8 mg/L of each tested material. RESULTS: Long multi-walledcarbonnanotubes (Long-MWCNTs) and short multi-walledcarbon nanotubes (Short-MWCNTs) showed a dose-dependent cytotoxicity within the exposure time 12-48 h. Especially, Long-MWCNTs showed greater cytotoxicity than Short-MWCNTs from 24 to 48 h at the same concentration. The relative cell viability of the 3 surface modified MWCNTs was higher than that of the pristine MWCNTs at h 12 at the concentration of 32 mg/L [COOH-MWCNTs (86.55±1.80)%, NH2-MWCNTs (84.67±1.32)%, Tau-MWCNTs (80.15±3.53)% and Pristine-MWCNTs (71.44±5.58)%], at h 24 at the concentration of 8 mg/L [COOH-MWCNTs (96.74±1.00)%, NH2-MWCNTs (96.74±3.35)%, Tau-MWCNTs (106.39±3.83)% and Pristine-MWCNTs (91.02±2.53)%], at h 24 at the concentration of 32 mg/L [COOH-MWCNTs (80.88±2.67)%, NH2-MWCNTs (82.90±3.25)%, Tau-MWCNTs (82.55±3.32)% and Pristine-MWCNTs (76.08±4.27)%] and at h 36 at the concentration of 8 mg/L [COOH-MWCNTs (96.87±1.05)%, NH2-MWCNTs (96.66±4.76)%, Tau-MWCNTs (100.23± 2.84)% and Pristine-MWCNTs (89.61±3.78)%], and the differences were statistically significant ($P<0.05$). Compared with the Pristine-MWCNTs, the relative cell viability of the 3 surface modified MWCNTs didn't demonstrate a statistically significant difference ($P>0.05$) at other observation time and exposure concentrations. The DNA strand breakage of the 3 surface modified MWCNTs: the Olive tail moment of COOH-MWCNTs was 1.56±0.22, the Olive tail moment of NH2-MWCNTs 2.25±1.62 and the Olive tail moment of Tau-MWCNTs 2.23±0.94; the tail DNA% of COOH-MWCNTs was (3.96± 0.60)%, the tail DNA% of NH2-MWCNTs (6.16±4.68)% and the tail DNA% of Tau-MWCNTs (6.05±2.31)%, which were lower than that of the pristine MWCNTs ($P<0.05$), whose Olive tail moment was 3.00±0.64 and tail DNA% (8.23±2.27)%. Moreover, the COOH-MWCNTs induced the lowest DNA damage among the three modified MWCNTs. CONCLUSION: Long-MWCNTs compared with Short-MWCNTs demonstrated a greater cytotoxicity and lower DNA strand breakage damage. The surface modifications of MWCNTs can reduce the cytotoxicity and DNA strand breakage in A549 cells." As taken from Pu J et al. 2013.Beijing Da Xue Xue Bao. 45(3), 405-11. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23774918

"The growing use of engineered nanoparticles (NPs) in commercial and medical applications raises the urgent need for tools that can predict NP toxicity. Global transcriptome and proteome analyses were conducted on three human cell types, exposed to two high aspect ratio NP types, to identify patterns of expression that might indicate high versus low NP toxicity. Three cell types representing the most common routes of human exposure to NPs, including macrophage-like (THP-1), small airway epithelial and intestinal (Caco-2/HT29-MTX) cells, were exposed to TiO2 nanobelts (TiO2-NB; high toxicity) and multi-walled carbon nanotubes (MWCNT; low toxicity) at low (10 μg/mL) and high (100 μg/mL) concentrations for 1 and 24 h. Unique patterns of gene and protein expressions were identified for each cell type, with no differentially expressed ($p < 0.05$, 1.5-fold change) genes or proteins overlapping across all three cell types. While unique to each cell type, the early response was primarily independent of NP type, showing similar expression patterns in response to both TiO2-NB and MWCNT. The early response might, therefore, indicate a general response to

insult. In contrast, the 24 h response was unique to each NP type. The most significantly ($p < 0.05$) enriched biological processes in THP-1 cells indicated TiO2-NB regulation of pathways associated with inflammation, apoptosis, cell cycle arrest, DNA replication stress and genomic instability, while MWCNT-regulated pathways indicated increased cell proliferation, DNA repair and anti-apoptosis. These two distinct sets of biological pathways might, therefore, underlie cellular responses to high and low NP toxicity, respectively." As taken from Tilton SC et al. 2014. Nanotoxicology 8, 533-48. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23659652

"Nanoparticles (NPs) can cause respiratory and cardiovascular problems, furthermore small carboxyl polystyrene NPs induce hemolysis, activate platelets and induce inflammation in human blood. Carbon nanoparticles (CNPs) are known to interfere with cellular metabolism, specific cellular functions and moreover may cause cellular toxicity. We aimed to study the influence of CNPs on oxidative stress, mitochondrial membrane damage and intracellular gene expression in human mesenchymal stem cells (hMSCs). CNPs cause a dose and time dependent growth inhibition in hMSCs at a dose range from 50 to 400µg/mL. Exposure of CNPs toxic doses viz., 50µg/mL (D1) and 100µg/mL (D2) decreased intracellular mitochondrial membrane potential compared to control. CNPs treated cells were found to lose their morphology due to cell membrane damage have been confirmed by propidium iodide staining and fluorescence microscopic analysis. Oxidative stress responsive genes like GSTM3 and GSR1 expression have increased a fold when compared to control, interim there is no change were observed in SOD and GPx. We found an increased expression of CYP1A and POR genes by at least 2- fold, which is involved in mitochondrial trans-membrane potential. In conclusion, routine and high exposure of CNPs to hMSCs increased oxidative stress and mitochondrial membrane damage." As taken from Alshatwi AA et al. 2013. Environ. Toxicol. Pharmacol. 36(1), 215-22. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23624273

"With the advancements in nanotechnology, studies on the synthesis, modification, application, and toxicology evaluation of nanomaterials are gaining increased attention. In particular, the applications of nanomaterials in biological systems are attracting considerable interest because of their unique, tunable, and versatile physicochemical properties. Artificially engineered nanomaterials can be well controlled for appropriate usage, and the tuned physicochemical properties directly influence the interactions between nanomaterials and cells. This review summarizes recently synthesized major nanomaterials that have potential biomedical applications. Focus is given on the interactions, including cellular uptake, intracellular trafficking, andtoxic response, while changing the physicochemical properties of versatile materials. The importance of physicochemical properties such as the size, shape, and surface modifications of the nanomaterials in their biological effects is also highlighted in detail…." As taken from Cheng LC et al. 2013. Nanoscale 5(9), 3547-69. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23532468

"In order to study the effects of nanoparticles (NPs) with different physicochemical properties on cellular viability and structure, Saccharomyces cerevisiae were exposed to different concentrations of TiO2-NPs (1-3 nm), ZnO-NPs (<100 nm), CuO-NPs (<50 nm), their bulk forms, Ag-NPs (10 nm) and single-walled carbon nanotubes (SWCNTs). The GreenScreen assay was used to measure cyto- and genotoxicity, and transmission electron microscopy (TEM) used to assess ultrastructure. CuO-NPs were highly cytotoxic, reducing the cell density by 80% at 9 cm(2)/ml, and inducing lipid droplet formation. Cells exposed to Ag-NPs (19 cm(2)/ml) and TiO2-NPs (147 cm(2)/ml) contained dark deposits in intracellular vacuoles, the cell wall and vesicles, and reduced cell density (40 and 30%, respectively). ZnO-NPs (8 cm(2)/ml) caused an increase in the size of intracellular vacuoles, despite not being cytotoxic. SWCNTs did not cause cytotoxicity or significant alterations in ultrastructure, despite high oxidative potential…." As taken from Bayat N et al. 2014. Nanotoxicology 8, 363-73. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23521755

"Single-wall carbon nanotubes (SWCNTs) and polyamidoamine dendrimers (PAMAM) have been proposed for a variety of biomedical applications. The combination of both molecules makes this

new composite nanomaterial highly functionalizable and versatile to theranostic and drug-delivery systems. However, recent toxicological studies have shown that nanomaterials such as SWCNTs and PAMAM may have high toxicity in biological environments. Aiming to elucidate such behavior, in vitro studies with different cultured cells have been conducted in the past few years. This study focuses on the effects of SWCNT-PAMAM nanomaterials and their individual components on the C2C12 murine cell line, which is a mixed population of stem and progenitor cells. The interactions between the cells and the nanomaterials were studied with different techniques usually employed in toxicological analyses. The results showed that SWCNT-PAMAM and PAMAM inhibited the proliferation and caused DNA damage of C2C12 cells. Data from flow cytometry revealed a less toxicity in C2C12 cells exposed to SWCNT compared to the other nanomaterials. The results indicated that the toxicity of SWCNT, SWCNT-PAMAM and PAMAM in C2C12 cells can be strongly correlated with the charge of the nanomaterials." As taken from Cancino J et al. 2013. Toxicol. Lett. 219(1), 18-25. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23454831

….Considering the potential application of carbon as scaffold materials and the lack of understanding of compatibility of amorphouscarbon with neuronal cells, the carbon-based materials in the forms of carbon films and continuous electrospun carbon nanofibers having average diameter of ~200 nm are being investigated with or without ultraviolet (UV) and oxy-plasma (OP) treatments for cytocompatibility property using mouse Neuroblastoma (N2a) and rat Schwann cells (RT4-D6P2T). The use of Raman spectroscopy in combination with Fourier transform infrared (FTIR) and X-ray diffraction establishes the amorphous nature and surface-bonding characteristics of the studied carbon materials. Although both UV and OP treatments make carbon surfaces more hydrophilic, the cell viability of N2a cells is statistically more significant on OP treated fibers/films compared to UV fiber/film substrates after 4 days in culture. The electrospun carbon fibrous substrate provides the physical guidance to the cultured Schwann cells. Overall, the experimental results of this study demonstrate that the electrospun amorphous carbon nanofibrous scaffolds can be used as a suitable biomaterial substrate for supporting cell adhesion and proliferation of neuronal cells in the context of their applications as artificial nerve implants" As taken from Jain S et al. 2013. J. Biomed. Mater. Res. B. Appl. Biomater. 101(4), 520-31. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23359403

"Multiwalled carbon nanotubes (MWCNTs) possess unique properties rendering them a potentially useful biomaterial for neurobiological applications such as providing nanoscale contact-guidance cues for directing axon growth within peripheral nerve repair scaffolds. The in vitro biocompatibility of MWCNTs with postnatal mouse spinal sensory neurons was assessed for this application. Cell culture medium conditioned with MWCNTs was not significantly toxic to dissociated cultures of postnatal mouse dorsal root ganglia (DRG) neurons. However, exposure of DRG neurons to MWCNTs dispersed in culture medium resulted in a time- and dose-dependent reduction in neuronal viability. At 250 μg mL^{-1}, dispersed MWCNTs caused significant neuronal death and unusual neurite morphologies illustrated by immunofluorescent labelling of the cytoskeletal protein beta (III) tubulin, however, at a dose of 5 μg mL^{-1} MWCNTs were nontoxic over a 14-day period. DRG neurons grown on fabricated MWCNT substrates produced neurite outgrowths with abnormal morphologies that were significantly inferior in length to neurons grown on the control substrate laminin. This evidence demonstrates that to be utilized as a biomaterial in tissue scaffolds for nerve repair, MWCNTs will require robust surface modification to enhance biocompatibility and growth promoting properties." As taken from Gladwin KM et al. 2013. Adv. Healthc. Mater. 2(5), 728-35. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23184463

"Carbon nanotubes (CNTs) have potential as not only electrical materials but also biomedical devices. However, some findings have been reported indicating that the use of CNTs is accompanied by a risk of the development of certain diseases such as pulmonary fibrosis and pleura mesothelioma; and one of the reasons for this risk may be macrophage cell death. In the present study, to elucidate the mechanism of macrophage cell death by CNTs, we focused on biomembrane damage caused by multi-walled CNTs (MWCNTs). When the distribution of MWCNTs in RAW264 cells was observed under a light microscope, MWCNTs were located on the surface of

the plasma membrane; and a portion of them seemed to stick into it. The acute cytotoxicity toward RAW264 cells was examined by performing the LDH cytotoxic test, and LDH release was detected after exposure to 100 μg/ml CNT. To examine the physical damage to biomembranes by CNT exposure, we conducted a calcein release assay using calcein-encapsulated liposomes. The results indicated that an increase in the permeability of the lipid bilayer was induced by MWCNTs. The present study thus demonstrated for the first time that a high concentration of MWCNTs was cytotoxic to macrophages and suggested that the direct physical perturbation of biomembranes by MWCNTs plays a role in this activity." As taken from Shimizu K et al. 2013. J. Toxicol. Sci. 38(1), 7-12. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23358135

"Etoposide is a semisynthetic, chemotherapeutic drug widely recommended to treat an extensive range of human cancers. Our studies indicate that, while etoposide is capable of killing human cancer cells, exposure to single-walled carbon nanotubes (SWCNTs) and etoposide results in enhanced cell death that appears to be synergistic and not merely additive. In this study, we used high pressure liquid chromatography and mass spectrometry to quantify the internal effective dose of etoposide when the human pancreatic cancer cell (PANC-1) was exposed to the combination of these agents. Our results unequivocally indicate that SWCNTs improve etoposide uptake and increase its capacity to kill cancer cells. We suggest that a combination of SWCNTs and etoposide may prove to be a more efficient chemotherapeutic protocol, especially because of the potential to lower toxicdrug doses to levels that may be useful in decreasing adverse side effects, as well as in lowering the probability of inducing chemoresistance in exposed cancer cells." As taken from Mahmood M et al. 2013. Nanotechnology 24(4), 045102. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23291321

"Despite the great use of nanomaterials for engineering and medical applications, nanomaterials may have adverse consequences by accidental exposure, because of their nanoscale size, composition and shape. Like many nanomaterials, carbon nanotubes (CNTs) have been used for many proven applications, but the size of the CNTs makes them more readily become airborne and can therefore create the risk of being inhaled by a worker. In this study, we evaluated single-walled CNT (SWCNT)-induced effects on cellular responses such as cell proliferation, inflammatory response and oxidative stress in dynamic cell growth condition. A dynamic cell growth environment was established to mimic the dynamic changes in the amount of circumferential and longitudinal expansion and contraction occurred during normal breathing movement in the lung. Two different length (short: outer diameter (OD) 1-2 nm, length 0.5-2 μm; long: OD 1-2 nm, length 5-30 μm) of SWCNTs were used at different exposure concentrations (5, 10 and 20 μg/ml) during the different exposure duration (24, 48 and 72 h). Dynamic environment facilitated altered interaction between SWCNTs and A549 monolayer. Cellular responses in dynamic condition were significantly different from those in static condition. Moreover, cellular responses were dependent on the length of SWCNTs both in static and dynamic cell growth conditions." As taken from Patel HJ & Kwon S. 2013. J. Expo. Sci. Environ. Epidemiol. 23(1), 101-8. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/22854519

"Effects on the liver C3A cell line treated with a panel of engineered nanomaterials (NMs) consisting of two zinc oxide particles (ZnO; coated 100 nm and uncoated 130 nm), two multi-walled carbon nanotubes (MWCNTs), one silver (Ag < 20 nm), one 7 nm anatase, two rutile TiO2 nanoparticles (10 and 94 nm) and two derivatives with positive and negative covalent functionalisation of the 10 nm rutile were evaluated. The silver particles elicited the greatest level of cytotoxicity (24 h LC50 - 2 μg/cm(2)). The silver was followed by the uncoated ZnO (24 h LC50 - 7.5 μg/cm(2)) and coated ZnO (24 h LC50 - 15 μg/cm(2)) particles with respect to cytotoxicity. The ZnO NMs were found to be about 50-60% soluble which could account for their toxicity. By contrast, the Ag was <1% soluble. The LC50 was not attained in the presence of any of the other engineered NMs (up to 80 μg/cm(2)). All NMs significantly increased IL-8 production. Meanwhile, no significant change in TNF-α, IL-6 or CRP was detected. Urea and albumin production were measured as indicators of hepatic function. These markers were only altered by the coated and uncoated ZnO, which significantly decreased albumin production." As taken from Kermanizadeh A

et al. 2013. Nanotoxicology 7(3), 301-13. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/22263564

“Single walled carbon nanotubes were studied with respect to cytotoxic and genotoxic properties in cells of the gastrointestinal tract as exemplified for the human colon carcinoma cell line HT29. No effect on cell growth in the sulphorhodamine B assay was observed after 24 h of incubation, whereas growth inhibitory properties were found after 48 and 72 h. After 24 h incubation a decrease of mitochondrial activity (WST-1) was measured (≥0.1 µg/ml), whereas membrane integrity (lactate dehydrogenase) was not affected. In cytotoxic concentrations, the formation of reactive oxygen species and a slight increase of total glutathione and nuclear Nrf2 were observed….” As taken from Pelka J et al. 2013. Nanotoxicology 7(1), 2-20. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/22007624

“…Various experiments have shown that lysosomal damage is one of the main reasons for CNTs to trigger apoptosis. It has been suggested that the exposure of CNT to the cell's environment results in destabilisation of lysosomal membranes leading to apoptotic as well as necrotic cell death. Mitochondrial damage, which eventually leads to lysosomal damage, is also another way, which has been suggested by other research groups, as a method for the induction of apoptosis by the CNT exposure to the cell. The injured lysosome releases digestive enzymes, which damage entire cells…” As taken from Madani SY et al. 2013. Nano. Rev. Dec 3, 4. PubMed, 2014, available at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3851535/?report=classic

“Some studies also indicate that CNT containing certain metals (nickel, 26%) [Lam et al. 2004] or higher metal content (17.7% vs. 0.2% iron) are more cytotoxic in vitro and in vivo [Shvedova et al. 2003, 2008].”

As taken from NIOSH, 2013.

“Graphene and its derivatives are promising candidates for important biomedical applications because of their versatility. The prospective use of graphene-based materials in a biological context requires a detailed comprehension of the toxicity of these materials. Moreover, due to the expanding applications of nanotechnology, human and environmental exposures to graphene-based nanomaterials are likely to increase in the future. Because of the potential risk factors associated with the manufacture and use of graphene-related materials, the number of nanotoxicological studies of these compounds has been increasing rapidly in the past decade. These studies have researched the effects of the nanostructural/biological interactions on different organizational levels of the living system, from biomolecules to animals. This review discusses recent results based on in vitro and in vivo cytotoxicity and genotoxicity studies of graphene-related materials and critically examines the methodologies employed to evaluate their toxicities. ……..” As taken from Seabra AB et al. 2014. Chem. Res. Toxicol. 27(2), 159-168. PubMed, 2015 available at http://www.ncbi.nlm.nih.gov/pubmed/24422439

“The biomedical application of graphene quantum dots (GQDs) is a new emerging area. However, their safety data are still in scarcity to date. Particularly, the effect of GQDs on the immune system remains unknown. This study aimed to elucidate the interaction of GQDs with macrophages and the underlying mechanisms. Our results showed that GQDs slightly affected the cell viability and membrane integrity of macrophages, whereas GQDs significantly increased reactive oxygen species (ROS) generation and apoptotic and autophagic cell death with an increase in the expression level of Bax, Bad, caspase 3, caspase 9, beclin 1, and LC3-I/II and a decrease in that of Bcl-2. Furthermore, low concentrations of GQDs significantly increased the expression of tumor necrosis factor-α (TNF-α), interleukin-1β (IL-1β), IL-8, whereas high concentrations of GQDs elicited opposite effects on the cytokines production. SB202190, a selective inhibitor of p38 mitogen-activated protein kinase (MAPK), abolished the cytokine-inducing effect of GQDs in macrophages. Moreover, GQDs significantly increased the phosphorylation of p38 MAPK and p65, and promoted the nuclear translocation of nuclear factor-κB (NF-κB). Taken together, these results show that GQDs induce ROS generation, apoptosis, autophagy, and inflammatory response via p38MAPK and NF-κB mediated signaling pathways in THP-1 activated macrophages.” As taken

from Qin Y et al. 2015. Toxicology 327, 62-76. PubMed, 2016 available at http://www.ncbi.nlm.nih.gov/pubmed/25446327

“An in vitro model resembling the respiratory epithelium was used to investigate the biological response to laboratory-made pristine and functionalised multi-walled carbon nanotubes (pMWCNT and MWCNT-COOH). Cell uptake was analysed by MWCNT-COOH, FITC labelled and the effect of internalisation was evaluated on the endocytic apparatus, mitochondrial compartment and DNA integrity. In the dose range 12.5-100μgml(-1), cytotoxicity and ROS generation were assayed, evaluating the role of iron (the catalyst used in MWCNTs synthesis). We observed a correlation between MWCNTs uptake and lysosomal dysfunction and an inverse relationship between these two parameters and cell viability ($P<0.01$). In particular, pristine-MWCNT caused a time- and dose-dependent ROS increase and higher levels of lipid hydroperoxides compared to the controls. Mitochondrial impairment was observed. Conversely to the functionalised MWCNT, higher micronuclei (MNi) frequency was detected in mono- and binucleate pMWCNT-treated cells, underlining an aneugenic effect due to mechanical damage. Based on the physical and chemical features of MWCNTs, several toxicological pathways could be activated in respiratory epithelium upon their inhalation. The biological impacts of nano-needles were imputable to their efficient and very fast uptake and to the resulting mechanical damages in cell compartments. Lysosomal dysfunction was able to trigger further toxic effects.” As taken from Visalli G et al. 2015. Toxicol. In Vitro 29(2), 352-62. PubMed, 2016 available at http://www.ncbi.nlm.nih.gov/pubmed/25499066

“Long carbon nanotubes (CNTs) resemble asbestos fibers due to their high length to diameter ratio and they thus have genotoxic effects. Another parameter that might explain their genotoxic effects is contamination with heavy metal ions. On the other hand, short (1-2 μm) CNTs do not resemble asbestos fibers, and, once purified from contaminations, they might be suitable for medical applications. To identify the role of fiber thickness and surface properties on genotoxicity, well-characterized short pristine and carboxylated single-walled (SCNTs) and multi-walled (MCNTs) CNTs of different diameters were studied for cytotoxicity, the cell's response to oxidative stress (immunoreactivity against hemoxygenase 1 and glutathione levels), and in a hypoxanthine guanine phosphoribosyltransferase (HPRT) assay using V79 chinese hamster fibroblasts and human lung adenocarcinoma A549 cells. DNA repair was demonstrated by measuring immunoreactivity against activated histone H2AX protein. The number of micronuclei as well as the number of multinucleated cells was determined. CNTs acted more cytotoxic in V79 than in A549 cells. Plain and carboxylated thin (<8 nm) SCNTs and MCNTs showed greater cytotoxic potential and carboxylated CNTs showed indication for generating oxidative stress. Multi-walled CNTs did not cause HPRT mutation, micronucleus formation, DNA damage, interference with cell division, and oxidative stress. Carboxylated, but not plain, SCNTs showed indication for in vitro DNA damage according to increase of H2AX-immunoreactive cells and HPRT mutation. Although short CNTs presented a low in vitro genotoxicity, functionalization of short SCNTs can render these particles genotoxic.” As taken from Mrakovcic M et al. 2015. Toxicol. Sci. 144(1), 114-27. PubMed, 2016 available at http://www.ncbi.nlm.nih.gov/pubmed/25505129

“Recent research on porous silica materials as drug carriers for amorphous and controlled drug delivery has shown promising results. However, due to contradictory literature reports on toxicity and high costs of production, it is important to explore alternative safe and inexpensive porous carriers. In this study, the potential of activated carbon (AC) as an amorphous drug carrier was investigated using paracetamol (PA) and ibuprofen (IBU) as model drugs. The solution impregnation method was used for drug loading, with loading efficiency determined by UV spectroscopy and drug release kinetics studied using USP II dissolution apparatus. The physical state of the drug in the complex was characterised using differential scanning calorimetry and X-ray diffractions techniques, whilst sites of drug adsorption were studied using Fourier transform infrared spectroscopy and N_2 adsorption techniques. In addition, the cytotoxicity of AC on human colon carcinoma (Caco-2) cells was assessed using the MTT assay. Results presented here reveal that, for PA/AC and IBU/AC complexes, the saturation solubility of the drug in the loading solvent appears to have an effect on the drug loading efficiency and the physical state of the drug loaded,

whilst drug release kinetics were affected by the wettability of the activated carbon particles. Furthermore, activated carbon microparticles exhibited very low cytotoxicity on Caco-2 cells at the concentrations tested (10-800µg/mL). This study, therefore, supports the potential of activated carbon as a carrier for amorphous drug delivery." As taken from Miriyala N et al. 2017. Eur. J. Pharm. Biopharm. 115, 197-205. PubMed, 2018 available at https://www.ncbi.nlm.nih.gov/pubmed/28284728

"The chemical and cytotoxicity properties of fine particulate matter (PM2.5) at indoor and outdoor environment were characterized in Xi'an, China. The mass concentrations of PM2.5 in urban areas (93.29~96.13 µg m-3 for indoor and 124.37~154.52 µg m-3 for outdoor) were higher than suburban (68.40 µg m-3 for indoor and 96.18 µg m-3 for outdoor). The PM2.5 concentrations from outdoor environment due to fossil fuel combustion were higher than indoor environment. An indoor environment without central heating demonstrated higher organic carbon-to-elemental carbon (OC / EC) ratios and n-alkanes values that potentially attributed to residential coal combustion activities. The cell viability of human epithelial lung cells showed dose-dependent decrease, while nitric oxide (NO) and oxidative potential showed dose-dependent increase under exposure to PM2.5. The variations of bioreactivities could be possibly related to different chemical components from different sources. Moderate (0.4 < R < 0.6) to strong (R > 0.6) correlations were observed between bioreactivities and elemental carbon (EC)/secondary aerosols (NO3-, SO42-, and NH4+)/heavy metals (Ni, Cu, and Pb). The findings suggest PM2.5 is associated with particle induced oxidative potential, which are further responsible for respiratory diseases under chronic exposure." As taken from Niu X et al. 2019. Environ. Sci. Pollut. Int. 26(31), 31913-31923. PubMed, 2020 available at https://pubmed.ncbi.nlm.nih.gov/31489544/

"Direct evidence about associations between fine particles (PM2.5) components and the corresponding PM2.5 bioreactivity at the individual level is limited. We conducted a panel study with repeated personal measurements involving 56 healthy residents in Hong Kong. Fractional exhaled nitric oxide (FeNO) levels were measured from these subjects. Out of 56 subjects, 27 (48.2%) participated in concurrent outdoor, indoor, and personal PM2.5 monitoring. Organic carbon (OC), elemental carbon (EC), particle bound-polycyclic aromatic hydrocarbons (PAHs), and phthalates were analyzed. Alteration in cell viability, lactic dehydrogenase (LDH), interleukin-6 (IL-6), and 8-isoprostane by 50 µg/mL PM2.5 extracts was determined in A549 cells in vitro. Moderate heterogeneities were shown in PM2.5 exposures and the corresponding PM2.5 bioreactivity across different sample types. Associations between the analyzed components and PM2.5 bioreactivity were assessed using the multiple regression models. Toxicological results revealed that indoor and personal exposure to OC as well as PAH compounds and their derivatives (e.g., Alkyl-PAHs, Oxy-PAHs) induced cell viability reduction and increase in levels of LDH, IL-6, and 8-isoprostane. Overall, OC in personal exposure played a dominant role in PM2.5-induced bioreactivity. Subsequently, we examined the associations of FeNO with IL-6 and 8-isoprostane levels using mixed-effects models. The results showed that per interquartile change in IL-6 and 8-isoprostane were associated with a 6.4% ($p < 0.01$) and 11.1% ($p < 0.01$) increase in FeNO levels, respectively. Our study explored the toxicological properties of chemical components in PM2.5 exposure, which suggested that residential indoors and personal OC and PAHs should be of great concern for human health. These findings indicated that further studies in inflammation and oxidative stress-related illnesses due to particle exposure would benefit from the assessment of in vitro PM2.5 bioreactivity." As taken from Chen XC et al. 2020. Environ. Res. 188, 109780. PubMed, 2021 available at https://pubmed.ncbi.nlm.nih.gov/32554275/

5.6. Carcinogenicity

Dermal carcinogenicity was evaluated in groups of male C3H/HeJ mice (40/group) receiving 25ul applications of either CF carbon fibers (100% carbon), MAT carbon fibers (98% carbon), PAN carbon fibers (94% carbon) or PAN oxidized carbon fibers (64% carbon) suspended in benzene to the skin of the back three times weekly until death, beginning at age 51 to 76 days. The mean

survival time of the CF carbon fibers treatment group and the PAN oxide treatment group were significantly greater ($p < 0.05$) than the solvent control group. In the CF carbon fiber treatment group, one mouse was observed with a papilloma on the skin of the back, and one mouse diagnosed with a squamous cell carcinoma on the skin of the back, and a third was diagnosed with an hemangiosarcoma in the subcutis of the right side. In the PAN oxidized treatment group, one mouse was diagnosed with a leiomyosarcoma of the skin and subcutis of the shoulder. The mean survival time of the MAT carbon fiber treatment group was 518 days. In the MAT carbon fiber treatment group, one mouse was observed with a squamous cell carcinoma of the skin in the inguinal region, one with fibrosarcomas on the skin of the axilla and one with a hemangiosarcoma in the subcutis of the abdomen. No skin or subcutaneous tumors were observed in the PAN carbon fiber treatment group and mean survival time was 522 days. The solvent control (benzene) group had a mean survival time of 435 days and no tumors were observed. [Bushy Run Research Center: Evaluation of the Dermal Carcinogenicity of Four Carbon Fiber Materials in Male C3H/HeJ Mice, Final Report, (1982), EPA Document No. 88-8200392, Fiche No. OTS0503334] **UNREVIEWED**

EPIDEMIOLOGY STUDIES/ /The objective was/ to investigate the risk of cancer and non-neoplastic respiratory diseases among workers who manufacture carbon electrodes, as this industry entails exposure to mixtures of polycyclic aromatic hydrocarbons. ... A historical cohort study was carried out of 1006 male workers employed for at least 1 year between 1945 and 1971 in a carbon (graphite) electrode production plant in central Italy, who were followed up for mortality between 1955 and 1996. The ratio of observed to expected deaths (standardised mortality ratios, SMRs) was computed from both national and (for the period 1964-96) regional age and period specific mortalities. A multivariate Poisson regression analysis was performed to investigate the relative risk (RR) of death according to duration of employment and time since first employment in the factory. ... A total of 424 workers had died, 538 were still alive, and 44 were lost to follow up. Mortalities from all causes, all cancers, and respiratory tract cancer were in line with the regional figure. An excess was found over the expected deaths from skin cancer including melanoma (SMR 3.16, 95% confidence interval (95% CI) 0.65 to 9.23) and from non-neoplastic respiratory diseases (SMR 1.58, 95% CI 1.16 to 2.11). Poisson regression analysis including age as a covariate showed an increased risk of dying from gastric cancer with increasing duration of employment, and an increase in the RR of dying from lung cancer and from non-neoplastic respiratory diseases with increasing time since first employment, although the linear trend was not significant. ... This study supports previous findings that working in the carbon electrode manufacturing industry may not increase the risk of dying from respiratory cancer.

As taken from HSDB, 2009

Tumor Inhibition Studies:

Species:	RAT
Number of Animals Tested:	(21,14)/(21,13)
Strain/Sex:	LIO/FEMALE
Dose (Inhibitor):	100 MG/KG BW AQUALEN (ACTIVATED CARBON FIBER ADSORBENT) IN DIET 5X/WK FOR 16 MONTHS (STUDY DURATION: 16 MONTHS)
Route (Inhibitor):	ORAL

Carcinogen:	N-METHYL-N'-NITRO-N-NITROSOGUANIDINE [70-25-7]
Route (Carcinogen):	ORAL
Dose (Carcinogen):	100 MG/L IN DRINKING WATER 5X/WK FOR 12 MONTHS (STUDY DURATION: 16 MONTHS)
Promoter:	NONE
Target Tissue: Type of Lesion:	STOMACH: CARCINOMA IN SITU
Endpoint (Incidence):	1/14 (7.1%), 4/13 (30.8%), -334%, NOT SIGNIFICANT
Reference:	[ANISIMOV,VN ZABEZHINSKI,MA POPOVICH,IG LIEBERMAN,AI AND SHMIDT,JL; PREVENTION OF SPONTANEOUS AND CHEMICALLY INDUCED CARCINOGENESIS USING ACTIVATED CARBON FIBER ADSORBENT. II.INHIBITORY EFFECT OF THE ACTIVATED CARBON FIBER ADSORBENT 'AQUALEN' ON N-METHYL-N'-NITRO-N-NITROSOGUANIDINE-INDUCED GASTRIC CARCINOGENESIS IN RATS; CANCER LETT. (SHANNON, IREL.) 138(1-2):23-26, 1999]
Species:	RAT
Number of Animals Tested:	(21,14)/(21,13)
Strain/Sex:	LIO/FEMALE
Dose (Inhibitor):	100 MG/KG BW AQUALEN (ACTIVATED CARBON FIBER ADSORBENT) IN DIET 5X/WK FOR 16 MONTHS (STUDY DURATION: 16 MONTHS)
Route (Inhibitor):	ORAL
Carcinogen:	N-METHYL-N'-NITRO-N-NITROSOGUANIDINE [70-25-7]
Route (Carcinogen):	ORAL
Dose (Carcinogen):	100 MG/L IN DRINKING WATER 5X/WK FOR 12 MONTHS (STUDY DURATION: 16 MONTHS)
Promoter:	NONE
Target Tissue: Type of Lesion:	STOMACH: INVASIVE ADENOCARCINOMA
Endpoint (Incidence):	5/14 (35.7%), 1/13 (7.7%), 78%, P<0.05
Reference:	[ANISIMOV,VN ZABEZHINSKI,MA POPOVICH,IG LIEBERMAN,AI AND SHMIDT,JL; PREVENTION OF SPONTANEOUS AND CHEMICALLY INDUCED CARCINOGENESIS USING ACTIVATED CARBON FIBER ADSORBENT. II.INHIBITORY EFFECT OF THE ACTIVATED CARBON FIBER ADSORBENT 'AQUALEN' ON N-METHYL-N'-NITRO-N-NITROSOGUANIDINE-INDUCED GASTRIC CARCINOGENESIS IN RATS; CANCER LETT. (SHANNON, IREL.) 138(1-2):23-26, 1999]

Species:	RAT
Number of Animals Tested:	(21,14)/(21,13)
Strain/Sex:	LIO/FEMALE
Dose (Inhibitor):	100 MG/KG BW AQUALEN (ACTIVATED CARBON FIBER ADSORBENT) IN DIET 5X/WK FOR 16 MONTHS (STUDY DURATION: 16 MONTHS)
Route (Inhibitor):	ORAL
Carcinogen:	N-METHYL-N'-NITRO-N-NITROSOGUANIDINE [70-25-7]
Route (Carcinogen):	ORAL
Dose (Carcinogen):	100 MG/L IN DRINKING WATER 5X/WK FOR 12 MONTHS (STUDY DURATION: 16 MONTHS)
Promoter:	NONE
Target Tissue: Type of Lesion:	DUODENUM: ADENOCARCINOMA
Endpoint (Incidence):	2/14 (14.3%), 0/13 (0.0%), 100%, NOT SIGNIFICANT
Reference:	[ANISIMOV,VN ZABEZHINSKI,MA POPOVICH,IG LIEBERMAN,AI AND SHMIDT,JL; PREVENTION OF SPONTANEOUS AND CHEMICALLY INDUCED CARCINOGENESIS USING ACTIVATED CARBON FIBER ADSORBENT. II.INHIBITORY EFFECT OF THE ACTIVATED CARBON FIBER ADSORBENT 'AQUALEN' ON N-METHYL-N'-NITRO-N-NITROSOGUANIDINE-INDUCED GASTRIC CARCINOGENESIS IN RATS; CANCER LETT. (SHANNON, IREL.) 138(1-2):23-26, 1999]
Species:	RAT
Number of Animals Tested:	(21,14)/(21,13)
Strain/Sex:	LIO/FEMALE
Dose (Inhibitor):	100 MG/KG BW AQUALEN (ACTIVATED CARBON FIBER ADSORBENT) IN DIET 5X/WK FOR 16 MONTHS (STUDY DURATION: 16 MONTHS)
Route (Inhibitor):	ORAL
Carcinogen:	N-METHYL-N'-NITRO-N-NITROSOGUANIDINE [70-25-7]
Route (Carcinogen):	ORAL
Dose (Carcinogen):	100 MG/L IN DRINKING WATER 5X/WK FOR 12 MONTHS (STUDY DURATION: 16 MONTHS)
Promoter:	NONE

Target Tissue: Type of Lesion:	LIVER: CYSTOCHOLANGIOMA
Endpoint (Incidence):	2/14 (14.3%), 0/13 (0.0%), 100%, NOT SIGNIFICANT
Reference:	[ANISIMOV,VN ZABEZHINSKI,MA POPOVICH,IG LIEBERMAN,AI AND SHMIDT,JL; PREVENTION OF SPONTANEOUS AND CHEMICALLY INDUCED CARCINOGENESIS USING ACTIVATED CARBON FIBER ADSORBENT. II.INHIBITORY EFFECT OF THE ACTIVATED CARBON FIBER ADSORBENT 'AQUALEN' ON N-METHYL-N'-NITRO-N-NITROSOGUANIDINE-INDUCED GASTRIC CARCINOGENESIS IN RATS; CANCER LETT. (SHANNON, IREL.) 138(1-2):23-26, 1999]

As taken from CCRIS, 2010.

“One of the key obstacles against the success in cancer chemotherapy is the toxic and side effects of the chemotherapeutic agents. The avoidance of these toxic and side effects will greatly improve the therapeutic effects of anticancer drugs while decrease the pains of the patients. Here we show that activated carbon nanoparticles (ACNP), one of the mesoporous nanoparticles, can decrease the genotoxicity and teratogenicity of mitomycin C (MMC). To study the effects of ACNP on genotoxicity and teratogenicity of MMC, methods of PCE micronucleus test, Chinese hamster lung cell chromosome aberration experiment and rat teratogenicity were employed to observe the differences in genotoxicity and teratogenicity between ACNP-adsorbed MMC (ACNP-MMC) and free MMC. Results demonstrated that free MMC 0.16-5.0 microg/kg significantly increased the positive rate of PCE micronucleus test, the chromosome aberration rate and rat teratogenecity, but ACNP-MMC did not increase these heredity and reproduction toxicological indexes in a dose range of 0.625-10.0 microg/kg. From these results, it can be concluded that ACNP-MMC have significant effects to decrease the genotoxicity and teratogenicity effects of MMC. These results will have a considerable impact on the strategy of anticancer chemotherapy”. Zhong et al. 2010). Journal of Nanoscience and Nanotechnology 10, 8603-8609). As taken from http://www.ncbi.nlm.nih.gov/pubmed/21121372

“Etoposide is a semisynthetic, chemotherapeutic drug widely recommended to treat an extensive range of human cancers. Our studies indicate that, while etoposide is capable of killing human cancer cells, exposure to single-walled carbon nanotubes (SWCNTs) and etoposide results in enhanced cell death that appears to be synergistic and not merely additive. In this study, we used high pressure liquid chromatography and mass spectrometry to quantify the internal effective dose of etoposide when the human pancreatic cancer cell (PANC-1) was exposed to the combination of these agents. Our results unequivocally indicate that SWCNTs improve etoposide uptake and increase its capacity to kill cancer cells. We suggest that a combination of SWCNTs and etoposide may prove to be a more efficient chemotherapeutic protocol, especially because of the potential to lower toxicdrug doses to levels that may be useful in decreasing adverse side effects, as well as in lowering the probability of inducing chemoresistance in exposed cancer cells.” As taken from Mahmood M et al. 2013. Nanotechnology 24(4), 045102. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23291321

“The aim of this study was to investigate the potential toxic mechanisms associated with multiwall carbon nanotubes (MWCNT) in normal mouse lung. A total of 100 μg of two types of MWCNT, namely, pristine MWCNT (PMWCNT) and acid-treated-MWCNT (TMWCNT), was administered to male C57BL/6 mice via intratracheal (IT) instillation for a period of 6 mo. Our results indicated that PMWCNT induced pulmonary autophagy accumulation and resulted in more potent tumorigenic effects compared to TMWCNT. Accordingly, MWCNT may exert differential toxicity attributed to various physicochemical properties. Data emphasize the need for careful regulation of production and use of CNT.” As taken from Yu KN et al. 2013. J. Toxicol. Environ. Health A. 76(23), 1282-92. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24283420

“Background: diesel engine exhaust (dee) has recently been classified as a known human carcinogen. objective: to derive a meta-exposure-response curve (erc) for dee and lungcancermortality and estimate lifetime excess risks (elrs) of lungcancermortality based on assumed occupational and environmental exposure scenarios. methods: we conducted a meta-regression of lungcancermortality and cumulative exposure to elementalcarbon(ec), a proxy measure of dee, based on relative risk (rr) estimates reported by three large occupational cohort studies (including two studies of workers in the trucking industry and one study of miners). Based on the derived risk function, we calculated ELRs for several lifetime occupational and environmental exposure scenarios, and also calculated the fractions of annual lungcancerdeaths attributable to DEE. RESULTS: We estimated a lnRR of 0.00098 (95% CI: 0.00055, 0.0014) for lungcancermortality with each 1-μg/m^3-year increase in cumulative EC based on a linear meta-regression model. Corresponding lnRRs for the individual studies ranged from 0.00061 to 0.0012. Estimated numbers of excess lungcancerdeaths through age 80 for lifetime occupational exposures of 1, 10, and 25 μg/m^3EC were 17, 200, and 689 per 10,000, respectively. For lifetime environmental exposure to 0.8 μg/m^3EC, we estimated 21 excess lungcancerdeaths per 10,000. Based on broad assumptions regarding past occupational and environmental exposures we estimate that approximately 6% of annual lungcancerdeaths may be due to DEE exposure. CONCLUSIONS: Combined data from three US occupational cohort studies suggest that DEE at levels common in the workplace and in outdoor air appear to pose substantial excess lifetime risks of lungcancer, above usually acceptable limits in the US and Europe, which are generally set at 1/1,000 and 1/100,000 based on lifetime exposure for the occupational and general population, respectively.” As taken from Vermeulen R et al. 2014. Environ. Health Perspect. 122(2), 172-7. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24273233

“The hallmark geometric feature of single-walled carbon nanotubes (SWCNT) and carbon nanofibers (CNF) - high length to width ratio - makes them similar to a hazardous agent - asbestos. Very limited data are available concerning long-term effects of pulmonary exposure to SWCNT or CNF. Here we compared inflammatory, fibrogenic and genotoxic effects of CNF, SWCNT or asbestos in mice one year after pharyngeal aspiration. In addition, we compared pulmonary responses to SWCNT by bolus dosing through pharyngeal aspiration and inhalation 5h/day for 4 days, to evaluate the effect of dose rate….No increased lung tumor incidence occurred after 1 year post exposure to SWCNT, CNF and asbestos. Overall, our data suggest that long-term pulmonary toxicity of SWCNT, CNF and asbestos - is defined not only by their chemical composition but also by the specific surface area and type of exposure.” As taken from Shvedova AA et al. 2014. Am. J. Physiol. Lung Cell. Mol. Physiol. 306(2), L170-82. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24213921

“Metastatic establishment and growth of Lewis lung carcinoma is promoted by single-walled carbon nanotubes (SWCNT) in C57BL6/J mice. The effect is mediated by increased local and systemic accumulation of myeloid-derived suppressor cells (MDSC), as their depletion abrogated pro-tumor activity in vivo. These data are important for the design of novel theranostics platforms with modules capable of depleting or functionally suppressing MDSC to ensure effective immunosurveillance in the tumor microenvironment.” As taken from Shvedova AA et al. 2013. Small 9(9-10), 1691-5. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/22996965

“Multiple-walled carbon nanotubes (MWCNTs) may cause carcinogenesis. We found that long-term exposure to MWCNTs can induce irreversible oncogenic transformation of human bronchial epithelial cells and tumorigenicity in vivo. A genome-wide array-comparative genomic hybridization (aCGH) analysis revealed global chromosomal aberration in MWCNTs-treated clones, predominantly at chromosome 2q31-32, where the potential oncogenes HOXD9 and HOXD13 are located. Functional assays confirmed that this variation can modulate oncogenic signaling and plays a part in MWCNTs-induced tumorigenesis, suggesting that MWCNTs are carcinogens that act by altering genomic stability and oncogenic copy numbers.” As taken from Wu P et al. 2013. Nano Lett. 13(10), 4632-41. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23984819

“Malignant mesothelioma is one of the most aggressive forms of cancer known. Recent studies have shown that carbon nanotubes (CNTs) are biopersistent and induce mesothelioma in animals, but the underlying mechanisms are not known. Here, we investigate the effect of long-term exposure to high aspect ratio CNTs on the aggressive behaviors of human pleural mesothelial cells, the primary cellular target of human lung mesothelioma. We show that chronic exposure (4 months) to single- and multiwalled CNTs induced proliferation, migration, and invasion of the cells similar to that observed in asbestos-exposed cells. An up-regulation of several key genes known to be important in cell invasion, notably matrix metalloproteinase-2 (MMP-2), was observed in the exposed mesothelial cells as determined by real-time PCR. Western blot and enzyme activity assays confirmed the increased expression and activity of MMP-2. Whole genome microarray analysis further indicated the importance of MMP-2 in the invasion gene signaling network of the exposed cells. Knockdown of MMP-2 in CNT and asbestos-exposed cells by shRNA-mediated gene silencing effectively inhibited the aggressive phenotypes. This study demonstrates CNT-induced cell invasion and indicates the role of MMP-2 in the process.” As taken from Lohcharoenkal W et al. 2013. ACS Nano. 7(9), 7711-23. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23924264

“Accumulating evidence indicates that carbon nanotubes (CNTs) are biopersistent and can cause lung damage. With similar fibrous morphology and mode of exposure to asbestos, a known human carcinogen, growing concern has arisen for elevated risk of CNT-induced lung carcinogenesis; however, relatively little is known about the long-term carcinogenic effect of CNT. Neoplastic transformation is a key early event leading to carcinogenesis. We studied the ability of single- and multi-walled CNTs to induce neoplastic transformation of human lung epithelial cells compared to asbestos. Long-term (6-month) exposure of the cells to occupationally relevant concentrations of CNT in culture caused a neoplastic-like transformation phenotype as demonstrated by increased cell proliferation, anchorage-independent growth, invasion and angiogenesis. Whole-genome expression signature and protein expression analyses showed that single- and multi-walled CNTs shared similar signaling signatures which were distinct from asbestos. These results provide novel toxicogenomic information and suggest distinct particle-associated mechanisms of neoplasia promotion induced by CNTs and asbestos” As take from Wang L et al. 2014. Nanotoxicology 8, 485-507. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23634900

“Novel materials are often commercialized without a complete assessment of the risks they pose to human health because such assessments are costly and time-consuming; additionally, sometimes the methodology needed for such an assessment does not exist. Carbon nanotubes have the potential for widespread application in engineering, materials science and medicine. However, due to the needle-like shape and high durability of multiwalled carbon nanotubes (MWCNTs), concerns have been raised that they may induce asbestos-like pathogenicity when inhaled. Indeed, experiments in rodents supported this hypothesis. Notably, the genetic alterations in MWCNT-induced rat malignant mesothelioma were similar to those induced by asbestos. Single-walled CNTs (SWCNTs) cause mitotic disturbances in cultured cells, but thus far, there has been no report that SWCNTs are carcinogenic. This review summarizes the recent noteworthy publications on the genotoxicity and carcinogenicity of CNTs and explains the possible molecular mechanisms responsible for this carcinogenicity. The nanoscale size and needle-like rigid structure of CNTs appear to be associated with their pathogenicity in mammalian cells, where carbon atoms are major components in the backbone of many biomolecules. Publishing adverse events associated with novel materials is critically important for alerting people exposed to such materials. CNTs still have a bright future with superb economic and medical merits. However, appropriate regulation of the production, distribution and secondary manufacturing processes is required, at least to protect the workers.” As taken from Toyokuni S. 2013. Adv. Drug Deliv. Rev. 65(15), 2098-110. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23751780

“In the NIOSH study, a group of laboratory mice were injected with a chemical that is a known cancer initiator, methylcholanthrene. Another group of mice were injected with a saline solution as a control group. The mice then were exposed by inhalation either to air or to a concentration of

MWCNT. These protocols enabled the researchers to investigate whether MWNCT alone would initiate cancer in mice, or whether MWCNT would promote cancer where the initiator, methylcholanthrene, had already been applied.

Mice receiving both the initiator chemical plus exposure to MWCNT were significantly more likely to develop tumors (90% incidence) and have more tumors (an average of 3.3 tumors/mouse lung) than mice receiving the initiator chemical alone (50% of mice developing tumors with an average of 1.4 tumors/lung). Additionally, mice exposed to MWCNT and to MWCNT plus the initiator chemical had larger tumors than the respective control groups. The number of tumors per animal exposed to MWCNT alone was not significantly elevated compared with the number per animal in the controls. These results indicate that MWCNT can increase the risk of cancer in mice exposed to a known carcinogen. The study does not suggest that MWCNTs alone cause cancer in mice.

Several earlier studies in the scientific literature indicated that MWCNT could have the potential to initiate or promote cancer. The new NIOSH study is the first to show that MWCNT is a cancer promoter in a laboratory experiment, and reports the growth of lung tumors in laboratory mice following inhalation exposure to MWCNT rather than injection, instillation, or aspiration. Inhalation exposure most closely resembles the exposure route of greatest concern in the workplace. In the study, laboratory mice were exposed to one type of MWCNT through inhalation at a concentration of 5 milligrams per cubic meter of air for five hours per day for a period of 15 days.

Risk of occupational cancer depends on the potency of a given substance to cause or promote cancer and the concentration and duration of worker exposure to that substance. This research is an important step in our understanding of the hazard associated with MWCNT, but before we can determine whether MWCNT pose an occupational cancer risk, we need more information about actual exposure levels and the types and nature of MWCNT being used in the workplace, and how that compares to the material used in this study. We also need to identify what work processes, tasks, and physical forms of the MWCNT are associated with exposure. Workplace studies are underway at NIOSH to learn more about actual worker exposure and to develop guidance on how to contain and control MWCNT processes to eliminate exposures, based on advancing knowledge about exposures. Further, similar research is needed for understanding the potential health effects and potential occupational risk of other types of carbon nanotubes and nanofibers, as well as other nanomaterials."

As taken from Castranova V et al. 2013. NIOSH Science Blog. Available at http://blogs.cdc.gov/niosh-science-blog/2013/03/11/mwcnt/

"We summarized the findings of in vivo toxicity studies of single-walled carbon nanotubes (SWCNTs) in laboratory animals. ….. Although no definitive study on the carcinogenicity of SWCNTs is available at present, evidence of carcinogenicity has not been reported in toxicity studies cited in this review. Overall, the available data provides initial information on SWCNT toxicity. To further clarify their toxicity and risk assessment, studies should be conducted using well-characterized SWCNTs, standard protocols, and the relevant route and doses of human exposure." As taken from Ema M et al. 2016. Regul. Toxicol. Pharmacol. 74, 42-63. PubMed, 2016 available at http://www.ncbi.nlm.nih.gov/pubmed/26619783

"Human Health Assessment

…… Hazards related to substances used in the workplace should be classified accordingly under the Workplace Hazardous Materials Information System (WHMIS). However, based on the available information on structurally related nanomaterials, the substance may cause ….. carcinogenicity following oral and inhalation exposure. ……."

As taken from Environment Canada, 2015

"Deteriorating air quality with high levels of fine particulate matter (PM2.5) over National Capital Region (NCR) of India is one of the serious environmental and scientific issues. In this paper, PM2.5 samples were collected for 24 h twice or thrice a week during December 2016-December

2017 at three sites [Delhi (IG), Modinagar (MN) and Mahendragarh (HR)] over NCR to analyse the carbonaceous aerosols. Source apportionment of PM2.5 was attempted using Principal Component analysis (PCA) and Positive Matrix Factorization (PMF) based on the analysed carbonaceous fractions [Organic carbon, Elemental carbon, Secondary organic carbon (SOC)]. Organic compounds: alkanes, hopanes, steranes, polycyclic aromatic hydrocarbons (PAHs), phthalates, levoglucosan and n-alkanoic acids were analysed to distinguish the emission sources. Total Carbonaceous Aerosols (TCA) contributed significantly (~26%) to PM2.5 which revealed their importance in source apportionment. Estimated SOC contributed 43.2%, 42.2% and 58.2% to OC and 5.4%, 5.3% and 7.8% to PM2.5 at IG, MN and HR sites respectively. PCA and PMF apportion five emission sources i.e., vehicular emissions (34.6%), biomass burning (26.8%), cooking emissions (15.7%), plastic and waste burning (13.5%) and secondary organic carbon (9.5%) for PM2.5. Source attributed health risk has also been calculated in terms of Lung cancer risk (LCR) associated with PAHs exposure and concluded that vehicular emissions (40.3%), biomass burning (38.1%), secondary organic carbon (12.8%) contributed higher to LCR (503.2 × 10-5; ~503 cases in 1,00,000). Health risk assessment combined with source apportionment inferences signifies the immediate implementation of emissions reduction strategies with special target on transport sector and biomass burning over the NCR of India." As taken from Shivani et al. 2019. Chemosphere 237, 124500. PubMed, 2020 available at https://pubmed.ncbi.nlm.nih.gov/31549639/

"Biomass is one of the prime domestic energy sources in the kitchens and about 60% of households are still using biomass and kerosene for cooking in India. These traditional cooking practices are incompetent as the use of biomass in traditional cookstove produces an enormous amount of carbonaceous aerosols that lead to indoor and outdoor air pollution. Emissions of various pollutants like black carbon (BC), PM10 and PM2.5 from burning of biomass cause serious health impacts like respiratory illness, lung cancer, watering of eyes, coughing, asthma and heart problems especially in women due to higher rate of inhalation of these fine particulate matters during the cooking period. Quantification of BC, PM2.5 and PM10 emissions from a different type of biomass in various types of kitchen arrangements and its associated impacts are poorly examined in India. Hence, daily concentrations of BC, PM2.5 and PM10 were monitored from different types of biomass user's households during January 2018 to December 2019 to assess indoor air quality by using aethalometer and nephelometer (pDR-1500) in three districts (Sitapur, Patna and Murshidabad) of Indo-Gangetic Plains (IGP) where approximately, 96% of rural families rely on biomass cooking. The highest mass concentrations were observed in biomass user's households and cow-dung cake users due to low calorific value. About 30.13% of PM10 and 35.89% of PM2.5 data exceeded the national ambient air quality standard on a daily basis in biomass user's households. A cancer risk assessment was also conducted in terms of mass concentration of these pollutants. The lifespan danger from exposure to BC was 4.33 × 10-7 in indoor for non-ventilated kitchens, 2.63 × 10-7 in indoor for ventilated kitchens, 3.98 × 10-7 in outdoor for separated kitchen, 3.22 × 10-7 for semi-open kitchen and 1.78 × 10-7 for open kitchen. The vulnerability assessment for cancer mortality under exposure of pollution was estimated to be highest for the age group of more than 50 years whereas lowest for the age group of 0-4 years for all kinds of kitchens in the study area." As taken from Arif M and Parveen S. 2021. Environ. Sci. Pollut. Res. Int. 28(2), 2082-2096. PubMed, 2021 available at https://pubmed.ncbi.nlm.nih.gov/32869181/

5.7. Irritation/immunotoxicity

/IMMUNOTOXICITY/ Human epidermal keratinocytes (HEKs) were dosed with 6-Aminohexanoic acid-derivatized single-wall carbon nanotubes (AHA-SWNTs) ranging in concentration from 0.00000005 to 0.05 mg/mL. MTT (3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide) cell viability decreased significantly ($p < .05$) from 0.00005 to 0.05 mg/mL after 24 hr. The proinflammatory mediators of inflammation cytokines interleukin (IL)-6, IL-8, tumor necrosis factor (TNF)-alpha, IL-10, and IL-1beta were also assessed. Cytokine analysis did not show a significant increase in IL-6 and IL-8 in the medium containing 0.000005 mg/mL of AHA-SWNTs from 1 to 48 hr. IL-6 increased in cells treated with 0.05 mg/mL of AHA-SWNTs from 1 to 48 hr, whereas IL-8

showed a significant increase at 24 and 48 hr. No significant difference ($p < .05$) was noted with TNF-alpha, IL-10, and IL-1beta expression at any time point. Transmission electron microscopy of HEKs treated with 0.05 mg/mL AHA-SWNTs for 24 hr depicted AHA-SWNTs localized within intracytoplasmic vacuoles in HEKs. Treatment with the surfactant 1% Pluronic F127 caused dispersion of the AHA-SWNT aggregates in the culture medium and less toxicity. These data showed that the lower concentration of 0.000005 mg/mL of AHA-SWNTs maintains cell viability and induces a mild cytotoxicity, but 0.05 mg/mL of AHA-SWNTs demonstrated an irritation response by the increase in IL-8. [Zhang LW et al; Int J Toxicol 26 (2): 103-13 (2007)] **PEER REVIEWED**

“One of priority approaches in occupational medicine and health risk evaluation is study of immune system features in individuals exposed to occupational chemical hazards. The studies revealed reliable changes in immune parameters (positive annexin tag, disorders of cytokine profile)-- that proves retarded apoptosis precesses in workers engaged into activated carbon and coagulants production. Marked disorders of cellular regulation in machinery operators of activated carbon and coagulants production are seen with observed normal content of phenol in the air of workplace” (Za-¡tseva et al., 2011. Meditsina truda i promyshlennaia ekologiia 2, 21-23). As taken from http://www.ncbi.nlm.nih.gov/pubmed/21506374

Skin, Eye and Respiratory Irritations:

It can cause a dust irritation, particularly to the eyes and mucous membranes. [Lewis, R.J. Sr. (ed) Sax's Dangerous Properties of Industrial Materials. 11th Edition. Wiley-Interscience, Wiley & Sons, Inc. Hoboken, NJ. 2004., p. 704] **PEER REVIEWED**

As taken from HSDB, 2009

“Carbon has been found to be neither irritating nor sensitizing.”

As taken from IUCLID Dataset (2000), Carbon (7440-44-0)

“It can ... cause conjunctivitis epithelial hyperplasia of cornea, as well as eczematous inflammation of eyelids.”

“In the form of graphite ... it can cause a dust irritation, particularly to the eyes ... Some forms of carbon dust can cause irritation of eyes and mucous membranes.”

“Exptl intravenous injection of pure carbon suspensions in rabbits produces no ocular inflammation, although carbon particles are deposited within the blood vessels.”

“Small quantities of carbon suspensions in the form of graphite or India ink injected into the anterior chamber of rabbits is mostly taken up by leukocytes and by the corneal endothelium, producing essentially no signs of inflammation. Large quantities may obstruct aqueous outflow mechanically.”

After 4 h of inhalation, mainly heat shock proteins were induced, whereas after 24 h, different immunomodulatory proteins (osteopontin, galectin-3 and lipocalin-2) were upregulated in alveolar macrophages and septal cells. In conclusion, these data indicate that inhalation of ultrafine carbon particles triggers a biphasic pro-inflammatory process in the lung, involving the activation of macrophages and the upregulation of immunomodulatory proteins.” As taken from Andre et al., (2006), Eur Respir J. 2006 Aug;28(2):275-85.

“Inhalation of carbon dust ... can immediately give rise to an increased mucociliary transport ... & airway resistance mediated by the vagus.”

“In the present study, we investigated the immunomodulatory activity of multi-walled carbon nanotubes (MWCNTs) in peripheral blood mononuclear cells (PBMCs) from healthy donors and mite-allergic subjects. Freshly prepared PBMCs, stimulated or not with Toll-like receptor (TLR)1-9 agonists, a T cell mitogen (phytohemagglutinin A) or mite allergen extract were cultured in the presence or absence of MWCNTs. Secretion of TNF-α, IL-2, IL-5, IL-6, IL-12/23p40 or IFN-γ was quantified in the culture supernatants by ELISA. Basal secretion of all the cytokines was not altered by MWCNTs in PBMCs from both healthy donors and allergic subjects. In PBMCs from healthy

donors, TNF-α, IL-6 and IL-12/23p40 secretion in response to the TLR4 agonist, lipopolysaccharide was however increased in a dose-dependent manner by MWCNTs. Significant increases in the release of these cytokines were also observed in PBMCs stimulated with a TLR2 or TLR3 agonist. MWCNTs also increased the release of IL-2 and IFN-γ by PBMCs stimulated with a T cell mitogen. In contrast, MWCNTs inhibited allergen-induced IL-5 secretion by PBMCs from mite-allergic subjects. As well, MWCNTs altered the capacity of PBMC-derived monocytes to differentiate into functional dendritic cells. All together, our data suggest that according to its immune cell target, MWCNTs may either promote or suppress immune responses in humans. Further investigations are necessary to fully understand the complexity behind interactions of engineered nanoparticles with the immune system." As taken from Laverny G et al. 2013. Toxicol. Lett. 217(2), 91-101. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23266719

"Aerosolized or aspirated manufactured carbon nanotubes have been shown to be cytotoxic, cause pulmonary lesions, and demonstrate immunomodulatory properties. CD-1 mice were used to assess pulmonary toxicity of helical carbon nanotubes (HCNTs) and alterations of the immune response to subsequent infection by Pseudomonas aeruginosa in mice. HCNTs provoked a mild inflammatory response following either a single exposure or 2X/week for three weeks (multiple exposures) but were not significantly toxic. Administering HCNTs 2X/week for three weeks resulted in pulmonary lesions including granulomas and goblet cell hyperplasia. Mice exposed to HCNTs and subsequently infected by P. aeruginosa demonstrated an enhanced inflammatory response to P. aeruginosa and phagocytosis by alveolar macrophages was inhibited. However, clearance of P. aeruginosa was not affected. HCNT exposed mice depleted of neutrophils were more effective in clearing P. aeruginosa compared to neutrophil-depleted control mice, accompanied by an influx of macrophages. Depletion of systemic macrophages resulted in slightly inhibited bacterial clearance by HCNT treated mice. Our data indicate that pulmonary exposure to HCNTs results in lesions similar to those caused by other nanotubes and pre-exposure to HCNTs inhibit alveolar macrophage phagocytosis of P. aeruginosa. However, clearance was not affected as exposure to HCNTs primed the immune system for an enhanced inflammatory response to pulmonary infection consisting of an influx of neutrophils and macrophages." As taken from Walling BE et al. 2013. PLoS One 8(11), e80283. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24324555

"Carbon-based nanomaterials (CBN), such as graphene nanosheets (GNS) and multiwalled carbon nanotubes (MWCNT), have been proposed for potential nanomedicine applications such as biomedical devices and carriers for drug delivery. However, our current understanding regarding the systemic toxicity of these CBN through intravenous (iv) injection is limited. In this study, we compare the immune response resulting from GNS and MWCNT exposure. We hypothesize that iv administration of GNS and MWCNT would result in divergent systemic inflammatory responses due to physicochemical differences between these two CBN. In the lungs of C57BL/6 mice, GNS actuate a Th2 immune response 1 day following iv administration, which consists of neutrophilic influx and a significant increase in interleukin (IL)-5, IL-13, IL-33, and its soluble receptor (sST2) in the bronchoalveolar lavage fluid. MWCNT elicited a significant increase in the messenger ribonucleic acid expression of cytokines in the spleen including IL-4 and IL-33, which are associated with an increase in splenic cell differentiation (CD)4(+) and CD8(+) T-cells in C57BL/6 mice following iv injection. The observed Th2 responses in both the lung and spleen are absent in ST2(-/-) mice administrated GNS or MWCNT, suggesting a critical role for IL-33. In conclusion, the use of GNS or MWCNT as nanocarriers for drug delivery may result in Th2 immune responses that are mediated through the IL-33/ST2 axis and therefore may promote adverse allergic reactions." As aken from Wang X et al. 2013. Int. J. Nanomedicine 8, 1733-48. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23662055

"It is increasingly important to understand the single-walled carbon nanotubes' (SWCNTs) immune response as their increasingly biomedical researches and applications. Macrophages and T cells play important roles in scavenging foreign materials and pathogens and regulating immune response. In this work, primarily cultured murine peritoneal macrophages and purified splenic T

cells were utilised to determine the toxic effects of SWCNTs and acid-functionalised SWCNTs (AF-SWCNTs) on the immune system, especially on macrophage functions. Macrophages were exposed to 0-50 μg/ml of CNTs for 24 h and no significant cytotoxicity was found by live/dead and annexin-V-FITC/PI analyses. The TEM images revealed that AF-SWCNTs were engulfed mostly through phagocytosis and located in lysosomes of macrophages. Measurement of mitochondrial membrane potential and proteasome subunit gene expression demonstrated that 10 and 50 μg/ml AF-SWCNTs could damage mitochondrial function and proteasome formation in a concentration-dependent manner. Functional analyses revealed that the percentage of phagocytic cells were affected significantly by 20 μg/ml CNTs, and 5 μg/ml AF-SWCNTs inhibited the phagocytic efficiency of latex beads in macrophages. The accessory cell function was affected by both AF-SWCNTs and SWCNTs at concentrations of 10 and 50 μg/ml, respectively. Furthermore, AF-SWCNT biased naïve T-cell differentiation to Th1 type by inducing the production of IFN-γ and TNF, implying the potential risk of Th1-associated diseases (e.g. autoimmune diseases and inflammation) on AF-SWCNT exposure." As taken from Dong PX et al. 2013. Nanotoxicology 7(5), 1028-42. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/22632544

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…. It is a severe eye irritant (MAS score = 68), a mild skin irritant (PII = 1.08) and at most a weak sensitizer (because the positive control was tested at a concentration 10X higher than the test substance). …... Hazards related to substances used in the workplace should be classified accordingly under the Workplace Hazardous Materials Information System (WHMIS). However, based on the available information on structurally related nanomaterials, the substance may cause …. immunotoxicity, …. following oral and inhalation exposure….."

As taken from Environment Canada, 2015

"The biomedical application of graphene quantum dots (GQDs) is a new emerging area. However, their safety data are still in scarcity to date. Particularly, the effect of GQDs on the immune system remains unknown. This study aimed to elucidate the interaction of GQDs with macrophages and the underlying mechanisms. Our results showed that GQDs slightly affected the cell viability and membrane integrity of macrophages, whereas GQDs significantly increased reactive oxygen species (ROS) generation and apoptotic and autophagic cell death with an increase in the expression level of Bax, Bad, caspase 3, caspase 9, beclin 1, and LC3-I/II and a decrease in that of Bcl-2. Furthermore, low concentrations of GQDs significantly increased the expression of tumor necrosis factor-α (TNF-α), interleukin-1β (IL-1β), IL-8, whereas high concentrations of GQDs elicited opposite effects on the cytokines production. SB202190, a selective inhibitor of p38 mitogen-activated protein kinase (MAPK), abolished the cytokine-inducing effect of GQDs in macrophages. Moreover, GQDs significantly increased the phosphorylation of p38 MAPK and p65, and promoted the nuclear translocation of nuclear factor-κB (NF-κB). Taken together, these results show that GQDs induce ROS generation, apoptosis, autophagy, and inflammatory response via p38MAPK and NF-κB mediated signaling pathways in THP-1 activated macrophages." As taken from Qin Y et al. 2015. Toxicology 327, 62-76. PubMed, 2016 available at http://www.ncbi.nlm.nih.gov/pubmed/25446327

"The potential of carbon nanotubes (CNTs) in medical applications has been attracting constant research interest as well as raising concerns related to toxicity. The immune system serves as the first line of defense against invasion. In this work, interactions of oxidized multiwalled carbon nanotubes (MWCNT) with macrophages were investigated to unravel the activation profile of macrophages, using cytokine array, ELISA assay, transwell assay, confocal microscopy, and reactive oxygen species examination. Results show that MWCNT initiate phagocytosis of macrophages and upregulate CD14, CD11b, TLR-4/MD2, and CD206, which does not alter the MHCII expression of the macrophages. The macrophages engulfing MWCNT (MWCNT-RAW) secrete a large amount of MIP-1α and MIP-2 to recruit naïve macrophages and produce angiogenesis-related cytokines MMP-9 and VEGF, while inducing much lower levels of proinflammatory cytokines than those activated by LPS. In conclusion, MWCNT activate

macrophages into a M1/M2 mixed status, which allows the cells to recruit naïve macrophages and support angiogenesis." As taken from Meng J et al. 2015. ACS Appl. Mater. Interfaces 7(5), 3180-8. PubMed, 2016 available at http://www.ncbi.nlm.nih.gov/pubmed/25591447

"The interleukin-1 (IL-1) family has been implicated in cellular responses to nanoparticles including carbon nanotubes (CNTs). IL-1α and β are key proinflammatory cytokines important in inflammatory and oxidative stress responses. The aim of this study was to characterize the role of IL-1 in cellular responses of CNTs in cells from IL-1α/β wild type (IL1-WT) mice and cells with reduced inflammatory potential from IL-1α/β deficient (IL1-KO) mice. Two multi-walled CNTs, CNT-1 containing long and thick fibers and CNT-2 containing short and thin fibers, were compared to UICC crocidolite asbestos fibers. Upon CNT exposure toxicity and apoptosis were affected differently in IL1-WT and IL1-KO cells. Upregulation of TNFα and IL-1α mRNA expression in IL1-WT cells was dependent on the type of CNT. On the contrary precursor IL-1α protein was downregulated after 24h. The mitogen-activated protein kinase (MAPK) c-Jun N-terminal kinase (JNK) was activated in IL1-KO cells and regulated by CNTs, whereas no significant changes of extracellular regulated kinase (ERK) were observed when comparing IL1-WT and IL1-KO cells. In summary, the results presented here indicate that IL-1 contributes to the cellular and molecular effects of CNT exposure and that the type of CNT has an important effect on the cellular response." As taken from Arnoldussen YJ et al. 2015. Cytokine 73(1), 128-37. PubMed, 2016 available at http://www.ncbi.nlm.nih.gov/pubmed/25748835

"OBJECTIVE: Activated carbon (AC) has been used in wound therapy as an active substance inside dressings. Applying AC directly on a wound is a new concept. The aim of this study was to analyse the outcomes of chronic wounds which were managed with directly applied activated carbon knitted cloth (ACC, Zorflex) in Swiss patients. METHOD: A retrospective analysis of the records of all patients with chronic wounds treated with ACC between 1 October 2013 and 31 December 2015 in an outpatient wound clinic. Chronic was defined as a wound being present for >3 weeks. Malignant wounds were excluded. The main outcome was the time to complete closure or readiness for spilt-thickness skin grafting (STSG). Descriptive data, including nutritional status and angiology results were obtained. RESULTS: There were 36 women and 34 men, median age 68 years old. The median body mass index (BMI) 28.1kg/m^2 and 76% (n=53) of patients had comorbidities. Angiology exam results showed signs of reduced arterial perfusion in 13% (n=9) of patients and malnutrition in 11% (n=8). Of the wounds included 34% (n=24) were on the trunk and 66% (n=46) on the extremities. The median wound size was 6.9cm^2 (range: 0.1-300cm^2). The wounds on the trunk were larger than wounds on extremities (10 versus 2cm^2). Overall, median time to wound closure was 51 days. In 94% (n=66) of patients, wounds closed without further intervention and 6% (n=4) underwent STSG. Patients with comorbidities showed longer wound healing times compared with those without. No adverse events such as allergies or skin irritation occurred. Cost analysis, including personnel and material and stratified according known wound closure times, showed ACC (US$ 1252) to be like hydrocolloids (US$ 1128), but substantially lower than white gauze (US$ 3026) and negative pressure wound therapy (NPWT) (US$ 2578). CONCLUSION: ACC applied directly on chronic wounds of different aetiology is safe with short closure times. The cost efficiency is high. It combines the positive features of other wound dressings, such as hydrocolloids and NPWT, without their disadvantages. The dressing change of ACC is easy and non-specialised nurses or even patients themselves can be taught to perform it." As taken from Scheer HS et al. 2017. J. Wound Care 26(8), 476-481. PubMed, 2018 available at https://www.ncbi.nlm.nih.gov/pubmed/28795884

"Ambient black carbon (BC) is found to be associated with increased risk of diverse pulmonary diseases, including acute respiratory inflammation and decreased lung function. Freshly emitted BC (FBC) can be transformed into oxidized BC (OBC) through the photochemical oxidization in the air. How this oxidization process influences the toxicity of BC particles is unclear. Previous studies found FBC and OBC could induce oxidative stress and inflammation. This study aimed to further compare the regulating pathways and tried to reveal the crucial target genes caused by FBC and OBC in A549 cells based on transcriptomic data. A total of 47,000 genes in A549 cells after treated

with FBC and OBC were examined using Affymetrix Human U133 plus 2.0 chips. Gene ontology (GO) classification (functional enrichment of differentially expressed genes) and Kyoto encyclopedia of genes and genomes (KEGG) classification (pathway enrichment of differentially expressed genes) were conducted and crucial genes were screened. The results showed that top 50 GO terms of FBC and OBC were not completely consistent. The Go term of cation channel was only identified in OBC group, probably caused by the characteristic that zeta potential of OBC is negative, while, that of FBC is positive. In addition transient receptor potential melastatin 7 (trpm7) gene was suggested to be closely related to this process caused by OBC. There are 47 identical pathways in FBC and OBC group among the top 50 KEGG. The inconsistent pathways are mostly related to inflammation with different up-regulation or down-regulation trends of crucial genes. The KEGG results suggested that FBC and OBC both cause inflammatory responses, but through different regulating pathways. In conclusion, OBC and FBC could induce similar toxic endpoints in A549 cells, but the underline regulating processes are not exactly the same." As taken from Kong J et al. 2019. J. Environ. Manage. 246, 289-298. PubMed, 2020 available at https://pubmed.ncbi.nlm.nih.gov/31181478/

"Background: Different markers have been used preoperatively to mark colonic lesions, especially India ink. In recent years, another kind of marker has been developed: sterile carbon particle suspension (SCPS). No comparison between these two markers has yet been made. The aim of the present study was to compare the pyrogenic, inflammatory and intraperitoneal effect of these two markers. Methods: From September 2015 to December 2018, adult patients who were candidates for elective laparoscopic colon resection were randomized to the SCPS or conventional India ink injection group using computer-based randomization. The primary endpoint of the study was the presence of intraoperative adhesions related to the endoscopic tattoo. Secondary endpoints were differences in white blood cell, C-reactive protein, and fibrinogen levels as well as, abdominal pain and body temperature at baseline (before endoscopic tattooing) and 6 and 24 h after colonoscopy. Finally, the visibility of the tattoo during the minimally invasive intervention was assessed. Results: Ninety-four patients were included in the study, 47 for each arm. There were 45/94 females (47.9%) and 49/94 males (52.1%), with a median age of 67.85 ± 9.22 years. No differences were found between groups in WBC, fibrinogen levels, body temperature or VAS scores, but we documented significantly higher CRP values at 6 and 24 h after endoscopic tattooing with India ink injection. There were significantly fewer adhesions in the SCPS Endoscopic Marker group. All the endoscopic tattoos were clearly visible. Conclusions: SCPS is an effective method for tattooing colonic lesions and has a better safety profile than traditional India ink in terms of post-procedure inflammatory response and intraoperative bowel adhesions." As taken from Milone M et al. 2019. Tech. Coloproctol. 23(11), 1073-1078. PubMed, 2020 available at https://pubmed.ncbi.nlm.nih.gov/31667693/

Background: Currently, considerable efforts to standardize methods for accurate assessment of properties and safety aspects of nanomaterials are being made. However, immunomodulation effects upon skin exposure to nanomaterial have not been explored.

Objectives: To investigate the immunotoxicity of single-wall carbon nanotubes, titanium dioxide, and fullerene using the current mechanistic understanding of skin sensitization by applying the concept of adverse outcome pathway (AOP).

Methods: Investigation of the ability of nanomaterials to interact with skin proteins using the micro-direct peptide reactivity assay; the expression of CD86 cell surface marker using the U937 cell activation test (OECD No. 442E/2018); and the effects of nanomaterials on modulating inflammatory response through inflammatory cytokine release by U937 cells.

Results: The nanomaterials easily internalized into keratinocytes cells, interacted with skin proteins, and triggered activation of U937 cells by increasing CD86 expression and modulating inflammatory cytokine production. Consequently, these nanomaterials were classified as skin sensitizers in vitro.

Conclusions: Our study suggests the potential immunotoxicity of nanomaterials and highlights the importance of studying the immunotoxicity and skin sensitization potential of nanomaterials to anticipate possible human health risks using standardized mechanistic nonanimal methods with high predictive accuracy. Therefore, it contributes toward the applicability of existing OECD (Organisation for Economic Co-operation and Development) testing guidelines for accurate assessment of nanomaterial skin sensitization potential.

As taken from Bezerra S et al. 2021, Available at https://pubmed.ncbi.nlm.nih.gov/32683706/

5.8. All other relevant types of toxicity

ALTERNATIVE and IN VITRO TESTS/ ... The toxicity of single-walled carbon nanotubes (SWCNT) was assessed in human keratinocyte cells. The results show increased oxidative stress and inhibition of cell proliferation in response to treatment of keratinocytes with SWCNT particles. In addition, the signaling mechanism in keratinocytes upon exposure to SWCNT particles was investigated. Results from the study suggest that SWCNT particles activate NF-kappaB in a dose-dependent manner in human keratinocytes. Further, the mechanism of activation of NF-kappaB was due to the activation of stress-related kinases by SWCNT particles in keratinocytes. [Manna SK et al; Nano Lett 5 (9): 1676-84 (2005)] **PEER REVIEWED**

/ALTERNATIVE and IN VITRO TESTS/ Carbon nanotube films were grown using a microwave plasma enhanced chemical vapor deposition system. Human epidermal keratinocytes (HEK) were exposed to 0.1, 0.2, and 0.4 mg/mL of multi-walled carbon nanotubes (MWCNT) for 1, 2, 4, 8, 12, 24 and 48 hr. HEK were examined by transmission electron microscopy for the presence of MWCNT. ... Chemically unmodified MWCNT were present within cytoplasmic vacuoles of the HEK at all time points. The MWCNT also induced the release of the proinflammatory cytokine interleukin 8 from HEKs in a time dependent manner. These data clearly show that MWCNT, not derivatized nor optimized for biological applications, are capable of both localizing within and initiating an irritation response in a target epithelial cell that composes a primary route of occupational exposure for manufactured nanotubes. [Monteiro-Riviere NA et al; Toxicol Lett 155 (3): 377-84 (2005)] **PEER REVIEWED**

/ALTERNATIVE and IN VITRO TESTS/ ... Recent studies in skin and lung reveal that carbon nanoparticles can cause toxicity. To generate a preliminary protein profile of nanotube exposure, ... human epidermal keratinocytes (HEKs) exposed to multi-walled carbon nanotubes (MWCNTs) in cell culture /were analyzed/ using large-format, two-dimensional (2D) gel electrophoresis and mass spectrometry (MS). Compared with controls, 24 hours of MWCNT exposure altered the expression of 36 proteins ($P < .01$), whereas 106 were altered at 48 hours. At both time points, roughly 67% of the affected proteins were significantly down-regulated. Peptide mass fingerprinting identified most of the differentially expressed proteins, and the various protein identities reflected a complex cellular response to MWCNT exposure. In addition to proteins associated with metabolism, cell signaling, and stress, we observed a consistent effect on the expression of cytoskeletal elements and vesicular trafficking components. These data clearly show that MWCNTs are capable of altering protein expression in a target epithelial cell that constitutes a primary route of occupational exposure for manufactured nanotubes. [Witzmann FA et al; Nanomedicine 2 (3): 158-68 (2006)] **PEER REVIEWED**

/ALTERNATIVE and IN VITRO TESTS/ ... Adverse effects of single-wall carbon nanotubes (SWCNT) /were investigated/ using a cell culture of immortalized human epidermal keratinocytes (HaCaT). After 18 hr of exposure of HaCaT to SWCNT, oxidative stress and cellular toxicity were indicated by formation of free radicals, accumulation of peroxidative products, antioxidant depletion, and loss of cell viability. Exposure to SWCNT also resulted in ultrastructural and morphological changes in cultured skin cells. These data indicate that dermal exposure to unrefined SWCNT may lead to dermal toxicity due to accelerated oxidative stress in the skin of exposed workers. [Shvedova AA et al; J Toxicol Environ Health A 66 (20): 1909-26 (2003)] **PEER REVIEWED**

/OTHER TOXICITY INFORMATION/ **...** Human exposure is expected to be negligible for carbon when it is used as one component in gas-producing cartridges placed in animal burrows. Ignited cartridges are to be quickly placed into burrows which are then covered to entrap the generated fumes. Improperly covered burrows could result in inhalation exposure to the fumes if the applicator remains in close proximity to the burrow. [USEPA/Office of Pesticide Programs; Reregistration Eligibility Decision Document - Carbon and Carbon Dioxide p.6 (September 1991). Available from, as of July 19, 2008: http://www.epa.gov/pesticides/reregistration/status.htm] **PEER REVIEWED**

As taken from HSDB, 2009

"BACKGROUND: REPETITIVE ELEMENTS TAKE UP >40% OF THE HUMAN GENOME AND CAN CHANGE DISTRIBUTION THROUGH TRANSPOSITION, THUS GENERATING SUBFAMILIES. Repetitive element DNA methylation has associated with several diseases and environmental exposures, including exposure to airborne pollutants. No systematic analysis has yet been conducted to examine the effects of exposures across different repetitive element subfamilies. The purpose of the study is to evaluate sensitivity of DNA methylation in differentially–evolved LINE, Alu, and HERV subfamilies to different types of airborne pollutants. METHODS: We sampled a total of 120 male participants from three studies (20 high-, 20 low-exposure in each study) of steel workers exposed to metal-rich particulate matter (measured as PM10) (Study 1); gas-station attendants exposed to air benzene (Study 2); and truck drivers exposed to traffic-derived elemental carbon (Study 3). We measured methylation by bisulfite-PCR-pyrosequencing in 10 differentially–evolved repetitive element subfamilies. RESULTS: High-exposure groups exhibited subfamily-specific methylation differences compared to low-exposure groups: L1PA2 showed lower DNA methylation in steel workers (P=0.04) and gas station attendants (P=0.03); L1Ta showed lower DNA methylation in steel workers (P=0.02); AluYb8 showed higher DNA methylation in truck drivers (P=0.05). Within each study, dose-response analyses showed subfamily-specific correlations of methylation with exposure levels. Interaction models showed that the effects of the exposures on DNA methylation were dependent on the subfamily evolutionary age, with stronger effects on older LINEs from PM10 (p–interaction=0.003) and benzene (p–interaction=0.04), and on younger Alus from PM10 (p-interaction=0.02). CONCLUSIONS: The evolutionary age of repetitive element subfamilies determines differential susceptibility of DNA methylation to airborne pollutants. As taken from Byun HM et al. 2013. Part. Fibre. Toxicol. 10, 28. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23855992

"Nanomaterials (NMs) are engineered for commercial purposes such as semiconductors, building materials, cosmetics, and drug carriers, while natural nanoparticles (NPs) already exist in the environment….This review will summarize and discuss recent reports derived from cell lines or animal models concerning the effects of NMs on, and their application in, the endocrine system of mammalian and other species. It will present an update on current studies of the effects of some typical NMs-such as metal-based NMs, carbon-based NMs, and dendrimers-on endocrine functions, in which some effects are adverse or unwanted and others are favorable or intended. Disruption of endocrine function is associated with adverse health outcomes including reproductive failure, metabolic syndrome, and some types of cancer. Further investigations are therefore required to obtain a thorough understanding of any potential risk of pathological endocrine disruption from products containing NMs. This review aims to provide impetus for further studies on the interactions of NMs with endocrine functions." As taken from Lu X et al. 2013. Small 9(9-10), 1654-71. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23401134

"Carbon nanotubes (CNTs) consist of a family of carbon built nanoparticles, whose biological effects depend on their physical characteristics and other constitutive chemicals (impurities and functions attached)….Oxidative stress is the main mechanism of toxicity but size, agglomeration, chirality as well as impurities and functionalization are some of the structural and chemical characteristic contributing to the CNTs toxicity outcomes. Among the many toxicity pathways, interference with cytoskeleton and fibrous mechanisms, cell signaling, membrane perturbations and the production of cytokines, chemokines and inflammation are some of the effects resulting from

exposure to CNTs. The aim of this review is to offer an up-to-date scope of the effects of CNTs on biological systems with attention to mechanisms of toxicity." As taken from Rodriguez-Yañez Y et al. 2013. Toxicol. Mech. Methods 23(3), 178-95. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23193995

"Graphene and its derivatives are promising candidates for important biomedical applications because of their versatility. The prospective use of graphene-based materials in a biological context requires a detailed comprehension of the toxicity of these materials. Moreover, due to the expanding applications of nanotechnology, human and environmental exposures to graphene-based nanomaterials are likely to increase in the future. Because of the potential risk factors associated with the manufacture and use of graphene-related materials, the number of nanotoxicological studies of these compounds has been increasing rapidly in the past decade. These studies have researched the effects of the nanostructural/biological interactions on different organizational levels of the living system, from biomolecules to animals. This review discusses recent results based on in vitro and in vivo cytotoxicity and genotoxicity studies of graphene-related materials and critically examines the methodologies employed to evaluate their toxicities. The environmental impact from the manipulation and application of graphene materials is also reported and discussed. Finally, this review presents mechanistic aspects of graphene toxicity in biological systems. More detailed studies aiming to investigate the toxicity of graphene-based materials and to properly associate the biological phenomenon with their chemical, structural, and morphological variations that result from several synthetic and processing possibilities are needed. Knowledge about graphene-based materials could ensure the safe application of this versatile material. Consequently, the focus of this review is to provide a source of inspiration for new nanotoxicological approaches for graphene-based materials." As taken from Seabra AB et al. 2014. Chem. Res. Toxicol. 27(2), 159-168. PubMed, 2015 available at http://www.ncbi.nlm.nih.gov/pubmed/24422439

"Carbon-based nanomaterials have attracted great interest in biomedical applications such as advanced imaging, tissue regeneration, and drug or gene delivery. The toxicity of the carbon nanotubes and graphene remains a debated issue although many toxicological studies have been reported in the scientific community. In this review, we summarize the biological effects of carbon nanotubes and graphene in terms of in vitro and in vivo toxicity, genotoxicity and toxicokinetics. The dose, shape, surface chemistry, exposure route and purity play important roles in the metabolism of carbon-based nanomaterials resulting in differential toxicity. Careful examination of the physico-chemical properties of carbon-based nanomaterials is considered a basic approach to correlate the toxicological response with the unique properties of the carbon nanomaterials. The reactive oxygen species-mediated toxic mechanism of carbon nanotubes has been extensively discussed and strategies, such as surface modification, have been proposed to reduce the toxicity of these materials. Carbon-based nanomaterials used in photothermal therapy, drug delivery and tissue regeneration are also discussed in this review. The toxicokinetics, toxicity and efficacy of carbon-based nanotubes and graphene still need to be investigated further to pave a way for biomedical applications and a better understanding of their potential applications to humans". As taken from Zhang Y et al. 2014. Drug Metab. Rev. 46(2), 232-46. PubMed, 2015 available at http://www.ncbi.nlm.nih.gov/pubmed/24506522

"Human Health Assessment

…... Hazards related to substances used in the workplace should be classified accordingly under the Workplace Hazardous Materials Information System (WHMIS). ……. t. Based on the low potential for direct and indirect exposure of the general population under the industrial uses identified in this submission, the substance is not likely to pose a significant health risk to the general population, and is therefore unlikely to be harmful to human health. However, based on the current understanding of carbon nanotubes and of nanomaterials in general, the risk arising from the use of the substance in consumer products is not known at this time. The use of the substance in consumer products or in products intended for use by or for children may significantly alter the exposure of the general population resulting in the substance becoming harmful to human health.

Similarly, the import or manufacture of the substance in quantities greater than 10 000 kg/yr may significantly increase the exposure levels of the general population resulting in the substance becoming harmful to human health. Consequently, more information is necessary to better characterize potential health risks."

As taken from Environment Canada, 2015.

Activated carbons are effective adsorbents for many volatile organic compounds and are used in cigarette filters to remove selected smoke toxicants. Polymer-derived carbon is more effective in removing many vapour phase toxicants found in cigarette smoke than coconut-shell-derived carbon. We compared mouth-level exposure to "tar", nicotine and five vapour phase constituents (1,3-butadiene, benzene, toluene, isoprene, acrylonitrile) in two groups of Romanian smokers of 4-mg or 8-mg International Organization for Standardization (ISO) "tar" bands. Test cigarettes with 4 and 8 mg ISO "tar" were manufactured for the study with two target levels of polymer-derived carbon (30 mg and 56 mg), along with control cigarettes containing a target level of 56 mg of coconut-shell-derived carbon in both "tar" bands. No significant differences were found between mouth-level exposure to "tar" or nicotine yields obtained from control and test products ($p > 0.05$) in either ISO "tar" band. Mouth-level exposure to each of the five vapour phase constituents was significantly lower from the test products with polymer-derived carbon ($p < 0.0001$) than from control cigarettes with coconut-shell-derived carbon, by an average of 25% with 30 mg polymer-derived carbon and around 50% with 56 mg." As taken from Nother K et al. 2016. Beiträge zur Tabakforschung International 27(2), 40–53. Available at https://doi.org/10.1515/cttr-2016-0007

6. Functional effects on

6.1. Broncho/pulmonary system

EPIDEMIOLOGY STUDIES/ /The objective was/ to investigate the risk of cancer and non-neoplastic respiratory diseases among workers who manufacture carbon electrodes, as this industry entails exposure to mixtures of polycyclic aromatic hydrocarbons. ... A historical cohort study was carried out of 1006 male workers employed for at least 1 year between 1945 and 1971 in a carbon (graphite) electrode production plant in central Italy, who were followed up for mortality between 1955 and 1996. The ratio of observed to expected deaths (standardised mortality ratios, SMRs) was computed from both national and (for the period 1964-96) regional age and period specific mortalities. A multivariate Poisson regression analysis was performed to investigate the relative risk (RR) of death according to duration of employment and time since first employment in the factory. ... A total of 424 workers had died, 538 were still alive, and 44 were lost to follow up. Mortalities from all causes, all cancers, and respiratory tract cancer were in line with the regional figure. An excess was found over the expected deaths from skin cancer including melanoma (SMR 3.16, 95% confidence interval (95% CI) 0.65 to 9.23) and from non-neoplastic respiratory diseases (SMR 1.58, 95% CI 1.16 to 2.11). Poisson regression analysis including age as a covariate showed an increased risk of dying from gastric cancer with increasing duration of employment, and an increase in the RR of dying from lung cancer and from non-neoplastic respiratory diseases with increasing time since first employment, although the linear trend was not significant. ... This study supports previous findings that working in the carbon electrode manufacturing industry may not increase the risk of dying from respiratory cancer.

/SIGNS AND SYMPTOMS/ ... INHALATION OF CARBON DUST ... CAN IMMEDIATELY GIVE RISE TO AN INCREASED MUCOCILIARY TRANSPORT ... & AIRWAY RESISTANCE MEDIATED BY THE VAGUS. /CARBON DUST/ [Friberg, L., G.R. Nordberg, and V.B. Vouk. Handbook on the Toxicology of Metals. New York: Elsevier North Holland, 1979., p. 72] **PEER REVIEWED**

/LABORATORY ANIMALS: Acute Exposure/ The aim of this study was to evaluate the acute lung toxicity of intratracheally instilled single-wall carbon nanotubes (SWCNT) in rats. The lungs of rats were instilled either with 1 or 5 mg/kg of the following control or particle types: (1) SWCNT, (2)

quartz particles (positive control), (3) carbonyl iron particles (negative control), (4) phosphate-buffered saline (PBS) + 1% Tween 80, or (5) graphite particles (lung tissue studies only). Following exposures, the lungs of PBS and particle-exposed rats were assessed using bronchoalveolar lavage (BAL) fluid biomarkers and cell proliferation methods, and by histopathological evaluation of lung tissue at 24 h, 1 week, 1 month, and 3 months postinstillation. Exposures to high-dose (5 mg/kg) SWCNT produced mortality in ~15% of the SWCNT-instilled rats within 24 h postinstillation. This mortality resulted from mechanical blockage of the upper airways by the instillate and was not due to inherent pulmonary toxicity of the instilled SWCNT particulate. Exposures to quartz particles produced significant increases versus controls in pulmonary inflammation, cytotoxicity, and lung cell parenchymal cell proliferation indices. Exposures to SWCNT produced transient inflammatory and cell injury effects. Results from the lung histopathology component of the study indicated that pulmonary exposures to quartz particles (5 mg/kg) produced dose-dependent inflammatory responses, concomitant with foamy alveolar macrophage accumulation and lung tissue thickening at the sites of normal particle deposition. Pulmonary exposures to carbonyl iron or graphite particles produced no significant adverse effects. Pulmonary exposures to SWCNT in rats produced a non-dose-dependent series of multifocal granulomas, which were evidence of a foreign tissue body reaction and were nonuniform in distribution and not progressive beyond 1 month postexposure (pe). The observation of SWCNT-induced multifocal granulomas is inconsistent with the following: (1) lack of lung toxicity by assessing lavage parameters, (2) lack of lung toxicity by measuring cell proliferation parameters, (3) an apparent lack of a dose response relationship, (4) nonuniform distribution of lesions, (5) the paradigm of dust-related lung toxicity effects, (6) possible regression of effects over time. In addition, the results of two recent exposure assessment studies indicate very low aerosol SWCNT exposures at the workplace. [Warheit DB et al; Toxicol Sci 77 (1): 117-25 (2004); Comment in: Toxicol Sci 77 (1): 3-5 (2004)] **PEER REVIEWED**

As taken from HSDB, 2009

“Male Sprague Dawley rats were exposed to carbon fibers 7 microns in diameter and 20 to 60 microns in length, for six hours a day and five days a week for up to 16 weeks at an average chamber concentration of 20 mg/m3. Rats were killed at 4, 8, 12, and 16 weeks of exposure and after a 32-week postexposure recovery period. A similar number of control rats exposed only to air were killed at the same times. Pulmonary function tests, conducted just prior to the animals' death, did not demonstrate any significant or consistent changes. The only pulmonary finding that could be causally related to the subchronic inhalation of carbon fibers was phagocytosis of the inhaled particles by alveolar macrophages. This physiologic response was not accompanied by any local reactive pulmonary inflammation or fibrosis.” As taken from Owen et al., (1986), J Occup Med. 1986 May;28(5):373-6., available at http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?db=pubmed&cmd=Retrieve&dopt=AbstractPlus&list_uids=3712116&query_hl=5&itool=pubmed_DocSum

“High levels of particulate matter in ambient air are associated with increased respiratory and cardiovascular health problems. It has been hypothesised that it is the ultrafine particle fraction (diameter <100 nm) that is largely responsible for these effects. To evaluate the associated mechanisms on a molecular level, the current authors applied an expression profiling approach. Healthy mice were exposed to either ultrafine carbon particles (UFCPs; mass concentration 380 microg x m(-3)) or filtered air for 4 and 24 h. Histology of the lungs did not indicate any pathomorphological changes after inhalation. Examination of the bronchoalveolar lavage fluid revealed a small increase in polymorphonuclear cell number (ranging 0.6-1%) after UFCP inhalation, compared with clean air controls, suggesting a minor inflammatory response. However, DNA microarray profile analysis revealed a clearly biphasic response to particle exposure. As taken from André E, Eur Respir J. 2006 Aug; 28(2):275-85 available at http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?db=pubmed&cmd=Retrieve&dopt=AbstractPlus&list_uids=16641123&query_hl=9&itool=pubmed_docsum

“Increased levels of particulate air pollution are associated with increased respiratory and cardiovascular mortality and morbidity. Some epidemiologic and toxicologic research suggests ultrafine particles (UFPs) (< 100 nm) to be more harmful per unit mass than larger particles. Our study was aimed at a quantitative comparison of acute adverse effects of different types of carbonaceous UFPs at a dose range that causes a moderate inflammatory response in lungs. We used six different particle types (primary particle size 10-50 nm, specific surface area 30-800 m2/g, and organic content 1-20%): PrintexG, Printex90, flame soot particles with different organic content (SootL, SootH), spark-generated ultrafine carbon particles (ufCP), and the reference diesel exhaust particles (DEP) SRM1650a. Mice were instilled with 5, 20, and 50 microg of each particle type, and bronchoalveolar lavage was analyzed 24 hr after instillation for inflammatory cells and the level of proinflammatory cytokines. At respective mass-doses, particle-caused detrimental effects ranked in the following order: ufCP > SootL > or = SootH > Printex90 > PrintexG > DEP. Relating the inflammatory effects to the particle characteristics--organic content, primary particle size, or specific surface area--demonstrates the most obvious dose response for particle surface area. Our study suggests that the surface area measurement developed by Brunauer, Emmett, and Teller is a valuable reference unit for the assessment of causative health effects for carbonaceous UFPs. Additionally, we demonstrated the existence of a threshold for the particle surface area at an instilled dose of approximately 20 cm2, below which no acute proinflammatory responses could be detected in mice.” As taken from Stoeger et al., (2006), Environ Health Perspect. 2006 Mar;114(3):328-33, available at http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?db=pubmed&cmd=Retrieve&dopt=AbstractPlus&list_uids=16507453&query_hl=9&itool=pubmed_docsum

“The hallmark geometric feature of single-walled carbon nanotubes (SWCNT) and carbon nanofibers (CNF) - high length to width ratio - makes them similar to a hazardous agent - asbestos. Very limited data are available concerning long-term effects of pulmonary exposure to SWCNT or CNF. Here we compared inflammatory, fibrogenic and genotoxic effects of CNF, SWCNT or asbestos in mice one year after pharyngeal aspiration. In addition, we compared pulmonary responses to SWCNT by bolus dosing through pharyngeal aspiration and inhalation 5h/day for 4 days, to evaluate the effect of dose rate. The aspiration studies showed that, these particles can be visualized in the lung at one year post-exposure, while some translocate to lymphatics. All these particles induced chronic bronchopneumonia and lymphadenitis, accompanied by pulmonary fibrosis. CNF and asbestos were found to promote the greatest degree of inflammation, followed by SWCNT, while SWCNT were the most fibrogenic of these three particles. Further, SWCNT induced cytogenetic alterations seen as micronuclei formation and nuclear protrusions in vivo. Importantly, inhalation exposure to SWCNT showed significantly greater inflammatory, fibrotic and genotoxic effects than bolus pharyngeal aspiration. Finally, SWCNT and CNF, but not asbestos exposures, increased the incidence of K-ras oncogene mutations in the lung….Overall, our data suggest that long-term pulmonary toxicity of SWCNT, CNF and asbestos - is defined not only by their chemical composition but also by the specific surface area and type of exposure.” As taken from Shvedova AA et al. 2014. J. Physiol. Lung Cell. Mol. Physiol. 306(2), L170-82. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24213921

“This article presents a regression-tree-based meta-analysis of rodent pulmonary toxicity studies of uncoated, nonfunctionalized carbon nanotube (CNT) exposure. The resulting analysis provides quantitative estimates of the contribution of CNT attributes (impurities, physical dimensions, and aggregation) to pulmonary toxicity indicators in bronchoalveolar lavage fluid: neutrophil and macrophage count, and lactate dehydrogenase and total protein concentrations. The method employs classification and regression tree (CART) models, techniques that are relatively insensitive to data defects that impair other types of regression analysis: high dimensionality, nonlinearity, correlated variables, and significant quantities of missing values. Three types of analysis are presented: the RT, the random forest (RF), and a random-forest-based dose-response model. The RT shows the best single model supported by all the data and typically contains a small number of variables. The RF shows how much variance reduction is associated with every variable in the data

set. The dose-response model is used to isolate the effects of CNT attributes from the CNT dose, showing the shift in the dose-response caused by the attribute across the measured range of CNT doses. It was found that the CNT attributes that contribute the most to pulmonary toxicity were metallic impurities (cobalt significantly increased observed toxicity, while other impurities had mixed effects), CNT length (negatively correlated with most toxicity indicators), CNT diameter (significantly positively associated with toxicity), and aggregate size (negatively correlated with cell damage indicators and positively correlated with immune response indicators). Increasing CNT N_2 -BET-specific surface area decreased toxicity indicators." As taken from Gernand JM & Casman EA. 2014. Risk Anal. 34(3), 583-97. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24024907

Aerosolized or aspirated manufactured carbon nanotubes have been shown to be cytotoxic, cause pulmonary lesions, and demonstrate immunomodulatory properties. CD-1 mice were used to assess pulmonary toxicity of helical carbon nanotubes (HCNTs) and alterations of the immune response to subsequent infection by Pseudomonas aeruginosa in mice. HCNTs provoked a mild inflammatory response following either a single exposure or 2X/week for three weeks (multiple exposures) but were not significantly toxic. Administering HCNTs 2X/week for three weeks resulted in pulmonary lesions including granulomas and goblet cell hyperplasia. Mice exposed to HCNTs and subsequently infected by P. aeruginosa demonstrated an enhanced inflammatory response to P. aeruginosa and phagocytosis by alveolar macrophages was inhibited. However, clearance of P. aeruginosa was not affected. HCNT exposed mice depleted of neutrophils were more effective in clearing P. aeruginosa compared to neutrophil-depleted control mice, accompanied by an influx of macrophages. Depletion of systemic macrophages resulted in slightly inhibited bacterial clearance by HCNT treated mice. Our data indicate that pulmonary exposure to HCNTs results in lesions similar to those caused by other nanotubes and pre-exposure to HCNTs inhibit alveolar macrophage phagocytosis of P. aeruginosa. However, clearance was not affected as exposure to HCNTs primed the immune system for an enhanced inflammatory response to pulmonary infection consisting of an influx of neutrophils and macrophages." As taken from Walling BE et al. 2013. PLoS One 8(11), e80283. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24324555

"Double-walled carbon nanotubes (DWCNT) are a rather new and unexplored variety of carbon nanotubes. Previously conducted studies established that exposure to a variety of carbon nanotubes produced lung inflammation and fibrosis in mice after pharyngeal aspiration. However, the bioactivity of double-walled carbon nanotubes (DWCNT) has not been determined. In this study, the hypothesis that DWCNT would induce pulmonary toxicity was explored by analyzing the pulmonary bioactivity of DWCNT. To test this hypothesis, C57Bl/6 mice were exposed to DWCNT by pharyngeal aspiration. Mice underwent whole-lung lavage (WLL) to assess pulmonary inflammation and injury, and lung tissue was examined histologically for development of pulmonary disease as a function of dose and time. The results showed that DWCNT exposure produced a dose-dependent increase in WLL polymorphonuclear leukocytes (PMN), indicating that DWCNT exposure initiated pulmonary inflammation. DWCNT exposure also produced a dose-dependent rise in lactate dehydrogenase (LDH) activity, as well as albumin levels, in WLL fluid, indicating that DWCNT exposure promoted cytotoxicity as well as decreases in the integrity of the blood-gas barrier in the lung, respectively. In addition, at 7 and 56 d postexposure, the presence of significant alveolitis and fibrosis was noted in mice exposed to 40 μg/mouse DWCNT. In conclusion, this study provides insight into previously uninvestigated pulmonary bioactivity of DWCNT exposure. Data indicate that DWCNT exposure promotes inflammation, injury, and fibrosis in the lung." As taken from Sager TM et al. 2013. J. Toxicol. Environ. Health A. 76(15), 922-36. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24156695

"The aim of this study was to investigate the potential toxic mechanisms associated with multiwall carbon nanotubes (MWCNT) in normal mouse lung. A total of 100 μg of two types of MWCNT, namely, pristine MWCNT (PMWCNT) and acid-treated-MWCNT (TMWCNT), was administered to male C57BL/6 mice via intratracheal (IT) instillation for a period of 6 mo. Our results indicated that

PMWCNT induced pulmonary autophagy accumulation and resulted in more potent tumorigenic effects compared to TMWCNT. Accordingly, MWCNT may exert differential toxicity attributed to various physicochemical properties. Data emphasize the need for careful regulation of production and use of CNT." As taken from Yu KN et al. 2013. J. Toxicol. Environ. Health A. 76(23), 1282-92. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24283420

"Carbon nanotubes (CNTs) represent promising vectors to facilitate cellular drug delivery and to overcome biological barriers, but some types may also elicit persistent pulmonary inflammation based on their fibre characteristics. Here, we show the pulmonary response to aqueous suspensions of block copolymer dispersed, double-walled carbon nanotubes (DWCNT, length 1-10 μm) in mice by bronchoalveolar lavage (BAL) analysis, and BAL and blood cytokine and lung antioxidant profiling. The intratracheally instilled dose of 50 μg DWCNT caused significant pulmonary inflammation that was not resolved during a 7-day observation period. Light microscopy investigation of the uptake of DWCNT agglomerates revealed no particle ingestion for granulocytes, but only for macrophages. Accumulating macrophage, multinucleated macrophage and lymphocyte numbers in the alveolar region further indicated ineffective resolution with chronification of the inflammation. The local inflammatory impairment of the lung was accompanied by pulmonary antioxidant depletion and haematological signs of systemic inflammation. While the observed inflammation during its acute phase was dominated by neutrophils and neutrophil recruiting cytokines, the contribution of macrophages and lymphocytes with related cytokines became more significant after day 3 of exposure. This study confirms that acute pulmonary toxicity can occur on exposure of high doses of DWCNT agglomerates and offers further insight for improved nanotube design parameters to avoid potential long-term toxicity." As taken from Tian F et al. 2013. Eur. J. Pharm. Biopharm. 84(2), 412-20. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23542608

"Carbon nanotubes (CNTs) find their extensive application as a promising material in medicine due to unique characteristics. However, such materials have been accompanied with potentially hazardous effects on human health. The toxicity of CNTs may vary depending on their structural characteristics, surface properties and chemical composition. To gain insight into the toxicity of CNTs in vivo and in vitro, we summarize contributing factors for the toxic effects of CNTs in this review. In addition, we elaborate on the toxic effects and mechanisms in target sites at systemic, organic, cellular, and biomacromolecule levels. Various issues are reported to be effected when exposed to CNTs including (1) blood circulation, (2) lymph circulation, (3) lung, (4) heart, (5) kidney, (6) spleen, (7) bone marrow, and (8) blood brain barrier. Though there have been published reports on thetoxic effects of CNTs to date, more studies will still be needed to gain full understanding of their potential toxicity and underlying mechanisms." As taken from Wang J et al. 2013a. Curr. Drug. Metab. 14(8), 891-9. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24016107

"Carbon nanotubes (CNTs) have been a subject of intensive research for a wide range of applications. However, because of their extremely small size and light weight, CNTs are readily inhaled into human lungs resulting in increased rates of pulmonary disorders, most notably fibrosis. Several studies have demonstrated the fibrogenic effects of CNTs given their ability to translocate into the surrounding areas in the lung causing granulomatous lesions and interstitial and sub-pleural fibrosis. However, the mechanisms underlying the disease process remain obscure due to the lack of understanding of the cellular interactions and molecular targets involved. Interestingly, certain physicochemical properties of CNTs have been shown to affect their respiratory toxicity, thereby becoming significant determinants of fibrogenesis. CNT-induced fibrosis involves a multitude of cell types and is characterized by the early onset of inflammation, oxidative stress and accumulation of extracellular matrix. Increased reactive oxygen species activate various cytokine/growth factor signaling cascades resulting in increased expression of inflammatory and fibrotic genes. Profibrotic growth factors and cytokines contribute directly to fibroblast proliferation and collagen production. Given the role of multiple players during the pathogenesis of CNT-induced fibrosis, the objective of this review is to summarize the key findings and discuss major cellular and molecular events governing pulmonary fibrosis. We also discuss the physicochemical properties of

CNTs and their effects on pulmonary toxicities as well as various biological factors contributing to the development of fibrosis." As taken from Manke A et al. 2013. Toxicol. Mech. Methods 23(3), 196-206. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23194015

"….This Account reviews the inhalation toxicity of manufactured nanomaterials and compares them with inhalation and intratracheal instillation studies of well-characterized fullerene and carbon nanotubes. In many reports, pulmonary inflammation and injury served as pulmonary endpoints for the inhalation toxicity. To assess pulmonary inflammation, we examined neutrophil and macrophage infiltration in the alveolar and/or interstitial space, and the expression of the neutrophil and/or monocyte chemokines. We also reported the release of lactate dehydrogenase (LDH) and alkaline phosphatase (ALP) in the bronchoalveolar lavage fluid (BALF), the expression of oxidative stress-related genes characteristic of lung injury, and the presence of granulomatous lesion and pulmonary fibrosis. In the inhalation and intratracheal instillation studies of well-characterized fullerenes, exposure to fullerene did not induce pulmonary inflammation or transient inflammation. By contrast, in an inhalation study, a high concentration of multiwall carbon nanotubes (MWCNTs) and single-wall carbon nanotubes (SWCNTs) induced neutrophil inflammation or granulomatous formations in the lung, and intratracheal instillation of MWCNTs and SWCNTs induced persistent inflammation in the lung. Among the physicochemical properties of carbon nanotubes, the increased surface area is associated with inflammatory activity as measured by the increase in the rate of neutrophils measured in bronchoalveolar lavage fluid. Metal impurities such as iron and nickel enhanced the pulmonary toxicity of carbon nanotubes, and SWCNTs that included an amorphous carbon induced multifocal granulomas in the lung while purer SWCNTs did not. The aggregation state also affects pulmonary response: Exposure to well-dispersed carbon nanotubes led to the thickening of the alveolar wall and fewer granulomatous lesions in the lung, while agglomerated carbon nanotubes produced granulomatous inflammation….." As taken from Morimoto Y et al. 2013. Acc. Chem. Res. 46(3), 770-81. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/22574947

"….In this Organization for Economic Cooperation and Development (OECD) 413 guideline inhalation study with VGCF-H carbon nanofibers (CNFs), rats were exposed to 0, 0.54, 2.5 or 25 mg/m(3) CNF for 13 weeks. The standard toxicology experimental design was supplemented with bronchoalveolar lavage (BAL) and respiratory cell proliferation (CP) endpoints. BAL fluid (BALF) recovery of inflammatory cells and mediators (i.e., BALF- lactate dehydrogenase [LDH], microprotein [MTP], and alkaline phosphatase [ALKP] levels) were increased only at 25 mg/m(3), 1 day after exposure. No differences versus control values in were measured at 0.54 or 2.5 mg/m(3) exposure concentrations for any BAL fluid endpoints. Approximately 90% (2.5 and 25 mg/m(3)) of the BAL-recovered macrophages contained CNF. CP indices at 25 mg/m(3) were increased in the airways, lung parenchyma, and subpleural regions, but no increases in CP versus controls were measured at 0.54 or 2.5 mg/m(3). Based upon histopathology criteria, the NOAEL was set at 0.54 mg/m(3), because at 2.5 mg/m(3), "minimal cellular inflammation" of the airways/lung parenchyma was noted by the study pathologist; while the 25 mg/m(3) exposure concentration produced slight inflammation and occasional interstitial thickening. In contrast, none of the more sensitive pulmonary biomarkers such as BAL fluid inflammation/cytotoxicity biomarkers or CP turnover results at 2.5 mg/m(3) were different from air-exposed controls. Given the absence of convergence of the histopathological observations versus more quantitative measures at 2.5 mg/m(3), it is recommended that more comprehensive guidance measures be implemented for setting adverse effect levels in (nano)particulate, subchronic inhalation studies including a WOE approach for establishing no adverse effect levels; and a suggestion that some findings should be viewed as normal physiological adaptations (e.g., normal macrophage phagocytic responses-minimal inflammation) to long-term particulate inhalation exposures." As taken from Warheit DB et al. 2013. Toxicol. Pathol. 41(2), 387-94. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23242579

"To evaluate pulmonary toxicity of multi-walled carbon nanotubes (MWCNTs), F344 rats of both sexes were exposed by inhalation to 0.2, 1 or 5 mg/m(3) MWCNT aerosol for 6 h/day, 5 days/week

for 2 weeks using a whole-body exposure system. At the end of the 2-week exposure period, one-half of the rats were necropsied, and at the end of an additional 4-week postexposure period, the remaining rats were necropsied. MWCNTs were deposited in the lungs of all MWCNT-exposed groups and mostly remained in the lungs throughout the 4-week postexposure period. Granulomatous changes in the lung were found in the rats exposed to 5 mg/m(3) MWCNTs, and these changes were slightly aggravated at the end of the 4-week postexposure period. In the bronchoalveolar lavage fluid (BALF), the numbers of neutrophils, percentages of bi- and multinucleated alveolar macrophages, levels of ALP activity and concentrations of total protein and albumin were elevated in the rats exposed to 1 and 5 mg/m(3) MWCNTs. At the end of the 4-week postexposure period, the values of the BALF parameters tended to remain elevated. In addition, goblet cell hyperplasias in the nasal cavity and nasopharynx were observed in the rats exposed to 1 and 5 mg/m(3) MWCNTs, but these lesions had largely regressed by the end of the postexposure period. Based on the histopathological and inflammatory changes, the no-observed-adverse-effect level (NOAEL) for inhalation of MWCNTs for 2 weeks was 0.2 mg/m(3).” As taken from Umeda Y et al. 2013. J. Toxicol. Pathol. 26(2), 131-40. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23914055

“For hazard assessment of multiwalled carbon nanotubes (MWCNTs), a 90-day inhalation toxicity study has been performed with Nanocyl NC 7000 in accordance with OECD 413 test guideline. MWCNTs produced no systemic toxicity. However, increased lung weights, multifocal granulomatous inflammation, diffuse histiocytic and neutrophilic infiltrates, and intra-alveolar lipoproteinosis were observed in lung and lung-associated lymph nodes at 0.5 and 2.5mg/m(3). Additional investigations of the lungs were performed, including special stains for examination of connective tissue, and electron microscopy was performed to determine the location of the MWCNTs. The alveolar walls revealed no increase of collagen fibers, whereas within the microgranulomas a slight increase of collagen fibers was observed. The pleura did not reveal any increase in collagen fibers. Only a slight increase in reticulin fibers in the alveolar walls in animals of the 0.5 and 2.5mg/m(3) concentration group was noted. In the 0.1mg/m(3) group, the only animal revealing minimal granulomas exhibited a minimal increase in collagen within the granuloma. No increase in reticulin was observed. Electron microscopy demonstrated entangled MWCNTs within alveolar macrophages. Occasionally electron dense particles/detritus were observed within membrane-bound vesicles (interpreted as phagosomes), which could represent degraded MWCNTs. If so, MWCNTs were degradable by alveolar macrophages and not persistent within the lung. Inhalation of MWCNTs caused granulomatous inflammation within the lung parenchyma but not the pleura in any of the concentration groups. Thus, there are some similarities to effects caused by inhaled asbestos, but the hallmark effects, namely pleural inflammation and/or fibrosis leading to mesotheliomas, are absent.” As taken from Treumann S et al. 2013. Toxicol. Sci. 134(1), 103-10. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23570993

“This study investigated the in vivo pulmonary toxicity of inhaled multi-walled carbon nanotubes (MWCNT). Mice-inhaled aerosolized MWCNT (10 mg/m³, 5 h/day) for 2, 4, 8 or 12 days. MWCNT lung burden was linearly related to exposure duration. MWCNT-induced pulmonary inflammation was assessed by determining whole lung lavage (WLL) polymorphonuclear leukocytes (PMN). Lung cytotoxicity was assessed by WLL fluid LDH activities. WLL fluid albumin concentrations were determined as a marker of alveolar air-blood barrier integrity. These parameters significantly increased in MWCNT-exposed mice versus controls and were dose-dependent. Histopathologic alterations identified in the lung included (1) bronciolocentric inflammation, (2) bronchiolar epithelial hyperplasia and hypertrophy, (3) fibrosis, (4) vascular changes and (5) rare pleural penetration. MWCNT translocated to the lymph node where the deep paracortex was expanded after 8 or 12 days. Acute inhalation of MWCNT induced dose-dependent pulmonary inflammation and damage with rapid development of pulmonary fibrosis, and also demonstrated that MWCNT can reach the pleura after inhalation exposure.” As taken from Porter DW et al. 2013. Nanotoxicology 7, 1179-94. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/22881873

"….The present study was designed to seek a simple, effective, and oxidative stress-based biomarker system used for screening toxicity of nanomaterials. Nano-ferroso-ferric oxide (nano-Fe3O4), nano-silicon dioxide (nano-SiO2), and single-walled carbon nanotubes (SWCNTs) were dispersed in corn oil and characterized using transmission electron microscopy (TEM). Rats were exposed to the three nanomaterials by intratracheal instillation once every 2 days for 5 weeks. We investigated their lung oxidative and inflammatory damage by bronchoalveolar lavage fluid (BALF) detection and comparative proteomics by lung tissue. Two-dimensional electrophoresis (2-DE) of proteins isolated from the lung tissue, followed by matrix-assisted laser desorption-ionization time-of-flight mass spectrometry, was performed. In the present study, we chose to detect lactate dehydrogenase, total antioxidant capacity, superoxide dismutase, and malondialdehyde as the biomarker system for screening the oxidative stress of nanomaterials and IL-6 as the inflammatory biomarker in BALF. Proteomics analysis revealed 17 differentially expressed proteins compared with the control group: nine were upregulated and eight were downregulated. Our results indicated that exposure by intratracheal instillation to any of the three typical nanomaterials may cause lung damage through oxidative damage and/or an inflammatory reaction." As taken from Lin Z et al. 2013. Nanoscale Res. Lett. 8(1), 521. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24321467

"NIOSH systematically reviewed 54 laboratory animal studies, many of which indicated that CNT/CNF could cause adverse pulmonary effects including inflammation (44/54), granulomas (27/54), and pulmonary fibrosis (25/54).

The estimated risk of developing early-stage (slight or mild) lung effects over a working lifetime if exposed to CNT at the analytical limit of quantification (NIOSH Method 5040) of 1 µg/m3 (8-hr time-weighted average [TWA] as respirable elemental carbon) is approximately 0.5% to 16% (upper confidence limit estimates) (Table A–8). In addition, the working lifetime equivalent estimates of the animal no observed adverse effect level (NOAEL) of CNT or CNF were also near 1 µg/m3 (8-hr TWA).

The concern about worker exposure to CNT or CNF arises from the results of recent laboratory animal studies with CNT and CNF. Short-term and subchronic studies in rats and mice have shown qualitatively consistent noncancerous adverse lung effects including pulmonary inflammation, granulomas, and fibrosis with inhalation, intratracheal instillation, or pharyngeal aspiration of several types of CNT (single or multiwall; purified or unpurified). These early-stage, noncancerous adverse lung effects in animals include: (1) the early onset and persistence of pulmonary fibrosis in CNT-exposed mice [Shvedova et al. 2005, 2008; Porter et al. 2010; Mercer et al. 2011], (2) an equal or greater potency of CNT compared with other inhaled particles known to be hazardous (e.g., crystalline silica, asbestos) in causing pulmonary inflammation and fibrosis [Lam et al. 2004; Shvedova et al. 2005; Muller et al. 2005], and (3) reduced lung clearance in mice or rats exposed to relatively low-mass concentrations of CNT [Mercer et al. 2009; Pauluhn 2010a]. Findings of acute pulmonary inflammation and interstitial fibrosis have also been observed in mice exposed to CNF [Murray et al. 2012]. The extent to which these animal data may predict clinically significant lung effects in workers is not known. However, NIOSH considers these animal study findings of pulmonary inflammation, granulomas, and fibrosis associated with exposure to CNT and CNF to be relevant to human health risk assessment because similar lung effects have been observed in workers in dusty jobs [Rom and Markowitz 2006; Hubbs et al. 2011].

…in experimental animal studies, both unpurified and purified (low metal content) CNT are associated with early onset and persistent pulmonary fibrosis and other adverse lung effects [Lam et al. 2004; Shvedova et al. 2005; 2008]. Other studies indicate that differences in physical-chemical properties, including functionalization or bio-modification, may alter the lung retention and biological responses [Kagan et al. 2010; Osmond-McLeod et al. 2011; Pauluhn 2010a; Oyabu et al. 2011]. Although a number of different types of CNT and CNF have been evaluated, uncertainty exists on the generalizability of the current animal findings to new CNT and CNF.

Studies in mice exposed to multi-walled carbon nanotubes (MWCNT) have shown the migration of MWCNT from the pulmonary alveoli to the intrapleural space [Hubbs et al. 2009; Porter et al. 2010; Mercer et al. 2010]. The intrapleural space is the same site in which malignant mesothelioma can develop due to asbestos exposure. Intraperitoneal injection of CNT in mice has resulted in inflammation from long MWCNT (> 5 μm in length), but not short MWCNT (< 1 μm in length) or tangled CNT [Poland et al. 2008; Takagi et al. 2008; Muller et al. 2009; Murphy et al. 2011]. In rats administered CNT by peritoneal injection, the pleural inflammation and mesothelioma were related to the thin diameter and rigid structure of MWCNT [Nagai et al. 2011]. In a study of rats administered MWCNT or crocidolite by intrapulmonary spraying, exposure to either material produced inflammation in the lungs and pleural cavity in addition to mesothelial proliferative lesions [Xu et al. 2012].

NIOSH considers the pulmonary responses of inflammation and fibrosis observed in short-term and subchronic studies in animals to be relevant to humans, as inflammatory and fibrotic effects are also observed in occupational lung diseases associated with workplace exposures to other inhaled particles and fibers. Uncertainties include the extent to which these lung effects in animals are associated with functional deficits and whether similar effects would be clinically significant among workers. However, these fibrotic lung effects observed in some of the animal studies developed early (e.g., 28 days after exposure) in response to relatively low-mass lung doses, and also persisted or progressed after the end of exposure [Shvedova et al. 2005, 2008; Ma-Hock et al. 2009; Pauluhn 2010a; Porter et al. 2010; Mercer et al. 2011; DeLorme et al. 2012; Murray et al. 2012]. Given the relevance of these types of lung effects to humans, the REL was derived using the published subchronic and short-term animal studies with dose-response data of early stage fibrotic and inflammatory lung responses to CNT exposure."

As taken from NIOSH, 2013.

"Toxicity of engineered nanomaterials is associated with their inherent properties, both physical and chemical. Recent studies have shown that exposure to multi-walled carbon nanotubes (MWCNTs) promotes tumors and tumor-associated pathologies and lead to carcinogenesis in model in vivo systems. Here in we examined the potential of purified MWCNTs used at occupationally relevant exposure doses for particles not otherwise regulated to affect human lung epithelial cells. The uptake of the purified MWCNTs was evaluated using fluorescence activated cell sorting (FACS), while the effects on cell fate were assessed using 2- (4-iodophenyl) - 3- (4-nitrophenyl) - 5-(2, 4-disulfophenyl) -2H-tetrazolium salt colorimetric assay, cell cycle and nanoindentation. Our results showed that exposure to MWCNTs reduced cell metabolic activity and induced cell cycle arrest. Our analysis further emphasized that MWCNTs-induced cellular fate results from multiple types of interactions that could be analyzed by means of intracellular biomechanical changes and are pivotal in understanding the underlying MWCNTs-induced cell transformation." As taken from Dong C et al. 2014. Environ. Sci. Nano. 1(6), 95-603. PubMed, 2015 available at http://www.ncbi.nlm.nih.gov/pubmed/25485116.

"Recent studies indicate that the brain is a target for toxic carbonaceous nanoparticles present in ambient air. It has been proposed that the neurotoxic effects of such particles are driven by nicotinamide adenine dinucleotide phosphate (NADPH) oxidase mediated generation of reactive oxygen species (ROS) in activated microglia. In the present study, we have evaluated the effects of short term (4h) nose-only inhalation exposure to carbon NP (CNP) in the brains and lungs of C57BL/6J mice and in p47(phox-/-) mice that lack a functional NADPH oxidase. It was shown that the lungs of the p47(phox-/-) mice are less responsive to CNP inhalation than lungs of the corresponding C57BL/6J control animals. Lung tissue mRNA expression of the oxidative stress/DNA damage response genes 8-oxoguanine glycosylase (OGG1) and apurinic/apyrimidinic endonuclease 1 (APE1) were induced by CNP exposure in C57BL/6J but not in the p47(phox-/-) mice. In contrast, the expression of these genes, as well as Tumor Necrosis Factor-α (TNFα), Cyclooxygenase-2 (COX-2) and Heme Oxygenase-1 (HO-1) was not altered in the olfactory bulb, cerebellum or remaining brain tissue part of either mouse background. This indicates that

neuroinflammation was not induced by this exposure. CNP inhalation for 4h or for 4h on three consecutive days also did not affect brain tissue protein expression of interleukin (IL)-1β, while a clear significant difference in constitutive expression level of this pro-inflammatory cytokine was found between C57BL/6J and p47(phox-/-) mice. In conclusion, short-term inhalation exposure to pure carbon nanoparticles can trigger mild p47(phox) dependent oxidative stress responses in the lungs of mice whereas in their brains at the same exposure levels signs of oxidative stress and inflammation remain absent. The possible role of p47(phox) in the neuro-inflammatory effects of nanoparticles in vivo remains to be clarified." As taken from van Berlo D et al. 2014. Neurotoxicology 43, 65-72. PubMed, 2015 available at http://www.ncbi.nlm.nih.gov/pubmed/24792328.

"Human Health Assessment

….. Hazards related to substances used in the workplace should be classified accordingly under the Workplace Hazardous Materials Information System (WHMIS). However, based on the available information on structurally related nanomaterials, the substance may cause respiratory toxicity, ….. following oral and inhalation exposure. ….."

As taken from Environment Canada, 2015

"Carbon nanotubes (CNTs) are rapidly emerging as high-priority occupational toxicants. CNT powders contain fibrous particles that aerosolize readily in places of manufacture and handling, posing an inhalation risk for workers. Studies using animal models indicate that lung exposure to CNTs causes prolonged inflammatory responses and diffuse alveolar injury. The mechanisms governing CNT-induced lung inflammation are not fully understood but have been suggested to involve alveolar macrophages (AMs). In the current study, we sought to systematically assess the effector role of AMs in vivo in the induction of lung inflammatory responses to CNT exposures and investigate their cell type-specific mechanisms. Multi-wall CNTs characterized for various physicochemical attributes were used as the CNT type. Using an AM-specific depletion and repopulation approach in a mouse model, we unambiguously demonstrated that AMs are major effector cells necessary for the in vivo elaboration of CNT-induced lung inflammation. We further investigated in vitro AM responses and identified molecular targets which proved critical to pro-inflammatory responses in this model, namely MyD88 as well as MAPKs and Ca(2+)/CamKII. We further demonstrated that MyD88 inhibition in donor AMs abrogated their capacity to reconstitute CNT-induced inflammation when adoptively transferred into AM-depleted mice. Taken together, this is the first in vivo demonstration that AMs act as critical effector cell types in CNT-induced lung inflammation and that MyD88 is required for this in vivo effector function. AMs and their cell type-specific mechanisms may therefore represent potential targets for future therapeutic intervention of CNT-related lung injury." As taken from Frank EA et al. 2015. Toxicol. Appl. Pharmacol. 288(3), 322-9. PubMed, 2016 available at http://www.ncbi.nlm.nih.gov/pubmed/26272622

"An in vitro model resembling the respiratory epithelium was used to investigate the biological response to laboratory-made pristine and functionalised multi-walled carbon nanotubes (pMWCNT and MWCNT-COOH). Cell uptake was analysed by MWCNT-COOH, FITC labelled and the effect of internalisation was evaluated on the endocytic apparatus, mitochondrial compartment and DNA integrity. In the dose range 12.5-100μgml(-1), cytotoxicity and ROS generation were assayed, evaluating the role of iron (the catalyst used in MWCNTs synthesis). We observed a correlation between MWCNTs uptake and lysosomal dysfunction and an inverse relationship between these two parameters and cell viability ($P<0.01$). In particular, pristine-MWCNT caused a time- and dose-dependent ROS increase and higher levels of lipid hydroperoxides compared to the controls. Mitochondrial impairment was observed. Conversely to the functionalised MWCNT, higher micronuclei (MNi) frequency was detected in mono- and binucleate pMWCNT-treated cells, underlining an aneugenic effect due to mechanical damage. Based on the physical and chemical features of MWCNTs, several toxicological pathways could be activated in respiratory epithelium upon their inhalation. The biological impacts of nano-needles were imputable to their efficient and very fast uptake and to the resulting mechanical damages in cell compartments. Lysosomal

dysfunction was able to trigger further toxic effects." As taken from Visalli G et al. 2015. Toxicol. In Vitro 29(2), 352-62. PubMed, 2016 available at http://www.ncbi.nlm.nih.gov/pubmed/25499066

"There is a current interest in reducing the in vivo toxicity testing of nanomaterials in animals by increasing toxicity testing using in vitro cellular assays; however, toxicological results are seldom concordant between in vivo and in vitro models. This study compared global multi-walled carbon nanotube (MWCNT)-induced gene expression from human lung epithelial and microvascular endothelial cells in monoculture and coculture with gene expression from mouse lungs exposed to MWCNT. Using a cutoff of 10% false discovery rate and 1.5 fold change, we determined that there were more concordant genes (gene expression both up- or downregulated in vivo and in vitro) expressed in both cell types in coculture than in monoculture. When reduced to only those genes involved in inflammation and fibrosis, known outcomes of in vivo MWCNT exposure, there were more disease-related concordant genes expressed in coculture than monoculture. Additionally, different cellular signaling pathways are activated in response to MWCNT dependent upon culturing conditions. As coculture gene expression better correlated with in vivo gene expression, we suggest that cellular cocultures may offer enhanced in vitro models for nanoparticle risk assessment and the reduction of in vivo toxicological testing." As taken from Snyder-Talkington BN et al. 2015. Toxicology 328, 66-74. PubMed, 2016 available at http://www.ncbi.nlm.nih.gov/pubmed/25511174

"We summarized the findings of in vivo toxicity studies of single-walled carbon nanotubes (SWCNTs) in laboratory animals. ..... Injected SWCNTs were distributed throughout most of the organs including the brain, mainly retained in the lungs, liver, and spleen, and eliminated through the kidney and bile duct. Orally administered SWCNTs are suggested to be absorbed from the gastrointestinal tract to the blood circulation in mice and rats. ..... Overall, the available data provides initial information on SWCNT toxicity. To further clarify their toxicity and risk assessment, studies should be conducted using well-characterized SWCNTs, standard protocols, and the relevant route and doses of human exposure." As taken from Ema M et al. 2016. Regul. Toxicol. Pharmacol. 74, 42-63. PubMed, 2016 available at http://www.ncbi.nlm.nih.gov/pubmed/26619783

"A 4-year-old, spayed female French Bulldog was presented for respiratory distress and suspected aspiration pneumonia after oral administration of activated charcoal for possible ingestion of a suspected toxic dose of trazodone. The patient had a moderate volume of pleural effusion, which contained free and intracellular black particulate matter consistent with charcoal. Due to presumed charcoal aspiration with subsequent lung rupture, the right middle and right caudal lung lobes were surgically removed. Histology revealed abundant black debris consistent with charcoal and severe granulomatous inflammation. Based on the clinical, gross, and histologic findings, a diagnosis of severe, chronic, locally extensive, aspiration pneumonia and lung rupture with secondary pleuritis and mediastinitis due to charcoal aspiration was made. Aspiration pneumonia is the main complication of activated charcoal administration, which can incite extensive, granulomatous inflammation in the respiratory tract. To the authors' knowledge, this is the first report describing the cytologic and histologic findings associated with inadvertent charcoal aspiration in a veterinary species." As taken from Caudill MN et al. 2019. Vet. Clin. Pathol. 48(1), 67-70. PubMed, 2019 available at: https://www.ncbi.nlm.nih.gov/pubmed/30924544

"Background: Ambient air pollution accelerates lung function decline among adults, however, there are limited data about its role in the development and progression of early stages of interstitial lung disease. Aims: To evaluate associations of long-term exposure to traffic and ambient pollutants with odds of interstitial lung abnormalities (ILA) and progression of ILA on repeated imaging. Methods: We ascertained ILA on chest CT obtained from 2618 Framingham participants from 2008 to 2011. Among 1846 participants who also completed a cardiac CT from 2002 to 2005, we determined interval ILA progression. We assigned distance from home address to major roadway, and the 5-year average of fine particulate matter (PM2.5), elemental carbon (EC, a traffic-related PM2.5 constituent) and ozone using spatio-temporal prediction models. Logistic regression models were adjusted for age, sex, body mass index, smoking status, packyears of smoking, household tobacco

exposure, neighbourhood household value, primary occupation, cohort and date. Results: Among 2618 participants with a chest CT, 176 (6.7%) had ILA, 1361 (52.0%) had no ILA, and the remainder were indeterminate. Among 1846 with a preceding cardiac CT, 118 (6.4%) had ILA with interval progression. In adjusted logistic regression models, an IQR difference in 5-year EC exposure of 0.14 µg/m3 was associated with a 1.27 (95% CI 1.04 to 1.55) times greater odds of ILA, and a 1.33 (95% CI 1.00 to 1.76) times greater odds of ILA progression. PM2.5 and O3 were not associated with ILA or ILA progression. Conclusions: Exposure to EC may increase risk of progressive ILA, however, associations with other measures of ambient pollution were inconclusive." As taken from Rice MB et al. 2019. Thorax 74(11), 1063-1069. PubMed, 2020 available at https://pubmed.ncbi.nlm.nih.gov/31391318/

6.2. Cardiovascular system

"To measure the inflammatory and autonomic responses of healthy humans and patients with coronary artery disease to controlled concentrations of two specific components of vehicle derived air pollution, carbon particles and sulphur dioxide (SO2). METHODS: Placebo controlled, double blind, random order human challenge study examining the effects of carbon particles (50 microg/m3) and SO2 (200 parts per billion (ppb)) on heart rate variability (HRV) and circulating markers of inflammation and coagulation in healthy volunteers and patients with stable angina. RESULTS: In healthy volunteers, markers of cardiac vagal control did not fall in response to particle exposure but, compared with the response to air, increased transiently immediately after exposure (root mean square of successive RR interval differences (RMSSD) 15 (5) ms with carbon particles and 4 (3) ms) with air, $p < 0.05$). SO2 exposure resulted in no immediate change but a significant reduction in HRV markers of cardiac vagal control at four hours (RMSSD -2 (3.6) ms with air, -7 (2.7) ms with SO2, $p < 0.05$). No such changes were seen in patients with stable angina. Neither pollutant caused any change in markers of inflammation or coagulation at zero, four, or 24 hours. CONCLUSION: In healthy volunteers, short term exposure to pure carbon particles does not cause adverse effects on HRV or a systemic inflammatory response. The adverse effects of vehicle derived particulates are likely to be caused by more reactive species found on the particle surface. SO2 exposure does, however, reduce cardiac vagal control, a response that would be expected to increase susceptibility to ventricular arrhythmia." As taken from Routeledge et al., (2006), Heart. 2006 Feb;92(2):220-7, available at http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?db=pubmed&cmd=Retrieve&dopt=AbstractPlus&list_uids=15923279&query_hl=26&itool=pubmed_docsum

"While environmental particles are associated with mortality and morbidity related to pulmonary and cardiovascular (CV) disease, the mechanisms involved in CV health effects are not known. Changes in systemic clotting factors have been associated with pulmonary inflammation. We hypothesized that inhaled ultrafine particles result in an inflammatory response which may stimulate systemic clotting factor release. Adult male Wistar rats were exposed to either fine or ultrafine carbon black (CB) for 7 h. The attained total suspended particle concentrations were 1.66 mg/m(3) for ultrafine CB and 1.40 mg/m(3) for fine CB. Particle concentration of ultrafine particles was more than 10 times greater than that of fine particles and the count median aerodynamic diameter averaged 114 nm for the ultrafine and 268 nm for the fine carbon particles. Data were collected immediately, 16 and 48 h following exposure. Only ultrafine CB caused an increase in total bronchoalveolar lavage (BAL) leukocytes, whereas both fine (2-fold) and ultrafine (4-fold) carbon particles caused an increase in BAL neutrophils at 16 h postexposure. Exposure to the ultrafine, but not fine, carbon was also associated with significant increases in the total numbers of blood leukocytes. Plasma fibrinogen, factor VII and von Willebrand factor (vWF) were unaffected by particle treatments as was plasma Trolox equivalent antioxidant status (TEAC). Macrophage inflammatory protein-2 mRNA was significantly increased in BAL cells 48 h following exposure to ultrafine CB. The data show that there is a small but consistent significant proinflammatory effect of this exposure to ultrafine particles that is greater than the effect of the same exposure to fine CB." As taken from Gilmour et al., (2004), Toxicol Appl Pharmacol. 2004 Feb 15;195(1):35-44, available

at
http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?db=pubmed&cmd=Retrieve&dopt=AbstractPlus&list_uids=14962503&query_hl=26&itool=pubmed_docsum

“Ever increasing use of engineered carbon nanoparticles in nanopharmacology for selective imaging, sensor or drug delivery systems has increased the potential for blood platelet–nanoparticle interactions. We studied the effects of engineered and combustion-derived carbon nanoparticles on human platelet aggregation in vitro and rat vascular thrombosis in vivo. Multiplewall (MWNT), singlewall (SWNT) nanotubes, C60 fullerenes (C60CS) and mixed carbon nanoparticles (MCN) (0.2–300 mgml1) were investigated. Nanoparticles were compared with standard urban particulate matter (SRM1648, average size 1.4 mm). Platelet function was studied using lumi aggregometry, phase-contrast, immunofluorescence and transmission electron microscopy, flow cytometry, zymography and pharmacological inhibitors of platelet aggregation. Vascular thrombosis was induced by ferric chloride and the rate of thrombosis was measured, in the presence of carbon particles, with an ultrasonic flow probe. Carbon particles, except C60CS, stimulated platelet aggregation (MCNN>SWNT>MWNT>SRM1648) and accelerated the rate of vascular thrombosis in rat carotid arteries with a similar rank order of efficacy. All particles resulted in upregulation of GPIIb/IIIa in platelets. In contrast, particles differentially affected the release of platelet granules, as well as the activity of thromboxane-, ADP, matrix metalloproteinase- and protein kinase C-dependent pathways of aggregation. Furthermore, particle-induced aggregation was inhibited by prostacyclin and S-nitroso-glutathione, but not by aspirin. Thus, some carbon nanoparticles and microparticles have the ability to activate platelets and enhance vascular thrombosis. These observations are of importance for the pharmacological use of carbon nanoparticles and pathology of urban particulate matter” (Radomski et al., 2005. British Journal of Pharmacology 146, 882–893). As taken from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1751219/pdf/146-0706386a.pdf

“Sachar and Saxena (Sachar and Saxena 2011) administered single doses (100 μg/animal) of either SWCNTs or acid functionalized SWCNTs (AF-SWCNTs) to inbred Swiss and C57BL76 female mice (6–12 week old, weighing 20-25 g; number per group not reported) by either intratracheal instillation, intravenous (i.v.) or intra-peritoneal (i.p.) injections, or orally by gavage. The acid functionalized (AF)-SWCNTs were surface oxidized by a mixture of nitric and sulphuric acid under pressure at elevated temperature. The carboxylic acid moieties formed were derivatised by a fluorophor for imaging purposes, and were intensively purified to remove excess fluorescent dye. The particle size distribution and surface charge was not indicated. A transient decrease was observed in the number of erythrocytes and levels of blood haemoglobin (from 3 to 48 hours but not after 72 hours) after i.v. injection and to a lesser extent after i.p. injections of AF-SWCNTs as compared to SWCNTs. Administration of AF-SWCNTs through oral gavage and the i.p. route did not reduce erythrocyte count (haemoglobin was apparently not measured for these routes of as no information is given in the paper).”

As taken from Binderup et al. 2013.

“Epidemiologic and toxicologic studies were carried out in concert to provide complementary insights into the compositional features of ambient particulate matter (PM*) that produce cardiovascular effects. In the epidemiologic studies, we made use of cohort data from two ongoing studies--the Multi-Ethnic Study of Atherosclerosis (MESA) and the Women's Health Initiative--Observational Study (WHI-OS)--to investigate subclinical markers of atherosclerosis and clinical cardiovascular events. In the toxicologic study, we used the apolipoprotein E null (ApoE(-/-)) hypercholesterolemic mouse model to assess cardiovascular effects of inhalation exposure to various atmospheres containing laboratory-generated pollutants. In the epidemiologic studies, individual-level residential concentrations of fine PM, that is, PM with an aerodynamic diameter of 2.5 microm or smaller (PM2.5), PM2.5 components (primarily elemental carbon [EC] and organic carbon [OC], silicon, and sulfur but also sulfate, nitrate, nickel, vanadium, and copper), and the gaseous pollutants sulfur dioxide and nitrogen dioxide were estimated using spatiotemporal

modeling and other exposure estimation approaches. In the MESA cohort data, evidence for associations with increased carotid intima-media thickness (CIMT) was found to be strongest for PM2.5, OC, and sulfur, as well as for copper in more limited analyses; the evidence for this was found to be weaker for silicon, EC, and the other components and gases. Similarly, in the WHI-OS cohort data, evidence for associations with incidence of cardiovascular mortality and cardiovascular events was found to be good for OC and sulfur, respectively, and for PM2.5; the evidence for this was found to be weaker for EC and silicon. Source apportionment based on extensive monitoring data in the six cities in the MESA analyses indicated that OC represented secondary formation processes as well as primary gasoline and biomass emissions, that sulfur represented largely secondary inorganic aerosols, and that copper represented brake dust and diesel emissions. In the toxicologic study, hypercholesterolemic mice were exposed for 50 days to atmospheres containing mixed vehicular engine emissions (MVE) consisting of mixed gasoline and diesel engine exhaust or to MVE-derived gases only (MVEG). Mice were also exposed to atmospheres containing sulfate, nitrate, or road dust, either alone or mixed with MVE or MVEG. Sulfate alone or in combination with MVE was associated with increased aortic reactivity. All exposures to atmospheres containing MVE (including a combination of MVE with other PM) were associated with increases in plasma and aortic oxidative stress; exposures to atmospheres containing only sulfate or nitrate were not. Exposure to MVE and to MVEG combinations except those containing road dust resulted in increased monocyte/macrophage sequestration in aortic plaque (a measure of plaque inflammation). Exposure to all atmospheres except those containing nitrate was associated with enhanced aortic vasoconstriction. Exposure to the MVEG was an independent driver of lipid peroxidation, matrix metalloproteinase (MMP) activation, and vascular inflammation. The epidemiologic and toxicologic study designs were intended to complement each other. The epidemiologic studies provided evidence in real-world human settings, and the toxicologic study directly assessed the biologic effects of various pollutant mixtures (in a way that is not possible in epidemiologic studies) by examining endpoints that probably underlie the subclinical and clinical cardiovascular endpoints examined in the epidemiologic studies. The epidemiologic studies were not suited to determining whether the observed associations were caused by direct effects of individual pollutants or by the mixtures in which individual pollutants are found. These studies were consistent in finding that OC and sulfate had the strongest evidence for associations with the cardiovascular disease endpoints, with much weaker evidence for EC and silicon. Both OC and sulfate reflected a large secondary aerosol component. Results from the toxicologic study indicated, for the most part, that MVE and mixtures of MVE and MVEG with other PM pollutants were important in producing the toxic cardiovascular effects found in the study. Further work on the effects of pollutant mixtures and secondary aerosols should allow better understanding of the pollution components and sources most responsible for the adverse cardiovascular effects of air pollution exposure." As taken from Vedal S et al. 2013. Resp. Rep. Health Eff. Inst. 178, 5-8. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24377210

"Carbon nanotubes (CNTs) find their extensive application as a promising material in medicine due to unique characteristics. However, such materials have been accompanied with potentially hazardous effects on human health. The toxicity of CNTs may vary depending on their structural characteristics, surface properties and chemical composition. To gain insight into the toxicity of CNTs in vivo and in vitro, we summarize contributing factors for the toxic effects of CNTs in this review. In addition, we elaborate on the toxic effects and mechanisms in target sites at systemic, organic, cellular, and biomacromolecule levels. Various issues are reported to be effected when exposed to CNTs including (1) blood circulation, (2) lymph circulation, (3) lung, (4) heart, (5) kidney, (6) spleen, (7) bone marrow, and (8) blood brain barrier. Though there have been published reports on thetoxic effects of CNTs to date, more studies will still be needed to gain full understanding of their potential toxicity and underlying mechanisms." As taken from Wang J et al. 2013a. Curr. Drug. Metab. 14(8), 891-9. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24016107

Pulmonary exposure to CNT has also produced systemic responses including an increase in inflammatory mediators in the blood, as well as oxidant stress in aortic tissue and increase

plaque formation in an atherosclerotic mouse model [Li et al. 2007; Erdely et al. 2009]. Pulmonary exposure to MWCNT also depresses the ability of coronary arterioles to respond to dilators [Stapleton et al. 2011]. These cardiovascular effects may be due to neurogenic signals from sensory irritant receptors in the lung. Mechanisms, such as inflammatory signals or neurogenic pathways causing these systemic responses, are under investigation.

As taken from NIOSH, 2013.

“We summarized the findings of in vivo toxicity studies of single-walled carbon nanotubes (SWCNTs) in laboratory animals. ….. Airway exposure to SWCNTs also induced cardiovascular diseases in mice. ….. Overall, the available data provides initial information on SWCNT toxicity. To further clarify their toxicity and risk assessment, studies should be conducted using well-characterized SWCNTs, standard protocols, and the relevant route and doses of human exposure.” As taken from Ema M et al. 2016. Regul. Toxicol. Pharmacol. 74, 42-63. PubMed, 2016 available at http://www.ncbi.nlm.nih.gov/pubmed/26619783

“Human Health Assessment

….. Hazards related to substances used in the workplace should be classified accordingly under the Workplace Hazardous Materials Information System (WHMIS). However, based on the available information on structurally related nanomaterials, the substance may cause …. cardiovascular toxicity …. following oral and inhalation exposure…….”

As taken from Environment Canada, 2015

6.3. Nervous system

“Recent observations have demonstrated that nanomaterials may be toxic to human tissue. While the ability of nano-scaled particulate matter is known to cause a range of problems in respiratory system, recent observations suggest that the nervous system may be vulnerable as well. In the current paper we asked whether exposure of primary neuronal cell cultures to nanoparticles might compromise regenerative axon growth. Regenerative response was triggered by performing a conditioning lesion of sciatic nerve five days prior to collection of dorsal root ganglia (DRG). DRG neurons were plated at a low density and incubated with multi-walled carbon nanotubes (MWCNTs) (0.1-10 μg/ml in 10% of surfactant in saline) overnight. The experiments showed that exposure of DRG cultures to MWCNT significantly impaired regenerative axonogenesis without concomitant cell death. These results indicate that MWNCTs may have detrimental effect on nerve regeneration and may potentially trigger axonal pathology” (Wu et al., 2012. Neuroscience Letters 507, 72-77). As taken from http://www.ncbi.nlm.nih.gov/pubmed/22172934

“This study was to investigate the neurotoxicity of multi-walled carbon nanotube (MWCNT) by measuring neuronal excitability in rat hippocampal neurons and exploring the underlying mechanism. Whole cell patch-clamp technique was used. Action potential properties and the pattern of repetitive firing rate were assessed. Our data showed that spike half-width and repetitive firing rate were significantly increased in a concentration-dependent manner. Furthermore, voltage-activated potassium currents were recorded. It was found that MWCNT produced a concentration-dependent inhibition in amplitudes of I(A) and I(K). In addition, MWCNT had effect on the activation kinetics of I(A) and I(K) with V(h) being shifted to the negative potential at high concentration, while I(A) inactivation curve was considerably shifted to the hyperpolarize potential with V(h) being increased. However, no effect was found on the recovery from inactivation of I(A). The results suggest that MWCNT increases the excitability of hippocampal CA1 neurons by inhibiting voltage-gated potassium current.” As taken from Chen T et al. 2013a. Toxicol. Lett. 217(2), 121-8. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23274715

“The assay of the toxic effects of carbon nanotubes (CNTs) on human health is a stringent need in view of their expected increasing exploitation in industrial and biomedical applications. Most studies so far have been focused on lung toxicity, as the respiratory tract is the main entry of airborne

particulate, but there is also recent evidence on the existence of toxic effects of multiwalled carbon nanotubes (MWCNTs) on neuronal and neuroendocrine cells (Belyanskaya et al., 2009; Xu et al., 2009; Gavello et al., 2012). Commercial MWCNTs often contain large amounts of metals deriving from the catalyst used during their synthesis. Since metals, particularly iron, may contribute to the toxicity of MWCNTs, we compared here the effects of two short MWCNTs samples (<5μm length), differing only in their iron content (0.5 versus 0.05% w/w) on the secretory responses of neurotransmitters in mouse chromaffin cells. We found that both iron-rich (MWCNT+Fe) and iron-deprived (MWCNT-Fe) samples enter chromaffin cells after 24h exposure, even though incorporation was attenuated in the latter case (40% versus 78% of cells). As a consequence of MWCNT+Fe or MWCNT-Fe exposure (50-263μg/ml, 24h), catecholamine secretion of chromaffin cells is drastically impaired because of the decreased Ca(2+)-dependence of exocytosis, reduced size of ready-releasable pool and lowered rate of vesicle release. On the contrary, both MWCNTs were ineffective in changing the kinetics of neurotransmitter release of single chromaffin granules and their quantal content. Overall, our data indicate that both MWCNT samples dramatically impair secretion in chromaffin cells, thus uncovering a true depressive action of CNTs mainly associated to their structure and degree of aggregation. This cellular "loss-of-function" is only partially attenuated in iron-deprived samples, suggesting a minor role of iron impurities on MWCNTs toxicity in chromaffin cells exocytosis." As taken from Gavello D et al. 2013. Neurotoxicology 39, 84-94. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23999117

"We evaluated local inflammatory activity of oxidized multiwalled carbon nanotubes in rat experimental models of acute inflammation (paw edema and hyperalgesia) by analyzing their toxicity in non-mesoendothelial tissues. Subcutaneous injection of the nanotubes induced paw edema, that was maximal in the first 2 h after administration at 0.1 mg/kg (43.25 +/- 3.8 AUC) and 1 mg/kg (30.1 +/- 1.8 AUC) compared to saline (18.32 +/- 02.05 AUC). The histopathological analysis showed acute inflammation characterized by vasodilatation, edema formation, neutrophil infiltrate and tissue damage. The nanotubes also elicited hyperalgesic response, seen by the increase of animal paw withdrawal that was maximal in the first 3 hours. The data obtained at the 3rd h was: 75 +/- 9.3% (0.01 mg/kg), 58 +/- 8.3% (0.1 mg/kg) and 53 +/- 6.69% (1 mg/kg) in relation with saline (28 +/- 3.5%). In conclusion, the oxidized multiwalled carbon nanotubes elicit inflammatory and hyperalgesic effects associated to severe tissue damage in rats." As taken from Pinto NV et al. 2013. J. Nanosci. Nanotechnol. 13(8), 5276-82. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23882754

"Carbon nanotubes (CNTs) have become an intriguing and promising biomaterial platform for the regeneration and functional recovery of damaged nerve tissues. The unique electrical, structural and mechanical properties, diversity of available surface chemistry and cell-penetrating ability of CNTs have made them useful implantable matrices or carriers for the delivery of therapeutic molecules. Although there are still challenges being faced in the clinical applications of CNTs mainly due to their toxicity, many studies to overcome this issue have been published. Modification of CNTs with chemical groups to ensure their dissolution in aqueous media is one possible solution. Functionalization of CNTs with biologically relevant and effective molecules (biofunctionalization) is also a promising strategy to provide better biocompatibility and selectivity for neural regeneration. Here, we review recent advances in the use of CNTs to promote neural regeneration." As taken from Hwang JY et al. 2013. Nanoscale 5(2), 487-97. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23223857

"Recent studies indicate that the brain is a target for toxic carbonaceous nanoparticles present in ambient air. It has been proposed that the neurotoxic effects of such particles are driven by nicotinamide adenine dinucleotide phosphate (NADPH) oxidase mediated generation of reactive oxygen species (ROS) in activated microglia. In the present study, we have evaluated the effects of short term (4h) nose-only inhalation exposure to carbon NP (CNP) in the brains and lungs of C57BL/6J mice and in p47(phox-/-) mice that lack a functional NADPH oxidase. It was shown that the lungs of the p47(phox-/-) mice are less responsive to CNP inhalation than lungs of the corresponding C57BL/6J control animals. Lung tissue mRNA expression of the oxidative

stress/DNA damage response genes 8-oxoguanine glycosylase (OGG1) and apurinic/apyrimidinic endonuclease 1 (APE1) were induced by CNP exposure in C57BL/6J but not in the p47(phox-/-) mice. In contrast, the expression of these genes, as well as Tumor Necrosis Factor-α (TNFα), Cyclooxygenase-2 (COX-2) and Heme Oxygenase-1 (HO-1) was not altered in the olfactory bulb, cerebellum or remaining brain tissue part of either mouse background. This indicates that neuroinflammation was not induced by this exposure. CNP inhalation for 4h or for 4h on three consecutive days also did not affect brain tissue protein expression of interleukin (IL)-1β, while a clear significant difference in constitutive expression level of this pro-inflammatory cytokine was found between C57BL/6J and p47(phox-/-) mice. In conclusion, short-term inhalation exposure to pure carbon nanoparticles can trigger mild p47(phox) dependent oxidative stress responses in the lungs of mice whereas in their brains at the same exposure levels signs of oxidative stress and inflammation remain absent. The possible role of p47(phox) in the neuro-inflammatory effects of nanoparticles in vivo remains to be clarified." As taken from van Berlo D et al. 2014. Neurotoxicology 43, 65-72. PubMed, 2015 available at http://www.ncbi.nlm.nih.gov/pubmed/24792328.

"Multi-walled carbon nanotubes (MWCNTs) have shown potential applications in many fields, especially in the field of biomedicine. Several studies have reported that MWCNTs induce apoptosis and oxidative damage in nerve cells during in vitro experiments. However, there are few studies focused on the neurotoxicity of MWCNTs used in vivo. Many studies have reported that autophagy, a cellular stress response to degrade damaged cell components, can be activated by diverse nanoparticles. In this study, we investigated the neurotoxic effects of MWCNTs on hippocampal synaptic plasticity and spatial cognition in rats. Then, we used an inhibitor of autophagy called chloroquine (CQ) to examine whether autophagy plays an important role in hippocampal synaptic plasticity, since this was damaged by MWCNTs. In this study, adult male Wister rats were randomly divided into three groups: a control group, a group treated with MWCNTs (2.5mg/kg/day) and a group treated with MWCNTs+CQ (20mg/kg/day). After two-weeks of intraperitoneal (i.p.) injections, rats were subjected to the Morris water maze (MWM) test, and the long-term potentiation (LTP) and other biochemical parameters were determined. Results showed that MWCNTs could induce cognitive deficits, histopathological alteration and changes of autophagy level (increased the ratio of LC3 II /LC3 I and the expression of Beclin-1). Furthermore, we found that CQ could suppress MWCNTs-induced autophagic flux and partly rescue the synapse deficits, which occurred with the down-regulation of NR2B (a subunit of NMDA receptor) and synaptophysin (SYP) in the hippocampus. Our results suggest that MWCNTs could induce cognitive deficits in vivo via the increased autophagic levels, and provide a potential strategy to avoid the adverse effects of MWCNTs." As taken from Gao J et al. 2015. Toxicology 337, 21-9. PubMed, 2016 available at http://www.ncbi.nlm.nih.gov/pubmed/26327526

6.4. Other organ systems, dependent on the properties of the substance

"The management of hyperphosphataemia remains a challenge in people with CKD, particularly those requiring dialysis. In this study, Wang et al demonstrate the potential efficacy of activated charcoal at lowering phosphate and PTH levels. ABSTRACT: Aim: Hyperphosphatemia is almost inevitable in end stage renal disease (ESRD) patients and is associated with increased morbidity and mortality. In this study we examined whether oral activated charcoal (oAC) reduces serum phosphate level in hemodialysis patients. Methods: This was an open-label, prospective, uncontrolled study. One hundred and thirty-five hemodialysis patients were included in this study, with cessation of treatment with any phosphate binders during a 2-week washout period. Patients with serum phosphate levels greater than 5.5mg/dl during the washout period were included for treatment with oAC. oAC was started at a dose of 600mg three times per day with meals, and was administered for 24 weeks. oAC dose was titrated up during the 24-week period to achieve phosphate control(3.5-5.5mg/dl). A second 2-week washout period followed the end of oAC treatment. Results: In the 114 patients who successfully completed the trial, the mean dose of activated charcoal was 3190±806mg/day. oAC reduced mean phosphate levels to below 5.5mg/dl,

with mean decreases of 2.60 ± 0.11 mg/dl($p<0.01$), and 103(90.4%) of the patients reached the phosphate target. After the second washout period the phosphate levels increased to 7.50 ± 1.03 mg/dl ($p<0.01$). Serum intact parathyroid hormone (iPTH) levels declined from 338.75±147.77 pg/ml to 276.51±127.82 pg/ml ($p<0.05$) during the study. oAC had no influence on serum prealbumin, total cholesterol, triglycerides, serum ferritin, haemoglobin or platelet levels, and the levels of 1,25-dihydroxyvitamin D were stable during the study. Conclusion: In this open-label uncontrolled study, oAC effectively controls hyperphosphatemia and hyperparathyroidism in hemodialysis patients. the safety and efficacy of oAC need to be assessed in a randomized controlled trial" (Wang et al. 2012. Nephrology (Carlton) 17(7), 616-20). As taken from http://www.ncbi.nlm.nih.gov/pubmed/22697887

"In the course of severe pathological conditions, such as acute liver failure and sepsis, toxic metabolites and mediators of inflammation are released into the patient's circulation. One option for the supportive treatment of these conditions is plasmapheresis, in which plasma, after being separated from the cellular components of the blood, is cleansed by adsorption of harmful molecules on polymers or activated carbon. In this work, the adsorption characteristics of activated carbon beads with levels of activation ranging from 0 to 86% were assessed for both hydrophobic compounds accumulating in liver failure (bilirubin, cholic acid, phenol and tryptophan) and cytokines (tumor necrosis factor α and interleukin-6). Progressive activation resulted in significant gradual reduction of both bulk density and mean particle size, in an increase in the specific surface area, and to changes in pore size distribution with progressive broadening of micropores. These structural changes went hand in hand with enhanced adsorption of small adsorbates, such as IL-6 and cholic acid and, to a lesser extent, also of large molecules, such as TNF-α" (Tripisciano et al. 2011. Biomacromolecules 12, 3733-3740). As taken from http://www.ncbi.nlm.nih.gov/pubmed/21842874

"Carbon nanotubes (CNTs) have been used in orthopaedic applications because of their exceptional mechanical properties. However, the influence of CNTs on the behaviour of bone-forming cells and on the ability of these cells to respond to growth factors, such as bone morphogenetic proteins (BMPs), remains poorly known. Therefore, in the present study, single-walled CNTs (SWCNTs) were synthesised using an induction thermal plasma process and purified using a multistep procedure. The impact of these purified SWCNTs on the Smad activation, cell proliferation and differentiation, with or without BMP-2 and BMP-9 (1.92 nM), was also studied using western blot, mitochondrial enzymatic activity, TUNEL, RT-PCR and alkaline phosphatase activity analyses. Pre-treatment of MC3T3-E1 preosteoblasts with SWCNTs accelerated the Smad1/5/8 activation, induced by both BMP-2 and BMP-9, within 15 min. It also slightly affected their proliferation at 48 h without apoptosis. Interestingly, at 72 h, BMP-9 favoured the differentiation of MC3T3-E1 preosteoblasts pretreated with SWCNTs to a larger extent than BMP-2 did. Therefore, the combination of BMP-9 with SWCNTs appears to be a promising avenue for bone applications." As taken from Alinejad Y et al. 2013. J. Biomed. Nanotechnol. 9(11), 1904-13. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24059089?dopt=AbstractPlus

"Carbon nanotubes (CNTs) find their extensive application as a promising material in medicine due to unique characteristics. However, such materials have been accompanied with potentially hazardous effects on human health. The toxicity of CNTs may vary depending on their structural characteristics, surface properties and chemical composition. To gain insight into the toxicity of CNTs in vivo and in vitro, we summarize contributing factors for the toxic effects of CNTs in this review. In addition, we elaborate on the toxic effects and mechanisms in target sites at systemic, organic, cellular, and biomacromolecule levels. Various issues are reported to be effected when exposed to CNTs including (1) blood circulation, (2) lymph circulation, (3) lung, (4) heart, (5) kidney, (6) spleen, (7) bone marrow, and (8) blood brain barrier. Though there have been published reports on thetoxic effects of CNTs to date, more studies will still be needed to gain full understanding of their potential toxicity and underlying mechanisms." As taken from Wang J et al. 2013a. Curr. Drug. Metab. 14(8), 891-9. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24016107

“Awasthi and co-workers (Awasthi et al. 2013) administered male Swiss albino mice (N=6/group) single doses of 0 (vehicle control, distilled water), 60, or 100 mg/kg bw) of MWCNTs and studied hepatotoxicity on post dosing days 7, 14, 21 and 28 using liver SOD and CAT activity and microscopic examination as end-points. The tested MWCNTs, which were synthesised by chemical vapour deposition (CVD) technique, were purified and washed to remove metallic and carbonaceous impurities. Their size range was determined by SEM as 20–30 nm and length of 5–50 µm. The testing suspensions were made by physical mixing and ultrasonication of surface-oxidised material, but any further data on characterization or aggregation was missing. Slight hepatotoxicity was reported at both dose levels, however, no incidences of the lesions were presented to enable comparison with the control group and support their relation to the treatment.”

As taken from Binderup et al. 2013.

For medical purposes activated charcoal is administered orally in a therapy for acute diarrhoea and, due to its ability to adsorb many chemicals and drugs, also for the treatment of acute oral poisonings. Adsorption characteristics can be influenced by the charcoal's particle size, thus different responses may be obtained with different preparations (Martindale, 2011; Ph. Eur. Comment., 2009). At therapeutic dose levels activated charcoal has the potential to reduce the absorption of other drugs from the gastrointestinal tract and thus reduce their efficacy (Martindale, 2011; Ph. Eur. Comment., 2009) (EFSA, 2012b)

“Activated charcoal (AC) is a sorbent that has been shown to remove urinary toxins like urea and indoxyl sulfate. Here, the influence of AC on kidney function of rats with experimental chronic renal failure (CRF) is investigated. CRF was induced in rats by feeding adenine (0.75%) for four weeks. As an intervention, AC was added to the feed at concentrations of 10%, 15% or 20%. Adenine treatment impaired kidney function: it lowered creatinine clearance and increased plasma concentrations of creatinine, urea, neutrophil gelatinase-associated lipocalin and vanin-1. Furthermore, it raised plasma concentrations of the uremic toxins indoxyl sulfate, phosphate and uric acid. Renal morphology was severely damaged and histopathological markers of inflammation and fibrosis were especially increased. In renal homogenates, antioxidant indices, including superoxide dismutase and catalase activity, total antioxidant capacity and reduced glutathione were adversely affected. Most of these changes were significantly ameliorated by dietary administration of AC at a concentration of 20%, while effects induced by lower doses of dietary AC on adenine nephrotoxicity were not statistically significant. The results suggest that charcoal is a useful sorbent agent in dietary adenine-induced CRF in rats and that its usability as a nephroprotective agent in human kidney disease should be studied”. As taken from Ali BH et al. 2014. Food Chem. Toxicol. 65, 321-8. PubMed, 2015 available at http://www.ncbi.nlm.nih.gov/pubmed/24412558.

“The effects of multi-walled carbon nanotubes (MWCNTs) exposure have garnered great interest in the field of public health, due to the high aspect ratio of MWCNTs. Because of worldwide increases in obesity prevalence, nonalcoholic fatty liver disease (NAFLD) is now the most common prevalent liver disease and is considered to be a component of metabolic syndrome, which is a cluster of disorders that also includes dyslipidemia, diabetes mellitus, arteriosclerosis, and hypertension. Exposure to MWCNTs is known to be a risk factor for lung and cardiovascular diseases, but its effect on NAFLD is unknown. In this study, we investigated the effects of intratracheal exposure of two different types of MWCNTs, namely, pristine multi-walled carbon nanotubes (PMWCNTs) and acid-treated multi-walled carbon nanotubes (TMWCNTs), on liver pathogenesis. Direct instillation of a test material into the lungs has been employed as a quantitatively reliable alternative method of inhalation exposure. The 10% weight loss dose was assessed in three months of subchronic study and is defined here as the maximum tolerated dose (MTD) of PMWCNTs and TMWCNTs; by this metric, MTD for a 1-year exposure of MWCNTs was determined to be 0.1 mg/mouse. Mice exposed to PMWCNTs and TMWCNTs for one year developed a nonalcoholic steatohepatitis (NASH)-like phenotype, characterized by inflammation, hepatic steatosis, and fibrosis. Furthermore, PMWCNTs induced a more severe NASH-like phenotype than TMWCNTs, which was related to consistent up-regulation of interleukin (IL)-6 and plasminogen activator inhibitor (PAI)-1. Impaired cholesterol

homeostasis, overexpression of NF-κBp65, and suppression of peroxisome proliferator-activated receptor gamma (PPARγ) in the liver were also observed." As taken from Kim JE et al. 2015b. Nanotoxicology 9(5), 613-623. PubMed, 2016 available at http://www.ncbi.nlm.nih.gov/pubmed/25265201

"Association between short-term exposure to fine particulate matter (PM2.5) and mortality or morbidity varies geographically, and this variation could be due to different chemical composition affected by local sources. However, there have been only a few Asian studies possibly due to limited monitoring data. Using nationwide regulatory monitoring data of PM2.5 chemical components in South Korea, we aimed to compare the associations between daily exposure to PM2.5 components and mortality across six major cities. We obtained daily 24-h concentrations of PM2.5 and 11 PM2.5 components measured from 2013 to 2015 at single sites located in residential areas. We used death certificate data to compute the daily counts of nonaccidental, cardiovascular, and respiratory deaths. Using the generalized additive model, we estimated relative risks of daily mortality for an interquartile range increase in each pollutant concentration, while controlling for a longer-term time trend and meteorology. While elemental carbon was consistently associated with nonaccidental mortality across all cities, nickel and vanadium were strongly associated with respiratory or cardiovascular mortality in Busan and Ulsan, two large port cities. Our study shows that PM2.5 components responsible for PM2.5-associated mortality differed across cities depending on the dominant pollution sources, such as traffic and oil combustion." As taken from Yoo SE et al. 2019. Int. J. Environ. Res. Public Health 16(16), 2872. PubMed, 2020 available at https://pubmed.ncbi.nlm.nih.gov/31405250/

7. Addiction

JTI is not aware of any information that demonstrates that this ingredient has any addictive effect.

8. Burnt ingredient toxicity

No data available to us at this time.

9. Heated/vapor emissions toxicity

No data available to us at this time.

10. Ecotoxicity

10.1. Environmental fate

Environmental Abiotic Degradation:

... is rapidly oxidized to carbon dioxide ... /which enters/ into animals and plants by photosynthesis and metabolism. /(14)C/
[O'Neil, M.J. (ed.). The Merck Index - An Encyclopedia of Chemicals, Drugs, and Biologicals. Whitehouse Station, NJ: Merck and Co., Inc., 2006.., p. 293] **PEER REVIEWED**

As taken from HSDB, 2009

The Ecological Categorization Results from the Canadian Domestic Substances List simply state that carbon is persistent in the environment.

Data accessed January 2017 on the OECD website: http://webnet.oecd.org/CCRWeb/Search.aspx

“Carbon nanotubes (CNT) have numerous industrial applications and may be released to the environment. In the aquatic environment, pristine or functionalized CNT have different dispersion behavior, potentially leading to different risks of exposure along the water column. Data included in this review indicate that CNT do not cross biological barriers readily.” As taken from Jackson P et al. 2013. Chem. Cent. J. 7(1), 154. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24034413

“With the large amount production and application of engineering carbon nanomaterials, their potential ecological risk has attracted extensive attention. The degradation and transformation of the carbon nanomaterials in the environment directly affect the fates and eco-toxicity of the nanomaterials in the environment, and the research of the degradation and transformation processes of the nanomaterials in the environment is the key link for the determination of the environmental capacity of the nanomaterials and for the evaluation of the nanomaterials life cycle in the environment. This paper briefly introduced the chemical transformation, microbial degradation, and photodegradation of the major engineering carbonnanomaterials (carbon nanotubes and fullerene) in the environment, and summarized the environmental and structural factors affecting the degradation of the nanomaterials and the related intrinsic mechanisms. The shortcomings of the related researches and the directions of the future research were also put forward.” As taken from Yue FN et al. 2013. Ying Yong Sheng Tai Xue Bao. 24(2), 589-96. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23705409

“The batch equilibrium approach was used to examine the influence of multi-walled carbon nanotubes (MWNTs) on the sorption behaviors of polyaromatic hydrocarbons (PAHs) in soil. To the knowledge of the authors, this is the first study of PAH sorption to MWNTs in real natural soil systems. The sorption behavior of three PAHs (naphthalene, fluorene, and phenanthrene) in the presence of commercially available MWNTs in two natural soils (a sandy loam and a silt loam) and Ottawa sand was evaluated. Adsorption of PAHs by MWNTs in this study was three orders of magnitude higher than that of natural soils. Sorption coefficients of PAHs (Kd and Koc) were unchanged in the presence of 2 mg g(-1) MWNTs in soil ($p > 0.05$). A micro-mechanics approach, termed 'the rule of mixtures' was used for predicting PAH sorption behaviors in mixtures based on sorption coefficients derived from single sorbents. The equation, $KT = KM\alpha + KN(1 - \alpha)$ (K, sorption coefficients, Kd or Koc), predicted sorption coefficients in a mixture based on mixture component sorption coefficients and mass fractions. Data presented in this study could be used to fill data gaps related to the environmental fate of carbon nanotubes in soil.” As taken from Li S et al. 2013. Environ. Sci. Process Impacts 15(6), 1130-6. PubMed, 2013 available at http://www.ncbi.nlm.nih.gov/pubmed/23591941

“Carbon nanotubes (CNTs) are exciting new materials that have been intensively researched and are becoming increasingly used in consumer products. With rapid growth in production and use of CNTs in many applications, there is the potential for emissions to the environment and thus research is needed to assess the risks associated with CNTs in the environment. Here we show that commercial CNTs differ in their stability, photoactivity, metal leachate, and toxicity to freshwater algae. The behavior between raw and purified variants of the CNTs differs considerably; for example purified CNTs are generally more photoactive, producing singlet oxygen and superoxide, while raw CNTs show little or no photoactivity. Residual metal catalysts differ based on synthesis method used to prepare CNTs and thus may be comprised of elements with varying degrees oftoxic potential. Influenced by pH and other constituents of the natural waters, our work shows that metals can leach out from all the commercial CNTs studied, even purified versions, albeit at different levels in many natural waters. As much as 10% of the total residual nickel leached from a purified CNT after 72 h. Aqueous concentrations of molybdenum leached from a different purified CNT were nearly 0.060 mg L(-1) after 72 h. With little sample preparation, CNTs are dispersible in most freshwaters and stable for several days. Not all tested CNTs were toxic; for those CNTs that did inducetoxicity we show that photoactivity, not metal leaching, contributes to the toxicity of commercial CNTs to freshwater algae, with growth rates significantly reduced by as much as

200%." As taken from Bennett SW et al. 2013. Water Res. 47(12), 4074-85. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23591109

"The quality of water is continuously deteriorating due to its increasing toxic threat to humans and the environment. It is imperative to perform treatment of wastewater in order to remove pollutants and to get good quality water. Carbon materials like porous carbon, carbon nanotubes and fullerene have been extensively used for advanced treatment of wastewaters. In recent years, carbon nanomaterials have become promising adsorbents for water treatment. This review attempts to compile relevant knowledge about the adsorption activities of porous carbon, carbonnanotubes and fullerene related to various organic and inorganic pollutants from aqueous solutions. A detailed description of the preparation and treatment methods of porous carbon, carbon nanotubes and fullerene along with relevant applications and regeneration is also included." As taken from Gupta VK & Saleh TA. 2013. Environ. Sci. Pollut. Res. Int. 20(5), 2828-43. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23430732

10.2. Aquatic toxicity

Toxicity to Microorganisms e.g. Bacteria

Remark: Peat based steam activated carbons, lignite based steam activated carbons and wood based chemical activated carbons were found not to be toxic to **waste–water bacteria.** An EC50 value for respiration inhibition could not be determined. Tests by RCC Notox B.V. The Netherlands.

Source: CHEMVIRON CARBON BRUXELLES

As taken from IUCLID Dataset (2000), Carbon (7440-44-0)

"Amendment of contaminated sediment with activated carbon (AC) is a remediation technique that has demonstrated its ability to reduce aqueous concentrations of hydrophobic organic compounds. The application of AC, however, requires information on possible ecological effects, especially effects on benthic species. Here, we provide data on the effects of AC addition on locomotion, ventilation, sediment avoidance, mortality, and growth of two benthic species, Gammarus pulex and Asellus aquaticus , in clean versus polycyclic aromatic hydrocarbon (PAH) contaminated sediment. Exposure to PAH was quantified using 76 µm polyoxymethylene passive samplers. In clean sediment, AC amendment caused no behavioral effects on both species after 3-5 days exposure, no effect on the survival of A. aquaticus , moderate effect on the survival of G. pulex (LC(50) = 3.1% AC), and no effects on growth. In contrast, no survivors were detected in PAH contaminated sediment without AC. Addition of 1% AC, however, resulted in a substantial reduction of water exposure concentration and increased survival of G. pulex and A. aquaticus by 30 and 100% in 8 days and 5 and 50% after 28 days exposure, respectively. We conclude that AC addition leads to substantial improvement of habitat quality in contaminated sediments and outweighs ecological side effects" (Kupryianchyk et al., 2011. Environmental Science and Technology 45, 8567-8574). As taken from http://www.ncbi.nlm.nih.gov/pubmed/21846106

The Ecological Categorization Results from the Canadian Domestic Substances List simply state that carbon is not inherently toxic to aquatic organisms.

Data accessed January 2017 on the OECD website: http://webnet.oecd.org/CCRWeb/Search.aspx

Record for carbon:

Spec. Sci. Name **Spec. Common Name**	**Exp. Type** **Chem. Anal.**	**Media Type** **Loc**	**Resp. Site** **Obs. Dur. (Days)**	**Endpoint** **BCF**	**Trend** **Eff %**	**Effect** **Effect Meas.**	**Conc (Standardized)** **Appl. Rate**	**Stat. Signif.** **Sig. Level**
Isochrysis	AQUA -	SW		LOEC	DEC	POP	A	ASIG

galbana Haptophyte	NR U	LAB	1 d			ABND	50000	ug/L	<=0.05
Navicula longa Diatom	AQUA - NR U	SW LAB	5 d	LOEC	INC >40-<50/	ENZ LADH	A 50000	ug/L	ASIG <=0.05
Navicula longa Diatom	AQUA - NR U	SW LAB	10 d	LOEC	DEC >30-<40/	ENZ ACPH	A 50000	ug/L	ASIG <=0.01
Navicula longa Diatom	AQUA - NR U	SW LAB	5 d	LOEC	DEC	POP ABND	A 1000000	ug/L	SIG <=0.05
Navicula longa Diatom	AQUA - NR U	SW LAB	2 d	LOEC	DEC	POP ABND	A 50000	ug/L	ASIG <=0.05
Navicula longa Diatom	AQUA - NR U	SW LAB	1 d	LOEC	DEC	POP ABND	A 50000	ug/L	ASIG <=0.01
Navicula longa Diatom	AQUA - NR U	SW LAB	10 d	LOEC	INC >50-<60/	ENZ LADH	A 50000	ug/L	ASIG <=0.01
Navicula longa Diatom	AQUA - NR U	SW LAB	1 d	LOEC	DEC >20-<30/	ENZ ACPH	A 50000	ug/L	ASIG <=0.05
Navicula longa Diatom	AQUA - NR U	SW LAB	5 d	LOEC	DEC >30-<40/	ENZ ACPH	A 50000	ug/L	ASIG <=0.05
Navicula longa Diatom	AQUA - NR U	SW LAB	9 d	LOEC	DEC	POP ABND	A 50000	ug/L	ASIG <=0.05
Navicula longa Diatom	AQUA - NR U	SW LAB	6 d	LOEC	DEC	POP ABND	A 50000	ug/L	ASIG <=0.05
Navicula longa Diatom	AQUA - NR U	SW LAB	0.083 d	LOEC	DEC	POP ABND	A 50000	ug/L	ASIG <=0.05

Navicula longa Diatom	AQUA - NR U	SW LAB	4 d	LOEC	DEC	POP ABND	A 50000 ug/L	ASIG <=0.01
Navicula longa Diatom	AQUA - NR U	SW LAB	8 d	LOEC	DEC	POP ABND	A 50000 ug/L	ASIG <=0.05
Navicula longa Diatom	AQUA - NR U	SW LAB	3 d	LOEC	DEC	POP ABND	A 1000000 ug/L	SIG <=0.05
Isochrysis galbana Haptophyte	AQUA - NR U	SW LAB	9 d	LOEC	DEC	POP ABND	A 50000 ug/L	ASIG <=0.05
Isochrysis galbana Haptophyte	AQUA - NR U	SW LAB	1 d	LOEC	INC >0-<40/	ENZ LADH	A 50000 ug/L	ASIG <=0.01
Isochrysis galbana Haptophyte	AQUA - NR U	SW LAB	7 d	LOEC	DEC	POP ABND	A 50000 ug/L	ASIG <=0.01
Isochrysis galbana Haptophyte	AQUA - NR U	SW LAB	5 d	LOEC	DEC	POP ABND	A 50000 ug/L	ASIG <=0.05
Isochrysis galbana Haptophyte	AQUA - NR U	SW LAB	0.083 d	LOEC	DEC	POP ABND	A 50000 ug/L	ASIG <=0.01
Isochrysis galbana Haptophyte	AQUA - NR U	SW LAB	10 d	LOEC	DEC >20-<25/	ENZ ACPH	A 50000 ug/L	ASIG <=0.05
Navicula longa Diatom	AQUA - NR U	SW LAB	7 d	LOEC	DEC	POP ABND	A 50000 ug/L	ASIG <=0.01
Isochrysis galbana Haptophyte	AQUA - NR U	SW LAB	6 d	LOEC	DEC	POP ABND	A 1000000 ug/L	SIG <=0.05
Isochrysis galbana	AQUA - NR	SW LAB	1 d	LOEC	DEC >10-	ENZ ACPH	A 50000 ug/L	ASIG <=0.05

Haptophyte	U				<15/			
Isochrysis galbana Haptophyte	AQUA - NR U	SW LAB	5 d	LOEC	INC >40-<60/	ENZ LADH	A 50000 ug/L	ASIG <=0.01
Isochrysis galbana Haptophyte	AQUA - NR U	SW LAB	10 d	LOEC	INC >40-<60/	ENZ LADH	A 50000 ug/L	ASIG <=0.01
Isochrysis galbana Haptophyte	AQUA - NR U	SW LAB	4 d	LOEC	DEC	POP ABND	A 50000 ug/L	ASIG <=0.05
Isochrysis galbana Haptophyte	AQUA - NR U	SW LAB	8 d	LOEC	DEC	POP ABND	A 50000 ug/L	ASIG <=0.05
Isochrysis galbana Haptophyte	AQUA - NR U	SW LAB	2 d	LOEC	DEC	POP ABND	A 50000 ug/L	ASIG <=0.05
Navicula longa Diatom	AQUA - NR U	SW LAB	5 d	NOEC	DEC	POP ABND	A 50000 ug/L	NOSIG <=0.05
Isochrysis galbana Haptophyte	AQUA - NR U	SW LAB	6 d	NOEC	DEC	POP ABND	A 50000 ug/L	NOSIG <=0.05
Navicula longa Diatom	AQUA - NR U	SW LAB	3 d	NOEC	DEC	POP ABND	A 50000 ug/L	NOSIG <=0.05
Isochrysis galbana Haptophyte	AQUA - NR U	SW LAB	3 d		DEC	POP ABND	A (50000-1000000) ug/L	MULT <=0.05
Isochrysis galbana Haptophyte	AQUA - NR U	SW LAB	(0.083 - 9) d		CHG	CEL CCHG/	A (50000-1000000) ug/L	
Isochrysis galbana Haptophyte	AQUA - NR U	SW LAB	5 d		INC >15-<20/	ENZ ACPH	A 50000 ug/L	MULT <=0.05
Navicula longa	AQUA - NR	SW			INC	ENZ	A (50000-	MULT

Diatom	U	LAB	1 d		>30-<40/	LADH	1000000) ug/L	<=0.01
Navicula longa Diatom	AQUA - NR U	SW LAB	(0.083 - 9) d		CHG	CEL CCHG/	A (50000-1000000) ug/L	
Danio rerio Zebra Danio	IJ U	FW LAB	0.99	NOEC	NEF 0/	MOR MORT	F 2 ng/org	ANOSIG <0.05
Danio rerio Zebra Danio	IJ U	FW LAB	14	NOEC	INC >20-<40/	MOR MORT	F 2 ng/org	ANOSIG <0.05
Danio rerio Zebra Danio	IJ U	FW LAB	28	NOEC	INC >20-<40/	MOR MORT	F 2 ng/org	ANOSIG <0.05
Danio rerio Zebra Danio	IJ U	FW LAB	56	NOEC	INC >20-<40/	MOR MORT	F 2 ng/org	ANOSIG <0.05
Danio rerio Zebra Danio	IJ U	FW LAB	0.99	NR-ZERO	NEF 0	MOR MORT	F 2 ng/org	
Danio rerio Zebra Danio	IJ U	FW LAB	MUL/ (0.115 - 0.323)		INC	HIS GHIS/	F 2 ng/org	
Danio rerio Zebra Danio	IJ U	FW LAB	<= 0.99		NEF	DVP NORM	F 2 ng/org	
Danio rerio Zebra Danio	IJ U	FW LAB	WO (0 - 0.99)		INC	IMM GIMM/	F 2 ng/org	
Danio rerio Zebra Danio	IJ U	FW LAB	WO/ (0 - 2.99)		INC	ACC RSDE	F 2 ng/org	
Cyprinus carpio Common Carp	E U	FW FIELDA	GI 120		NEF	HIS GHIS	F 10000 ug/L	

As taken from EPA ECOTOX database.

"….The objective of this study was to optimize NIRF-based imaging and quantitation methods for tracking and quantifying SWCNTs in an aquatic vertebrate model in conjunction with assessing toxicological endpoints. Fathead minnows (Pimephales promelas) were exposed by single gavage to SWCNTs and their distribution was tracked using a custom NIRF imaging system for 7 days. No overt toxicity was observed in any of the SWCNT treated fish; however, histopathology observations from gastrointestinal (GI) tissue revealed edema within the submucosa and altered mucous cell morphology. NIRF images showed strong SWCNT-derived fluorescence signals in whole fish and excised intestinal tissues. Fluorescence was not detected in other tissues examined, indicating that no appreciable intestinal absorption occurred. SWCNTs were quantified in intestinal tissues using a NIRF spectroscopic method revealing values that were consistent with the pattern of fluorescence observed with NIRF imaging….." As taken from Bisesi JH et al. 2014. Environ. Sci. Technol. 48(3), 1973-83. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24383993

"Fish behaviours are often considered to be sensitive endpoints of waterborne contaminants, but little attention has been given to engineered nanomaterials. The present study aimed to determine the locomotor and social behaviours of rainbow trout (Oncorhynchus mykiss) during waterborne exposure to single-walled carbon nanotubes (SWCNTs), and to ascertain the physiological basis for any observed effects. Dispersed stock suspensions of SWCNTs were prepared by stirring in sodium dodecyl sulphate (SDS), an anionic surfactant, on an equal w/w basis. Trout were exposed to control (no SWCNT or SDS), 0.25mgL(-1) SDS (dispersant control), or 0.25mgL(-1) of SWCNT for 10 days. Video tracking analysis of spontaneous locomotion of individual fish revealed no significant effects of SWCNT on mean velocity when active, total distance moved, or the distribution of swimming speeds. Hepatic glycogen levels were also unaffected. Fish exposed to SWCNTs retained competitive fitness when compelled to compete in energetically costly aggressive interactions with fish from both control groups. Assessment of the respiratory physiology of the fish revealed no significant changes in ventilation rate or gill injuries. Haematocrit and haemoglobin concentrations in the blood were unaffected by SWCNT exposure; and the absence of changes in the red and white pulp of the spleen excluded a compensatory haematopoietic response to protect the circulation. Despite some minor histological changes in the kidneys of fish exposed to SWCNT compared to controls, plasma ion concentrations and tissue electrolytes were largely unaffected. Direct neurotoxicity of SWCNT was unlikely with the brains showing mostly normal histology, and with no effects on acetylcholinesterase or Na(+)/K(+)-ATPase activities in whole brain homogenates. The minimal effects of waterborne exposure to SWCNT observed in this study are in contrast to our previous report of SWCNT toxicity in trout, suggesting that details of the dispersion method and co-exposure concentration of the dispersing agent may alter toxicity." As taken from Boyle D et. al. 2014. Aquat. Toxicol. 146, 154-64. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24308918

"The potential toxic effects of carboxylated (COOH) single-walled carbon nanotubes (SWNTs) were investigated on the cell growth and viability of two reference (Silicibacter pomeroyi, Oceanospirillum beijerinckii) and two environmental (Vibrio splendidus, Vibrio gigantis) Gram-negative marine bacterial strains. Bacterial cells were exposed to six concentrations of SWNT-COOH, during different incubation times. Our results revealed different sensitivity levels of marine bacterial strains toward SWNT-COOH exposure. A bactericidal effect of SWNT-COOH has been observed only for Vibrio species, with cell loss viability estimated to 86% for V. gigantis and 98% for V. splendidus exposed to 100µgmL(-1) of SWNT-COOH during 2h. For both Vibrio strains, dead cells were well individualized and no aggregate formation was observed after SWNT-COOH treatment. The toxic effect of SWNT-COOH on O. beijerinckii cells displayed time dependence, with a longer exposure time reducing their specific growth rate by a factor of 1.2. No significant effect of SWNT-COOH concentration or incubation time had been demonstrated on both growth ability and viability of S. pomeroyi, suggesting a stronger resistance capacity of this strain to carbon nanotubes. The analysis of the relative expression of some functional genes involved in stress responses, using the

real-time reverse transcriptase PCR, suggests that the cell membrane damage is not the main toxicity mechanism by which SWNT-COOH interacts with marine bacterial strains. Overall, our results show that SWNT-COOH present a strain dependent toxic effect to marine bacteria and that membrane damage is not the main toxicity mechanism of SWNT in these bacteria." As taken from Berdjeb L et al. 2013. Aquat. Toxicol. 144-145, 230-41. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24184842

"Carbon nanotubes (CNT) have numerous industrial applications and may be released to the environment. In the aquatic environment, pristine or functionalized CNT have different dispersion behavior, potentially leading to different risks of exposure along the water column. Data included in this review indicate that CNT do not cross biological barriers readily. When internalized, only a minimal fraction of CNT translocate into organism body compartments. The reported CNT toxicity depends on exposure conditions, model organism, CNT-type, dispersion state and concentration. In the ecotoxicological tests, the aquatic organisms were generally found to be more sensitive than terrestrial organisms. Invertebrates were more sensitive than vertebrates. Single-walled CNT were found to be more toxic than double-/multi-walled CNT. Generally, the effect concentrations documented in literature were above current modeled average environmental concentrations. Measurement data are needed for estimation of environmental no-effect concentrations. Future studies with benchmark materials are needed to generate comparable results. Studies have to include better characterization of the starting materials, of the dispersions and of the biological fate, to obtain better knowledge of the exposure/effect relationships." As taken from Jackson P et al. 2013. Chem. Cent. J. 7(1), 154. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24034413

"The present study explored the ecotoxicology of single-walled carbon nanotubes (SWCNTs) and their likely interaction with dissolved metals, with a focus on the effect of in vivo exposure in marine mussels. Any nano-scale effects were negated by the tendency of uncoated SWCNTs to agglomerate in water, particularly with high ionic strength as is the case in estuarine and full-strength seawater…..For the first time, the authors describe a potentiating toxicological effect, expressed as DNA strand breaks obtained using the comet assay, on divalent metals afforded by negatively charged SWCNT agglomerates in seawater at concentrations as low as 5 $\mu g\ L^{-1}$. This is supported by the observation that SWCNTs alone were only toxic at concentrations ≥100 $\mu g\ L^{-1}$ and that the SWCNT-induced DNA damage was correlated with oxidative stress only in the absence of metals. If these laboratory experiments are confirmed in the natural environment, the present results will have implications for the understanding of the role of carbon nanotubes in environmental metal dynamics, toxicology, and consequently, regulatory requirements." As taken from Al-Shaeri M et al. 2013. Environ. Toxicol. Chem. 32(12), 2701-10. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23982896

"There are currently over ninety products incorporating carbon nanomaterials (CNMs) on the market today for a variety of applications. Modifications in core structure and surface chemistry of manufactured nanomaterials are used to optimize nanomaterials for specific uses. However, there is a notable lack of information on how core structure and surface chemistry may alter toxicity in low-level, chronic exposures. This paper examines the effects of twelve CNMs that differ in their core structure and surface chemistry to Daphnia magna over a 21-day chronic exposure. Overall, nanomaterials with a carbon nanotube core were more toxic to daphnids than fullerenes, with the one exception of fullerenes with a gamma-cyclodextrin surface chemistry. Acute mortality was not a good predictor of chronic effects as none of the CNMs induced toxicity at tested concentrations after 48 h, yet chronic assays indicated significant differences in mortality, reproduction, and growth realized after 21 days. Our results indicate that (1) acute exposure assays do not accurately describe the impact of CNMs to biological systems, (2) chronic exposures provide valuable information that indicates the potential for different modes of action for nanomaterials of differing chemistries, and (3) core structure and surface chemistry both influence particletoxicity." As taken from Arndt DA et al. 2013. Environ. Sci. Technol. 47(16), 9444-52. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23862695

“With the development and application of carbon nanotubes (CNTs), the potential hazards of CNTs to biological systems and the environment are getting more and more attention. This review evaluated the effects of physicochemical properties of CNTs on toxicity and summarized the advances on the mechanism of CNTs toxicity. We also proposed the possible hazards associated with CNTs and harmful effects resulting from exposure of aquatic animals, bacteria and higher plants to CNTs in vitro and in vivo. The current knowledge and gaps on CNTs were outlined as a potential problem for the environment and human health. The current research gaps on CNTs toxicity were identified and the further studying focus was proposed, too. This essay concluded with a set of recommendations for the advancement of understanding of the role of CNTs and future challenges in environmental and ecotoxicological research.” As taken from Du J et al. 2013. Environ. Toxicol. Pharmacol. 36(2), 451-62. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23770455

“Carbon nanotubes (CNTs) are exciting new materials that have been intensively researched and are becoming increasingly used in consumer products. With rapid growth in production and use of CNTs in many applications, there is the potential for emissions to the environment and thus research is needed to assess the risks associated with CNTs in the environment. Here we show that commercial CNTs differ in their stability, photoactivity, metal leachate, and toxicity to freshwater algae. The behavior between raw and purified variants of the CNTs differs considerably; for example purified CNTs are generally more photoactive, producing singlet oxygen and superoxide, while raw CNTs show little or no photoactivity. Residual metal catalysts differ based on synthesis method used to prepare CNTs and thus may be comprised of elements with varying degrees of toxic potential. Influenced by pH and other constituents of the natural waters, our work shows that metals can leach out from all the commercial CNTs studied, even purified versions, albeit at different levels in many natural waters. As much as 10% of the total residual nickel leached from a purified CNT after 72 h. Aqueous concentrations of molybdenum leached from a different purified CNT were nearly 0.060 mg L(-1) after 72 h. With little sample preparation, CNTs are dispersible in most freshwaters and stable for several days. Not all tested CNTs were toxic; for those CNTs that did induce toxicity we show that photoactivity, not metal leaching, contributes to the toxicity of commercial CNTs to freshwater algae, with growth rates significantly reduced by as much as 200%.” As taken from Bennett SW et al. 2013. Water Res. 47(12), 4074-85. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23591109

“With the rapid increase of carbon nanotube (CNT) applications, there are considerable concerns of their inevitable releases into the aquatic environments. CNTs may interact with and further influence the fate and transport of other pollutants such as toxic metals. In the present study, non-covalent and nontoxic dispersant polyvinyl pyrrolidone (PVP) was used to provide a relatively stable test solution for CNTs. The dissolved uptake rate constant (ku) and the dietary assimilation efficiency (AE) of cadmium (Cd) and zinc (Zn) were then quantified in a freshwater zooplankton Daphnia magna in the presence of different CNTs (without functionalized - single-walled nanotubes-SWNTs, multi-walled nanotubes-MWNTs, and with functionalized - F-SWNTs, F-MWNTs, containing oxygen functional groups at the defect sites of CNTs) concentrations. We demonstrated that different CNTs exposures led to distinctive metal accumulation patterns. Non-functionalized CNTs significantly decreased the metal uptake rate from the dissolved phase, possibly because of their effects on the physiological activity of animals. In contrast, the F-CNTs (F-SWNTs and F-MWNTs) adsorbed the metals and increased the metal accumulation in daphnids in a concentration-dependent manner, due to the ingestion of F-CNTs associated metals. The AEs of metals in D. magna were elevated by CNTs physical blocking of the animal guts. Our present study showed that CNTs could serve as a new pathway for metal accumulation. This raised a new environmental problem of CNTs since they may induce the accumulation of toxic metals from the dietary exposure.” As taken from Yu ZG & Wang WX. 2013. Water Res. 47(12), 4179-87. PubMed, 204 available at http://www.ncbi.nlm.nih.gov/pubmed/23582308

“In this study the freshwater zebrafish (Danio rerio) was exposed to two kinds of carbon NM, single-wall carbon nanotubes (SWCNT) and fullerenol [C60(OH)18-22(OK4)] to analyze oxidative stress

responses on fish brain. Adult zebrafish (mean mass: 0.52±0.01g) were submitted to intraperitoneal injections of SWCNT suspension and fullerenol solution (30mg/kg of fish), receiving one or two doses with a time interval of 24h. Results showed that total antioxidant capacity was lowered in brains of fish exposed 24h to fullerenol when compared to those from SWCNT treatment ($p<0.05$). After 48h, fullerenol induced higher expression of both catalytic and regulatory subunits of enzyme glutamate cysteine ligase when compared to control group ($p<0.05$), indicating an antioxidant behavior. In vitro assays showed a dual effect of SWCNT, since a pro-oxidant behavior was observed at low concentrations (0.1 and 1.0mg/L) and an antioxidant one at the highest concentration (10.0mg/L). Few biological responses were altered by this NM: decrease in total antioxidant capacity and induction of the expression of the transcription factor Nrf2 when compared to control group." As taken from da Rocha AM et al. 2013. Comp. Biochem. Physiol. A Mol. Integr. Physiol. 165(4), 460-7. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23542748

"Black carbon (BC) has a strong affinity for hydrophobic organic compounds (HOCs), and it is a potential material to control HOCs pollution in aquatic ecosystems. Here, flow cytometry (FCM) was used to evaluate the ecotoxicological effect of fly ash, rice-straw ash, and their acid-demineralised products on the growth of Microcystis aeruginosa. It was found that the BCs had little negative effect on cyanobacteria, when the content of BCs was not above 1mgml(-1). However, higher doses of BCs (>2mgml(-1)) had an obvious negative effect on cell density and esterase activity, especially for BCs with acid treatment, which greatly inhibited cell density caused by its high adsorptivity for cyanobacteria. The BCs had little impact on the fluorescence intensity, only with a slight stimulation in later period, so the fluorescence intensity was a less sensitive indicator than cell density and esterase activity. Considering ecotoxicological effect of BCs on the algae, the application concentration of BCs for HOCs pollution control as in situ remediation material would better not exceed 1mgml(-1)." As taken from Lou L et al. 2013. Ecotoxicol. Environ. Saf. 92, 51-6. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23522529

10.3. Sediment toxicity

"Sediment amendment with activated carbon (AC) is a promising technique for in situ sediment remediation. To date it is not clear whether this technique sufficiently reduces sediment-to-water fluxes of sediment-bound hydrophobic organic chemicals (HOCs) in the presence of bioturbators. Here, we report polychlorobiphenyl (PCB) pore water concentrations, fluxes, mass transfer coefficients, and survival data of two benthic species, for four treatments: no AC addition (control), powdered AC addition, granular AC addition and addition and subsequent removal of GAC (sediment stripping). AC addition decreased mass fluxes but increased apparent mass transfer coefficients because of dissolved organic carbon (DOC) facilitated transport across the benthic boundary layer (BBL). In turn, DOC concentrations depended on bioturbator activity which was high for the PAC tolerant species Asellus aquaticus and low for AC sensitive species Lumbriculus variegatus. A dual BBL resistance model combining AC effects on gradients, DOC facilitated transport and biodiffusion was evaluated against the data and showed how the type of resistance differs with treatment and chemical hydrophobicity. Data and simulations illustrate the complex interplay between AC and contaminant toxicity to benthic organisms and how differences in species tolerance affect mass fluxes from sediment to the water column." As taken from Kupryianchyk D et al. 2013. Environ. Sci. Technol. 47(10), 5092-100. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23590290

"As the use of single-walled carbon nanotubes (SWNTs) increases over time, so does the potential for environmental release. This research aimed to determine the toxicity, bioavailability, and bioaccumulation of SWNTs in marine benthic organisms at the base of the food chain. The toxicity of SWNTs was tested in a whole sediment exposure with the amphipod Ampelisca abdita and the mysid Americamysis bahia. In addition, SWNTs were amended to sediment and/or food matrices to determine their bioavailability and bioaccumulation through these routes in A. abdita, A. bahia, and the estuarine amphipod Leptocheirus plumulosus. No significant mortality to any species via

sediment or food matrices was observed at concentrations up to 100 ppm. A novel near-infrared fluorescence spectroscopic method was utilized to measure and characterize the body burdens of pristine SWNTs in nondepurated and depurated organisms. We did not detect SWNTs in depurated organisms but quantified them in nondepurated A. abdita fed SWNT-amended algae. After a 28-d exposure to [(14) C]SWNT-amended sediment (100 µg/g) and algae (100 µg/g), [(14) C]SWNT was detected in depurated and nondepurated L. plumulosus amphipods at 0.50 µg/g and 5.38 µg/g, respectively. The results indicate that SWNTs are bioaccessible to marine benthic organisms but do not appear to accumulate or cause toxicity." As taken from Parks AN et al. 2013. Environ. Toxicol. Chem. 32(6), 1270-7. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23404747

10.4. Terrestrial toxicity

BIRDS and MAMMALS/ ... Several non-target organisms, including burrowing owls, may inhabit the burrows of target pests ... . Due to the potential risk to non-target organisms, the EPA is currently developing more extensive labeling regarding timing of application and observation of signs indicating the presence or absence of target and non-target organisms. These instructions will be explicit concerning actions users must take before applying the product. [USEPA/Office of Pesticide Programs; Reregistration Eligibility Decision Document - Carbon and Carbon Dioxide p.12 (September 1991). Available from, as of July 19, 2008: http://www.epa.gov/pesticides/reregistration/status.htm] **PEER REVIEWED**

As taken from HSDB, 2009

"Premise of the study: Single-walled carbon nanotubes (SWCNTs) have many unique structural and mechanical properties. Their potential applications, especially in biomedical engineering and medical chemistry, have been increasing in recent years, but the toxicological impact of nanoparticles has rarely been studied in plants. • Methods: We exposed Arabidopsis and rice leaf protoplasts to SWCNTs and examined cell viability, DNA damage, reactive oxygen species generation, and related gene expression. We also tested the effects of nanoparticles on Arabidopsis leaves after injecting a SWCNT solution. EM-TUNEL (electron-microscopic terminal deoxynucleotidyl transferase-mediated dUTP nick end-labeling) and a cerium chloride staining method were used. • Key results: SWCNTs caused adverse cellular responses including cell aggregation, chromatin condensation along with a TUNEL-positive reaction, plasma membrane deposition, and H(2)O(2) accumulation. The effect of SWCNTs on the survival of cells was dose dependent, with 25 µg/mL inducing 25% cell death in 6 h. In contrast, activated carbon, which is not a nano-sized carbon particle, did not induce cell death even 24 h after treatments. The data indicated that the nano-size of the particle is a critical factor for toxicity. Moreover, endocytosis-like structures with cerium chloride deposits formed after SWCNT treatment, suggesting a possible pathway for nanoparticles to traverse the cell membrane. • Conclusions: Consequently, SWCNTs have an adverse effect on protoplasts and leaves through oxidative stress, leading to a certain amount of programmed cell death. Although nanomaterials have great advantages in many respects, the benefits and side effects still need to be assessed carefully" (Shen et al., 2010. American Journal of Botany 97, 1602-1609). As taken from http://www.ncbi.nlm.nih.gov/pubmed/21616795

"….The potential impact of single-walled carbon nanotubes (SWCNTs) was evaluated using Caenorhabditis elegans (C. elegans) as a toxicological animal model. SWCNTs are extremely hydrophobic to form large agglomerates in aqueous solutions. Highly soluble amide-modified SWCNTs (a-SWCNTs) were therefore used in the present study so that the exact impact of SWCNTs could be studied. No significant toxicity was observed in C. elegans due to the amide modification. a-SWCNTs were efficiently taken up by worms and caused acute toxicity, including

retarded growth, shortened lifespan and defective embryogenesis. The resulting toxicity was reversible since C. elegans could recover from a-SWCNT-induced toxicity once the exposure terminates. Chronic exposure to low doses of a-SWCNTs during all development stages could also cause a toxic accumulation in C. elegans. Genome-wide gene expression analysis was performed to investigate the toxic molecular mechanisms. Functional genomic analysis and molecular biology validation suggest that defective endocytosis, the decreased activity of the citrate cycle and the reduced nuclear translocation of DAF-16 transcription factor play key roles in inducing the observed a-SWCNT toxicityin worms….." As taken from Chen PH et al. 2013b. Biomaterials 34(22), 5661-9. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23623425?dopt=AbstractPlus

"With the development and application of carbon nanotubes (CNTs), the potential hazards of CNTs to biological systems and the environment are getting more and more attention. This review evaluated the effects of physicochemical properties of CNTs on toxicity and summarized the advances on the mechanism of CNTs toxicity. We also proposed the possible hazards associated with CNTs and harmful effects resulting from exposure of aquatic animals, bacteria and higher plants to CNTs in vitro and in vivo. The current knowledge and gaps on CNTs were outlined as a potential problem for the environment and human health. The current research gaps on CNTs toxicity were identified and the further studying focus was proposed, too. This essay concluded with a set of recommendations for the advancement of understanding of the role of CNTs and future challenges in environmental and ecotoxicological research." As taken from Du J et al. 2013. Environ. Toxicol. Pharmacol. 36(2), 451-62. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23770455

"The high surface area of multi-walled carbon nanotubes (MWCNTs) tends to adsorb a large variety of toxic chemicals, which may enhance the toxicityof both MWCNTs and chemicals to organisms. In order to evaluate the combined toxicity of nonylphenol (NP) and MWCNTs to the earthworm Eisenia fetida in soil, artificial soil systems containing distilled water, 0.1 g kg(-1) MWCNTs, 1 g kg(-1) MWCNTs, 1 g kg(-1) MWCNTs absorbed 5 mg kg(-1) NP, and 10 mg kg(-1) NP alone were prepared and exposed to earthworms for 7 days. Antioxidative responses, and activities of cellulase, Na(+), K(+)-ATPase and acetylcholinesterase (TChE) as well as DNA damage were chosen as toxicological endpoints. The results showed that 1 g kg(-1) MWCNTs adsorbed 5 mg kg(-1) NP from the soil which caused much more adverse effects on the earthworms than each chemical alone, evident from the responses of cellulase, Na(+), K(+)-ATPase and comet assay. This study indicated that MWCNTs facilitated the bioavailability of NP to the earthworm and increased the harmful effects of NP." As taken from Hu C et al. 2013. Environ. Sci. Process Impacts 15(11), 2125-30. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24104387

"Carbon nanotubes (CNT) have numerous industrial applications and may be released to the environment. In the aquatic environment, pristine or functionalized CNT have different dispersion behavior, potentially leading to different risks of exposure along the water column. Data included in this review indicate that CNT do not cross biological barriers readily. When internalized, only a minimal fraction of CNT translocate into organism body compartments. The reported CNT toxicity depends on exposure conditions, model organism, CNT-type, dispersion state and concentration. In the ecotoxicological tests, the aquatic organisms were generally found to be more sensitive than terrestrial organisms. Invertebrates were more sensitive than vertebrates. Single-walled CNT were found to be more toxic than double-/multi-walled CNT. Generally, the effect concentrations documented in literature were above current modeled average environmental concentrations. Measurement data are needed for estimation of environmental no-effect concentrations. Future studies with benchmark materials are needed to generate comparable results. Studies have to include better characterization of the starting materials, of the dispersions and of the biological fate, to obtain better knowledge of the exposure/effect relationships." As taken from Jackson P et al. 2013. Chem. Cent. J. 7(1), 154. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/24034413

“The inconsistent impact of nanomaterials on different plant species has been reported, but little is known about this effect at the cellular and genetic levels. Here we report that single-walled carbon nanotubes (SWCNTs) accelerate maize seminal root growth, but display little effect on the primary root growth. In contrast, root hair growth inhibition by SWCNTs is observed. Further gene transcription analysis shows that SWCNTs could increase the expression of seminal root associated genes whereas decrease root hair associated gene expression. Their effect is on both tissue and gene selectiveness since both enhanced and inhibited gene expression and tissue growth are observed during root development. Microscopy images reveal the distribution of SWCNTs inside the root and mainly in the intercellular space in cortex tissues. We also find that SWCNT-treatment dynamically and selectively induces the up-regulation of epigenetic modification enzyme genes, leading to global deacetylation of histone H3, similar to the response of plants to other stress. Our results suggest that the nanoparticle-root cell interaction could cause the change in gene expression, and consequently affect relative root growth and development.” As taken from Yan S et al. 2013. J. Hazard. Mater. 246-247, 110-8. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23291336

“Nanomaterials such as single-walled carbon nanotubes (SWCNTs) may enter the soil environment with unknown consequences resulting from the development of nanotechnology for a variety of applications. We determined the effects of SWCNTs on soil enzyme activity and microbial biomass through a 3-week incubation of urban soils treated with different concentrations of SWCNTs ranging from 0 to 1000 μg g(-1) soil. The activities of cellobiohydrolase, β-1,4-glucosidase, β-1,4-xylosidase, β-1,4-N-acetylglucosaminidase, L-leucine aminopeptidase, and acid phosphatase and microbial biomass were measured in soils treated with powder and suspended forms of SWCNTs. SWCNTs of concentrations at 300-1000 μg g(-1) soil significantly lowered activities of most enzymes and microbial biomass. It is noteworthy that the SWCNTs showed similar effects to that of multi-walled carbon nanotubes (MWCNTs), but at a concentration approximately 5 times lower; we suggest that this is mainly due to the higher surface area of SWCNTs than that of MWCNTs. Indeed, our results show that surface area of CNTs has significant negative relationship with relative enzyme activity and biomass, which suggests that greater microorganism-CNT interactions could increase the negative effect of CNTs on microorganisms. Current work may contribute to the preparation of a regulatory guideline for the release of CNTs to the soil environment.” As taken from Jin L et al. 2013. Ecotoxicol. Environ. Saf. 88, 9-15. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23218497

“Culture-dependent and -independent methods were employed to determine the impact of carboxyl-functionalized single-walled carbon nanotubes (SWNTs) on fungal and bacterial soil microbial communities. Soil samples were exposed to 0 (control), 250, and 500 μg of SWNTs per gram of soil. Aliquots of soil were sampled for up to 14 days for culture-dependent analyses, namely, plate count agar and bacterial community level physiological profiles, and culture-independent analyses, namely, quantitative real-time polymerase chain reaction (qPCR), mutliplex-terminal restriction fragment length polymorphism (M-TRFLP), and clone libraries. Results from culture-independent and -dependent methods show that the bacterial soil community is transiently affected by the presence of SWNTs. The major impact of SWNTs on bacterial community was observed after 3 days of exposure, but the bacterial community completely recovered after 14 days. However, no recovery of the fungal community was observed for the duration of the experiment. Physiological and DNA microbial community analyses suggest that fungi and bacteria involved in carbon and phosphorus biogeochemical cycles can be adversely affected by the presence of SWNTs. This study suggests that high concentrations of SWNTs can have widely varying effects on microbial communities and biogeochemical cycling of nutrients in soils.” As taken from Rodrigues DF et al. 2013. Environ. Sci. Technol. 47(1), 625-33. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23205469

“This study evaluated the impacts of multiwalled carbon nanotubes (MWNTs) on microbial community composition and functioning in a sandy loam soil over 90 d. We used test concentrations in the range of lower MWNT concentrations (10mg/kg) to extremely high MWNT

concentrations (10,000 mg/kg) as a worst case scenario. We observed no effects of MWNTs on soil respiration, enzymatic activities, and microbial community composition at 10, 100 and 1,000 mg/kg. However, increases in fungal fatty acid methyl ester markers were observed at the highest treatment. In addition, pyrosequencing demonstrated a decreased abundance of some bacterial genera like Derxia, Holophaga, Opitutus and Waddlia at the highest treatment while bacterial genera that are considered potential degraders of recalcitrant contaminants (such as polycyclic aromatic hydrocarbons) like Rhodococcus, Cellulomonas, Nocardioides and Pseudomonas increased. These results suggest a shift in soil microbial community composition to more tolerant microbial populations in the presence of extremely high MWNT concentrations. It is unlikely that the change observed at 10,000 mg/kg is due to metal or carbon impurities as the MWNTs used in this study were of high purity. Given the need for wide-ranging data for regulation and risk assessment of nanomaterials, this study provides valuable data." As taken from Shrestha B et al. 2013. J. Hazard. Mater. 261, 188-97. PubMed, 2014 available at http://www.ncbi.nlm.nih.gov/pubmed/23921182

Record for carbon:

Spec. Sci. Name **Spec. Common Name**	**Resp. Site** **Exp. Dur. (Days)**	**Media Type** **Test Loc.**	**Exp. Type** **Chem. Anal.**	**Dose #** **Res. Sample Unit**	**Endpoint** **BAF/BCF**	**Effect** **Effect Meas.**	**Signif.** **Sig. Level**	**Dose** **Dose Stat. Meth.**
Chen caerulescens Blue Goose	4	NONE FIELDN	EN U	2	LOEL	AVO CHEM	ASIG <0.05	A 3.4 AI kg/ha
Stipa bigeniculata Doublejointed Speargrass	21 d	NAT LAB	EN U	2	LOEL	REP GERM	ASIG <0.01	F 200/ (NR/-NR/) kg/ha
Cucurbita pepo Vegetable Marrow	RO 5 d	AQU LAB	DA U	2	NOEL	GRO LGTH	ANOSIG <0.05	A 1000/ (NR/-NR/) mg/L
Cucurbita pepo Vegetable Marrow	WO 15 d	AQU LAB	DA U	2	NOEL	GRO BMAS	ANOSIG <0.05	A 1000/ (NR/-NR/) mg/L
Cucurbita pepo Vegetable Marrow	SD 12 d	AQU LAB	DA U	2	NOEL	REP GERM	ANOSIG <0.05	F 1000/ (NR/-NR/) mg/L
Themeda australis Kangaroo Grass	21 d	NAT LAB	EN U	2	NOEL	REP GERM	ANOSIG <0.01	F 200/ (NR/-NR/) kg/ha
Bothriochloa macra		NAT	EN	2	NOEL	REP	ANOSIG	F 200/ (NR/-

Bluestem	21 d	LAB	U			GERM	<0.01	NR/) kg/ha
Danthonia sp. Oatgrass	21 d	NAT LAB	EN U	2	NOEL	REP GERM	ANOSIG <0.01	F 200/ NR/) (NR/- kg/ha

As taken from EPA ECOTOX database.

“With the aim of investigating the effects of carbonaceous sorbent amendment on plant health and end point contaminant bioavailability, plant experiments were set up to grow maize (Zea mays) in soil contaminated with polycyclic aromatic hydrocarbons (PAHs) and metals. Maize and pine derived biochars, as well as a commercial grade activated carbon, were used as amendments. Plant growth characteristics, such as chlorophyll content and shoot to root biomass, improved with sorbent amendment to varying extents and contaminant uptake to shoots was consistently reduced in amended soils. By further defining the conditions in which sorbent amended soils successfully reduce contaminant bioavailability and improve plant growth, this work will inform field scale remediation efforts.” As taken from Brennan A et al. 2014. Environ. Pollut. 193, 79-87. PubMed, 2015 available at http://www.ncbi.nlm.nih.gov/pubmed/25014015.

“Carbonaceous amendments reduce PAH dissolved concentrations (Cfree), limiting their uptake and toxicity. A soil contaminated with PAHs was mixed with activated carbon (AC), charcoal or compost and planted with radish (Raphanus sativus L.), and Cfree, chemical activities and diffusive uptake of the PAHs measured over 2 months. For AC, Cfree and diffusive uptake were decreased by up to 94% compared to the unamended soil within one week. In addition, the sum chemical activity of the PAHs remained below the threshold for baseline toxicity. In contrast, charcoal and compost only led to modest reductions in Cfree and diffusive uptake, with sum chemical activities that could potentially result in baseline toxicity being observed. Furthermore, both Cfree and diffusive uptake were lower in the planted compared to unplanted soils. Therefore, only AC successfully reduced PAH acute toxicity in the soil, but plant-promoted microbial degradation may also play an important role in PAH attenuation.” As taken from Marchal G et al. 2014. Environ. Pollut. 188, 124-31. PubMed, 2015 available at http://www.ncbi.nlm.nih.gov/pubmed/24583710

“Activated carbon (AC), biochar from wheat straw (BCS), and biochar from willow (BCW) were added to the soils sampled from areas of strong anthropogenic influence at doses of 0.5%, 1%, 2.5%, or 5% (w/w) and incubated for 2 mo. At the end of this period, the toxicity of the soils was measured. The effect of AC and biochars on the toxicity of the soils varied based on soil, type of amendment, dose, and test organism. For most of the parameters tested, the highest effectiveness of AC in terms of reduction of toxicity was observed in soil POPI (from bitumen processing plant area). In the case of the remaining soils, after the addition of AC varied results were observed, in which a reduction or an increase of toxicity, relative to the control soil, occurred. As in the case of AC, biochars also caused a significant reduction of phytotoxicity of soil POPI. In soils KB (from coking plant area, industrial waste deposit) and KOK (from coking plant area, coking battery), the reduction or increase of toxicity depended on biochar dose. Compared with the biochars, the effectiveness of AC in the reduction of toxicity depended also on soil, type of amendment, dose, and test organism. Generally, the AC was more effective than biochars in relation to mortality and reproduction of Folsomia candida (in all soils) and for reduction of luminescence inhibition of Vibrio fischeri (in POPI soil).” As taken from Koltowski M et al. 2016. Environ. Toxicol. Chem. 35(5), 1321-8. PubMed, 2017 available at https://www.ncbi.nlm.nih.gov/pubmed/26378767

10.5. All other relevant types of ecotoxicity

The Ecological Categorization Results from the Canadian Domestic Substances List simply state that the bioaccumulative potential of carbon in the environment has not been determined.

Data accessed January 2017 on the OECD website: http://webnet.oecd.org/CCRWeb/Search.aspx

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13. Last audited

March 2023

I U C L I D

D a t a s e t

Existing Chemical	Substance ID: 7440–44–0
CAS No.	7440–44–0
EINECS Name	carbon
EINECS No.	231–153–3
Molecular Weight	12
Molecular Formula	C

Dataset created by: EUROPEAN COMMISSION – European Chemicals Bureau

This dossier is a compilation based on data reported by the European Chemicals Industry following 'Council Regulation (EEC) No. 793/93 on the Evaluation and Control of the Risks of Existing Substances'. All (non–confidential) information from the single datasets, submitted in the IUCLID/HEDSET format by individual companies, was integrated to create this document.

The data have not undergone any evaluation by the European Commission.

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1.0.1 OECD and Company Information

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Cedex: 20032

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Telefax: +44/1483 304 863

1.0.2 Location of Production Site

-

1.0.3 Identity of Recipients

-

1.1 General Substance Information

Substance type: element
Physical status: solid

Substance type: inorganic
Physical status: solid

Substance type: natural substance
Physical status: solid

Substance type: organic
Physical status: solid

1.1.1 Spectra

-

1.2 Synonyms

Activated carbon
Source: UOP Ltd. Guildford, Surrey

activated coal, activated charcoal, active carbon
Remark: Please note that another CAS no and EINECS no exist for thiscarbon, following is also used in the industry:
CAS no 64365-11-3
EINECS no 264-846-4
Source: NORIT N.V. Amersfoort

Activated coal, activated charcoal, active carbon
Remark: Please note that another cas no and einecs no exist for this carbon, following is also used in the industry :
CAS no. 64365-11-3
EINECS no. 264-846-4
Source: CHEMVIRON CARBON BRUXELLES

ACTIVATED COAL, ACTIVATED CHARCOAL, ACTIVE CARBON
Remark: Please note that another cas no and einecs no exist for thiscarbon, following is also used in the industry:
CAS no. 64365-11-3
EINECS no. 264-846-4
Source: CECA SA Paris-La Defence 2

ADSORBENTE
Source: ACQUENYMCO CORMANO
CAMEL CHEMICALS POZZUOLO MARTESANA

CARBONE ATTIVO
Source: ACQUENYMCO CORMANO
CAMEL CHEMICALS POZZUOLO MARTESANA

CHEMISORB
Source: MARE S.p.A. Ossona/Fraz. Asmonte (MI)

WATERCARB
Source: MARE S.p.A. Ossona/Fraz. Asmonte (MI)

1.3 Impurities

-

1.4 Additives

-

1.5 Quantity

Quantity 50 000 - 100 000 tonnes

1.6.1 Labelling

-

1.6.2 Classification

-

1.7 Use Pattern

Type: type
Category: Non dispersive use

Type: industrial
Category: Basic industry: basic chemicals

Type: industrial
Category: Fuel industry

Type: industrial
Category: Paints, lacquers and varnishes industry

Type: industrial
Category: other

Type: use
Category: Absorbents and adsorbents

1.7.1 Technology Production/Use

-

1.8 Occupational Exposure Limit Values

Type of limit: MAC (NL)
Limit value: 2 mg/m3
Remark: There is no MAC value for activated carbon; the given value is applicable to inconvenient dust
Source: NORIT N.V. Amersfoort

Type of limit: MAK (DE)
Limit value: 6 mg/m3
Remark: There is no MAC value for activated carbon. The given value is applicable to inconvenient dust with a respirable quartz content of over 1 w/w %.
Source: CHEMVIRON CARBON BRUXELLES

Type of limit: MAK (DE)
Limit value: 6 mg/m3
Remark: There is no MAC value for activated carbon. Tha given value is applicable to inconvenient dust with a respirable quartz content of over 1 w/w %.
Source: CECA SA Paris-La Defence 2

1.9 Source of Exposure

-

1.10.1 Recommendations/Precautionary Measures

-

1.10.2 Emergency Measures

-

1.11 Packaging

-

1.12 Possib. of Rendering Subst. Harmless

-

1.13 Statements Concerning Waste

-

1.14.1 Water Pollution

-

1.14.2 Major Accident Hazards

-

1.14.3 Air Pollution

-

1.15 Additional Remarks

Remark: Not dangerous for transport.
Source: MARE S.p.A. Ossona/Fraz. Asmonte (MI)

1.16 Last Literature Search

-

1.17 Reviews

-

1.18 Listings e.g. Chemical Inventories

-

2.1 Melting Point

Value: >= 3500 degree C
Decomposition: no
Sublimation: no
Method: other
GLP: yes
Source: ACQUENYMCO CORMANO

2.2 Boiling Point

Value: ca. 4000 degree C
Decomposition: no
Method: other
GLP: yes
Source: ACQUENYMCO CORMANO

2.3 Density

Type: bulk density
Value: .25 – .75 kg/m3 at 20 degree C
Method: other
Source: CHEMVIRON CARBON BRUXELLES

Type: relative density
Value: = 250 – 600 kg/m3 at 25 degree C
Method: other
GLP: yes
Source: ACQUENYMCO CORMANO

2.3.1 Granulometry

–

2.4 Vapour Pressure

Value:
Remark: NON APPLICABILE.
Source: ACQUENYMCO CORMANO

2.5 Partition Coefficient

log Pow:
Method:
Year:
Remark: NON APPLICABILE
Source: ACQUENYMCO CORMANO

2.6.1 Water Solubility

Qualitative: not soluble
Source: CHEMVIRON CARBON BRUXELLES

Remark: NON APPLICABILE
Source: ACQUENYMCO CORMANO

2.6.2 Surface Tension

-

2.7 Flash Point

Value:
Type:
Method:
Year:
Remark: NON APPLICABILE
Source: ACQUENYMCO CORMANO

2.8 Auto Flammability

Value: > 400 degree C
Method: other
GLP: yes
Source: ACQUENYMCO CORMANO

Value: 300 degree C
Remark: Ignition point in air is 300-500 degree C.
Source: CHEMVIRON CARBON BRUXELLES

2.9 Flammability

Result: non flammable
Source: CHEMVIRON CARBON BRUXELLES

Result: non flammable
Remark: NON INFIAMMABILE
Source: ACQUENYMCO CORMANO

2.10 Explosive Properties

Result: no data
Remark: NON ESPLOSIVO; NUBI DI POLVERE POSSONO CREARE IN PARTICOLARISITUAZIONI, CONDIZIONI DI ESPLOSIVITA'
Source: ACQUENYMCO CORMANO

Result: not explosive
Source: CHEMVIRON CARBON BRUXELLES

2.11 Oxidizing Properties

Result: no oxidizing properties
Source: CHEMVIRON CARBON BRUXELLES

Result: no oxidizing properties
Remark: NON APPLICABILE
Source: ACQUENYMCO CORMANO

2.12 Additional Remarks

Remark: IL CARBONE ATTIVO NON E’ CONSIDERATO PRODOTTO PERICOLOSO E TROVA LARGHI IMPIEGHI NELLA POTABILIZZAZIONE DELLE ACQUE O NEI PROCESSI ALIMENTARI
Source: ACQUENYMCO CORMANO

3.1.1 Photodegradation

–

3.1.2 Stability in Water

–

3.1.3 Stability in Soil

–

3.2 Monitoring Data (Environment)

–

3.3.1 Transport between Environmental Compartments

–

3.3.2 Distribution

–

3.4 Mode of Degradation in Actual Use

Remark: IL PRODOTTO E’ STABILE ALLE CONDIZIONI NORMALI DI IMPIEGO
Source: ACQUENYMCO CORMANO

3.5 Biodegradation

–

3.6 BOD5, COD or BOD5/COD Ratio

B O D 5

Method: ISO 5815 "Water quality – Determination of biochemical oxygen demand after 5 days (BOD5) – Dilution and seeding method"
BOD5: ca. 2 mgO2/l

C O D

Method: ISO DP 6060 "Water quality – Determination of the chemical oxygen demand"
COD: 2000 mg/g substance

Source: CHEMVIRON CARBON BRUXELLES

3.7 Bioaccumulation

–

3.8 Additional Remarks

Source: ACQUENYMCO CORMANO

AQUATIC ORGANISMS

4.1 Acute/Prolonged Toxicity to Fish

-

4.2 Acute Toxicity to Aquatic Invertebrates

-

4.3 Toxicity to Aquatic Plants e.g. Algae

-

4.4 Toxicity to Microorganisms e.g. Bacteria

Type:
Species:
Exposure period:
Unit: **Analytical monitoring:**
Method:
Year: **GLP:**
Test substance:
Remark: Peat based steam activated carbons, lignite based steam activated carbons and wood based chemical activated carbons were found not to be toxic to waste-water bacteria.
An EC50 value for respiration inhibition could not be determined.
Tests by RCC Notox B.V. The Netherlands.
Source: CHEMVIRON CARBON BRUXELLES

4.5 Chronic Toxicity to Aquatic Organisms

4.5.1 Chronic Toxicity to Fish

-

4.5.2 Chronic Toxicity to Aquatic Invertebrates

-

TERRESTRIAL ORGANISMS

4.6.1 Toxicity to Soil Dwelling Organisms

–

4.6.2 Toxicity to Terrestrial Plants

–

4.6.3 Toxicity to other Non–Mamm. Terrestrial Species

–

4.7 Biological Effects Monitoring

–

4.8 Biotransformation and Kinetics

–

4.9 Additional Remarks

–

5.1 Acute Toxicity

5.1.1 Acute Oral Toxicity

Type: LD50
Species: rat
Sex:
Number of Animals:
Vehicle:
Value: > 10000 mg/kg bw
Method: other
Year: 1979 **GLP:**
Test substance:
Remark: Determination for toxic substances – Test conducted in 1979 by the American Agency FHSA.
Activated carbon is not an oral toxic substance.
Determination for toxic substances, tests conducted in 1977 by CIVO TNO, the Netherlands.
Source: CHEMVIRON CARBON BRUXELLES

5.1.2 Acute Inhalation Toxicity

Type: LC50
Species: rat
Sex:
Number of Animals:
Vehicle:
Exposure time:
Value: > 64.4 mg/l
Method: other
Year: 1979 **GLP:**
Test substance:
Remark: Determination for toxic substances. Tests conducted in 1979 by the American Agency FHSA.
Source: CHEMVIRON CARBON BRUXELLES

5.1.3 Acute Dermal Toxicity

Type:
Species:
Sex:
Number of Animals:
Vehicle:
Value:
Method:
Year: **GLP:**
Test substance:
Remark: Activated carbon is not a primary skin irritant.
Source: CHEMVIRON CARBON BRUXELLES

5.1.4 Acute Toxicity, other Routes

–

5.2 Corrosiveness and Irritation

5.2.1 Skin Irritation

Species:
Concentration:

Exposure:
Exposure Time:
Number of Animals:
PDII:
Result:
EC classificat.:
Method:
Year: **GLP:**
Test substance:
Remark: No data – None irritating
Source: CHEMVIRON CARBON BRUXELLES

5.2.2 Eye Irritation

Species: other
Concentration:
Dose:
Exposure Time:
Comment:
Number of Animals:
Result:
EC classificat.: not irritating
Method:
Year: **GLP:**
Test substance:
Remark: LA POLVERE DI CARBONE ATTIVO PUO’ PROVOCARE LIEVE IRRITAZIONE DEGLI OCCHI.
Source: ACQUENYMCO CORMANO

Species:
Concentration:
Dose:
Exposure Time:
Comment:
Number of Animals:
Result:
EC classificat.:
Method:
Year: **GLP:**
Test substance:
Remark: No data – None irritating
Source: CHEMVIRON CARBON BRUXELLES

5.3 Sensitization

Type:
Species:
Number of Animals:
Vehicle:
Result:
Classification:
Method:
Year: **GLP:**
Test substance:
Remark: No data – Not sensitizing
Source: CHEMVIRON CARBON BRUXELLES

5.4 Repeated Dose Toxicity

-

5.5 Genetic Toxicity 'in Vitro'

-

5.6 Genetic Toxicity 'in Vivo'

-

5.7 Carcinogenicity

-

5.8 Toxicity to Reproduction

-

5.9 Developmental Toxicity/Teratogenicity

-

5.10 Other Relevant Information

-

5.11 Experience with Human Exposure

Source: CHEMVIRON CARBON BRUXELLES

(1)

(1) Wet activated carbon removes oxygen from air causing severe hazard to workers inside carbon vessels and closed or confined spaces. Before entering such an area, sampling and work procedures for low oxygen levels should be taken to ensure ample oxygen availability.

7.1 Risk Assessment

-

European Food Safety Authority

EFSA Journal 2014;12(2):3571

SCIENTIFIC OPINION

Scientific Opinion on the safety assessment of the active substances, sodium erythorbate, sodium carbonate, sodium bicarbonate, iron sulphate, activated carbon, cellulose, calcium hydroxide, calcium chloride and water, for use as active system in food contact materials[1]

EFSA Panel on Food Contact Materials, Enzymes, Flavourings and Processing aids (CEF)[2, 3]

European Food Safety Authority (EFSA), Parma, Italy

This scientific output, published on 6 May 2014, replaces the earlier version published on 12 February 2014*.

ABSTRACT

This scientific opinion of EFSA Panel on Food Contact Materials, Enzymes, Flavourings and Processing Aids deals with the safety assessment of the active substances sodium erythorbate, sodium carbonate, sodium bicarbonate, iron sulfate, activated carbon, cellulose, calcium hydroxide, calcium chloride and water, used in mixture which is packed into sachets for absorbing oxygen/carbon dioxide emitting from/into the headspace surrounding packed food. All substances of this formulation have been evaluated and approved for use as additives in plastic food contact materials or as food additives. No migration of calcium, iron and sodium ions was detected. No volatile organic compounds other than carbon dioxide were detected at the limit of detection of 0.5 µg/l. The CEF Panel concluded that the use of the substances sodium erythorbate, sodium carbonate, sodium bicarbonate, iron sulfate, activated carbon, cellulose, calcium hydroxide, calcium chloride and water does not raise a safety concern when used in oxygen absorber/carbon dioxide emitter systems, in sachets that prevent the physical release of their contents into the food. The sachets are to be placed in the headspace of the packaging and as such may come into occasional contact with the food, e.g. during handling. The sachet should not come into direct contact with liquid foods or foods that have and external aqueous liquid phase on the surface (liquid or exudates).

[1] On request from the Direction Générale de la Concurrence, de la Consommation et de la Répression des Fraudes, France, Question No EFSA-Q-2011-00240, adopted on 29 January 2014.

[2] Panel members: Ulla Beckman Sundh, Mona-Lise Binderup, Claudia Bolognesi, Leon Brimer, Laurence Castle, Alessandro Di Domenico, Karl-Heinz Engel, Roland Franz, Nathalie Gontard, Rainer Gürtler, Trine Husøy, Klaus-Dieter Jany, Martine Kolf-Clauw, Catherine Leclercq (until July 2013), Jean-Claude Lhuguenot (until November 2012), Wim Mennes, Maria Rosaria Milana, Maria de Fátima Tavares Poças, Iona Pratt, Kettil Svensson, Fidel Toldrá and Detlef Wölfle. Correspondence: cef@efsa.europa.eu

[3] Acknowledgement: The Panel wishes to thank the members of the Working Group on Food Contact Materials: Mona-Lise Binderup, Laurence Castle, Riccardo Crebelli, Roland Franz, Nathalie Gontard, Ragna Bogen Hetland, Eugenia Lampi, Maria Rosaria Milana, Maria de Fátima Tavares Poças, Philippe Saillard, Kettil Svensson and Detlef Wölfle for the preparatory work on this scientific opinion.

* Minor changes of an editorial nature were made. The changes do not affect the contents of this report. To avoid confusion, the original version of the opinion has been removed from the website, but is available on request, as a version showing all the changes made.

Suggested citation: EFSA CEF Panel (EFSA Panel on Food Contact Materials, Enzyme, Flavourings and Processing Aids), 2014. Scientific Opinion on the safety assessment of the active substances, sodium erythorbate, sodium carbonate, sodium bicarbonate, iron sulphate, activated carbon, cellulose, calcium hydroxide, calcium chloride and water, for use as active system in food contact materials. EFSA Journal 2014;12(2):3571, 11 pp. doi:10.2903/j.efsa.2014.3571

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KEY WORDS

sodium erythorbate, sodium carbonate, sodium bicarbonate, food contact materials, safety assessment, evaluation

SUMMARY

According to the Commission Regulation (EC) No 450/2009 of the Commission of European Communities of 29 May 2009 on active and intelligent materials and articles intended to come into contact with food, substances responsible for the active or intelligent function need first to be evaluated by the EFSA before their inclusion into a positive Community list. The procedure of the evaluation and the tasks of EFSA are described in the Regulation (EC) No. 1935/2004 of the European Parliament and of the Council of 27 October 2004 on materials and articles intended to come into contact with food.

In the context of this evaluation procedure, following a request from the Direction Générale de la Concurrence, de la Consommation et de la Répression des Fraudes , France, the EFSA Panel on Food Contact Materials, Enzymes and Processing aids (CEF) was asked to deliver an opinion on the safety of a mixture comprising sodium erythorbate (CAS 6381-77-7 and FCM Substance No 1042), sodium carbonate (CAS No 497-19-8 and FCM Substance No 21), sodium bicarbonate (CAS No 144-55-8 and FCM Substance No 21), iron sulphate (CAS No 7782-63-0 and FCM Substance No 511), activated carbon (CAS No 7440-44-0, FCM Substance No 984), cellulose (CAS No 9004-34-6 and FCM Substance No 553), calcium hydroxide (CAS No 1305-62-0 and FCM Substance No 394), calcium chloride (CAS No 10043-52-4 and FCM Substance No 585) and water (CAS No 7732-18-5, FCM Substance No 515), for use as oxygen absorber and carbon dioxide emitter. The mixture is intended to be placed in a sachet made from perforated polyethylene terephtalate (PET)/cellulosic non woven (NT)polypropylene (PP) material. The dossier was submitted by the applicant, Atmosphère Contrôle SAS (ATCO), France.

The active ingredient responsible for the oxygen absorbing function is sodium erythorbate, which reacts with the oxygen present in the primary packaging. The carbon dioxide emitting function is fulfilled by the presence of sodium carbonate or sodium bicarbonate. All the other substances are used to provide adequate media to facilitate both reactions. This oxygen absorber/carbon dioxide emitter system is intended to be used in various applications, such as meat and meat products, precooked dishes, delicatessen, cheese, bakery, cakes, pastry products. These foods are generally stored at +4 °C. Shelf-lives vary from several days to several weeks.

All starting substances have been evaluated and approved for use as additives in plastic food contact materials or as food additives. Activated carbon was not evaluated as such, but it meets the specifications for activated charcoal, which is authorised as additive for plastic materials and articles in contact with foods (Regulation (EU) No 10/2011) i.e. same purity requirements as for Vegetable Carbon (E 153) set out by Regulation (EC) No 1333/2008 with the exception of ash content which may be up to 10 %.

Specific migration of calcium, iron and sodium were determined under realistic conditions, in minced meat, in contact with one sachet for 7 days, at 5 °C. By comparing the average content of calcium, iron and sodium naturally present in minced meat, with the corresponding concentrations measured in minced meat in direct contact with sachets, no significant migration of the ions present in the sachet is expected.

Potential byproducts linked to the use of the oxygen absorber/carbon dioxide emitter system were investigated. No volatile organic compounds other than carbon dioxide were detected at the limit of detection of 0.5 µg/l.

Based on the level of migration and the intended uses (no direct contact with food), no toxicity studies on the formulation and migrants were required. The use the oxygen absorber/carbon dioxide emitter formulation is toxicologically acceptable.

Therefore, the CEF Panel concluded that the use of the substances sodium erythorbate, iron sulfate, activated carbon, cellulose, calcium hydroxide, sodium carbonate, sodium bicarbonate, calcium

chloride and water does not raise a safety concern when used in oxygen absorber/carbon dioxide emitter systems, in sachets that prevent the physical release of their contents into the food. The sachets are to be placed in the headspace of the packaging and as such may come into occasional contact with the food, e.g. during handling. The sachet should not come into direct contact with liquid foods or foods that have and external aqueous liquid phase on the surface (liquid or exudates).

Activated carbon should in addition comply with the same purity requirements as for Vegetable Carbon (E 153) set out by Regulation (EC) No 1333/2008 with exception of ash content which can be up to 10 % (w/w).

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BACKGROUND AS PROVIDED BY THE LEGISLATION

Regulation (EC) No 450/2009[4] of the Commission of European Communities is a specific measure that lays down specific rules for active and intelligent materials and articles intended for contact with foodstuffs in addition to the general requirements established in Regulation (EC) No 1935/2004[5] of the European Parliament and of the Council on materials and articles intended to come into contact with food. Active materials and articles are intended to extend the shelf-life or to maintain or improve the condition of packaged food; they are designed to deliberately incorporate components that would release or absorb substances into or from the packaged food or the environment surrounding the food. In the context of this evaluation procedure, the CEF Panel received a request from a competent Member State Authority for safety evaluation of three mixtures of substances following the corresponding applications from the industry.

The substance(s) responsible for the active and/or intelligent function of the material should be included in a positive list by the Commission following a safety evaluation by EFSA according to the procedure described in the abovementioned regulations.

According to this procedure the industry submits applications to the Member States competent Authorities which in their turn transmit the applications to EFSA for evaluation. The application is supported by a technical dossier submitted by the industry following the EFSA guidelines on "submission of a dossier for safety evaluation by EFSA of active or intelligent substances present in active and intelligent materials and articles intended to come into contact with food" (EFSA, 2009).

In this context, EFSA received an application from the Direction Générale de la Concurrence, de la Consommation et de la Répression des Fraudes, France, requesting the evaluation of a mixture comprising iron sulfate, activated carbon, sodium erythorbate, cellulose, calcium hydroxide, sodium carbonate, sodium bicarbonate, calcium chloride solution and water, for use as use as oxygen scavenger and carbon dioxide emitter.

TERMS OF REFERENCE AS PROVIDED BY THE LEGISLATION

EFSA is required to carry out a risk assessment on the risks originating from the migration into food of the substances activated carbon, sodium erythorbate, iron sulfate, cellulose, calcium hydroxide, sodium carbonate, sodium bicarbonate, calcium chloride solution, and water, used in oxygen absorbing systems in food contact materials, and deliver a scientific opinion, according to the Regulation (EC) No 1935/2004 of the European Parliament and of the Council on materials and articles intended to come into contact with food.

The opinion of EFSA will be considered by the Commission for adoption of a Community list of authorised substances where according to the Regulation (EC) No 450/2009 there will be specified:

(a) the identity of the substance(s);
(b) the function of the substance(s);
(c) the reference number;
(d) if necessary, the conditions of use of the substance(s) or component;
(e) if necessary, restrictions and/or specifications of use of the substance(s);
(f) if necessary, conditions of use of the material or article to which the substance or component is added or into which it is incorporated.

[4] Commission Regulation (EC) No 450/2009 of 29 May 2009 on active and intelligent materials and articles intended to come into contact with food. OJ L 135, 30.5.2009, p. 3–11

[5] Regulation (EC) No 1935/2004 of the European parliament and of the council of 27 October 2004 on materials and articles intended to come into contact with food and repealing Directives 80/590/EEC and 89/109/EEC. OJ L 338, 13.11.2004, p. 4–17

ASSESSMENT

1. Introduction

The European Food Safety Authority was asked by the Direction Générale de la Concurrence, de la Consommation et de la Répression des Fraudes, France to evaluate the safety of a mixture comprising sodium erythorbate (CAS 6381-77-7 and FCM Substance No 1042), sodium carbonate (CAS No 497-19-8 and FCM Substance No 21), sodium bicarbonate (CAS No 144-55-8 and FCM Substance No 21), iron sulphate (CAS No 7782-63-0 and FCM Substance No 511), activated carbon (CAS No 7440-44-0, FCM Substance No 984), cellulose (CAS No 9004-34-6 and FCM Substance No 553), calcium hydroxide (CAS No 1305-62-0 and FCM Substance No 394), calcium chloride (CAS No 10043-52-4 and FCM Substance No 585) and water (CAS No 7732-18-5, FCM Substance No 515). The request has been registered in the EFSA's register of received questions under the number EFSA-Q-2011-00240. The dossier was submitted by the applicant, Atmosphère Contrôle SAS (ATCO), France.

2. General information

According to the applicant, the active mixture constituting the oxygen absorber and carbon dioxide emitter system is a powder comprising sodium erythorbate, sodium carbonate, sodium bicarbonate, iron sulphate, activated carbon, cellulose, calcium hydroxide, calcium chloride and water. It is introduced into multilayer sachet made from polyethylene terephtalate (PET)/cellulosic non-woven/polypropylene (PP) material, and heat sealed after filling. Both PET and PP are perforated prior lamination to allow gas exchanges.

According to the applicant, sachets containing the active mixture, with a weight of active formulation per unit of the sachet surface of 6 g/dm², are introduced in food packaging to scavenge oxygen and to produce carbon dioxide. Sachets should be placed in the headspace (to allow air circulation) of the packaging. Nevertheless, unintended occasional contact with dry or other solid foods cannot be excluded. The sachets must not be put in direct contact with acid food (pH < 4.5), with liquid foods (i.e. dressings, soups, beverages) or foods with external aqueous liquid fraction (liquids or exudates) to avoid inhibition of the oxygen absorption.

This oxygen absorber/carbon dioxide emitter system is intended to be used in various applications, such as meat and meat products, precooked dishes, delicatessen, cheese, bakery, cakes, pastry products. These foods are generally stored at +4 °C. Shelf-lives vary from several days to several weeks.

The active mixture has not been evaluated by the SCF or EFSA in the past. However, all the substances constituting the mixture (activated carbon, sodium erythorbate, iron sulfate, cellulose, calcium hydroxide, sodium carbonate, sodium bicarbonate, calcium chloride solution) are authorised either for plastic materials and articles in contact with foods (Regulation (EU) No 10/2011[6]) or food additives (Regulation (EC) No 1333/2008[7]) as follows:

- Sodium erythorbate is authorised as a food additive (E316), with the lowest limit of 500 mg/kg for cured meat products and preserved meat products. Iron sulphate is authorised as sulphuric acid, salts (FCM Substance No 511), as additive for plastic materials and articles in contact with foods, with no restriction.

[6] Commission Regulation (EU) No 10/2011 of 14 January 2011 on plastic materials and articles intended to come into contact with food
OJ L 12. 15.1.2011, p. 1-89

[7] Regulation (EC) No 1333/2008 of the European Parliament and the Council of 16 December 2008 on food additives, OJ L 354.31.12.2008, p.16-33

- Carbonic acid salts is authorised as additive for plastic materials and articles in contact with foods, with no specific restriction (FCM Substance No 21); it is also authorised as a food additive (E 500) so its sodium salts are also authorised.
- Activated carbon has been evaluated for use as additive for plastic materials and articles in contact with foods (EFSA, 2004) and for use in oxygen scavenger mixtures (EFSA CEF Panel, 2012). For use in oxygen scavenger mixtures placed in sachets which would prevent the physical release of their contents into the food and placed in the headspace of the packaging or when used in direct contact with dry foods, the CEF Panel concluded that activated carbon does not raise safety concern if it complies with the same purity requirements as for Vegetable Carbon (E 153) set out by Regulation (EC) No 1333/2008 with exception of ash content which can be up to 10 % (w/w). (FCM Substance No 984)
- Cellulose is authorised as additive for plastic materials and articles in contact with foods, with no specific restriction (FCM Substance No 553).
- Calcium hydroxide is authorised as an additive for plastic materials and articles in contact with foods with no specific migration restriction (FCM Substance No 394). It is also listed in Regulation (EU) No 1129/2011 amending Annex II to Regulation (EC) No 1333/2008 of the European Parliament and of the Council by establishing a Union list of Food Additives (specific maximum level: *quantum satis*) (E 526)[8].
- Hydrochloric acid is authorised as additive for plastic materials and articles in contact with foods, with no specific restriction (FCM Substance No 507).
- Calcium chloride is an authorised food additive (E509).
- Water is authorised as additive or monomer for plastic materials and articles in contact with foods, with no specific restrictions. The water specifications must be in compliance with Directive 98/83/EC (FCM Substance No 51).

3. Data available in the dossier used for this evaluation

The studies submitted for evaluation followed the EFSA guidelines on submission of a dossier for safety evaluation by EFSA of active or intelligent substances present in active and intelligent materials and articles intended to come into contact with food (EFSA, 2009).

Non-toxicity data:

- Data on identity
- Data on physical and chemical properties
- Data on manufacturing process
- Data on function, intended use and authorisation
- Data on overall and specific migration
  Screening on potential volatile byproducts

Toxicity data:

- Bacterial gene mutation tests on overall migration solution
- *In vitro* micronucleus test on overall migration solution

[8] Regulation (EC) No 1333/2008 of the European Parliament and of the Council of 16 December 2008 on food additives, OJ L 354.31.12.2008, p.16-33

4. Evaluation

4.1. Non-toxicological data

The active powder, used for oxygen scavenging and carbon dioxide emission, comprises sodium erythorbate, iron sulphate, activated carbon, cellulose, calcium hydroxide, sodium carbonate or bicarbonate, calcium chloride solution and water. The active ingredient responsible of the oxygen absorber function is sodium erythorbate which reacts with oxygen, removing the oxygen from the primary packaging. Sodium carbonate/bicarbonate is involved into the carbon dioxide release into the packaging headspace. The other chemicals are used to provide adequate media to facilitate both reactions.

Overall and specific migration tests for iron, sodium, calcium, as well as a screening of volatile byproducts were performed. Measurements were done by total immersion and under more realistic conditions (minced meat). The Panel considered that experiments by total immersion of sachets are not representative of the intended conditions of use and reported only the results from experiments carried out under more realistic conditions.

Specific migration of calcium, iron and sodium were determined in minced meat in contact with one sachet for 7 days, at 5 °C. The average content of calcium, iron and sodium naturally present in minced meat, without contact with sachets, was respectively: 88 ±20 mg/kg food; 32 ±6 mg/kg food and 609 ±92 mg/kg food. The corresponding concentrations measured in minced meat in direct contact with sachets were respectively 73 ± 16 mg/kg for calcium; 24 ± 3mg/kg for iron and 616 ± 71 mg/kg for sodium. Based on these values, no significant migration of the ions present in the sachet is expected.

The release of volatile byproducts was analysed by placing seven sachets in one liter sealed plastic bag containing air at 23 °C. Samples have been collected after 30 min, 102 min and 1 week. No volatile organic compounds other than carbon dioxide were detected at the limit of detection of 0.5 µg/l.

4.2. Toxicological data

All ingredients of the oxygen absorber/carbon dioxide emitter formulation have been evaluated and approved for use in food contact materials, without specific restriction limits, or as food additives. Activated carbon was not evaluated as such, but it meets the specifications for activated charcoal, which is authorized as additive for plastic materials and articles in contact with foods (Regulation (EU) No 10/2011) i.e. same purity requirements as for Vegetable Carbon (E 153) set out by Regulation (EC) No 1333/2008 with the exception of ash content which may be up to 10 %.

All ingredients of the active formulation are expected to be stable in normal storage and handling conditions. Moreover, the oxygen absorber/carbon dioxide emitter formulation is not intended for direct contact with liquid food or food with external liquid fraction, so no migration of non volatile species is expected. No migration of volatile byproducts was detected. Thus no toxicity studies on the formulation and migrants are required.

Nevertheless, two limited *in vitro* genotoxicity studies, namely a gene mutation test in bacteria and an *in vitro* micronucleus tests, were performed on migration solutions obtained under extreme conditions (10 days at 40 °C, by immersion). The tests were negative.

The Panel concluded that under the intended conditions of use the oxygen absorber/carbon dioxide emitter formulation is toxicologically acceptable.

CONCLUSIONS

Having considered the above-mentioned data, the CEF Panel concluded that the use of the substances sodium erythorbate, sodium carbonate, sodium bicarbonate, iron sulphate, activated carbon, cellulose, calcium hydroxide, calcium chloride and water does not raise a safety concern when used in oxygen absorber/carbon dioxide emitter systems, in sachets that prevent the physical release of their contents into the food. The sachets are to be placed in the headspace of the packaging and as such may come into occasional contact with the food, e.g. during handling. The sachet should not come into direct contact with liquid foods or foods that have and external aqueous liquid phase on the surface (liquid or exudates).

Activated carbon should in addition comply with the same purity requirements as for Vegetable Carbon (E 153) set out by Regulation (EC) No 1333/2008 with exception of ash content which can be up to 10 % (w/w).

DOCUMENTATION PROVIDED TO EFSA

1. Dossier referenced: 03/3434 Dated: 07/03/2011. Submitted by the applicant, Atmosphère Control SAS (ATCO).

REFERENCES

EFSA (European Food Safety Authority), 2009. Guidelines on submission of a dossier for safety evaluation by the EFSA of active or intelligent substances present in active and intelligent materials and articles intended to come into contact with food. The EFSA Journal 2009, 1208, 10-1.

EFSA CEF Panel (EFSA Panel on Food Contact Materials, Enzymes, Flavourings and Processing Aids), 2012. Scientific Opinion on the safety evaluation of the active substances, activated carbon, water, iron powder, kaolin calcined, sulphur and sodium chloride for use as active component in food contact materials. EFSA Journal 2012;10(3):2643, 12 pp. doi:10.2903/j.efsa.2012.2643

EFSA CEF Panel (EFSA Panel on Food Contact Materials, Enzymes, Flavourings and Processing Aids), 2013a. Scientific Opinion on the safety evaluation of the active substances, iron, polyethyleneglycol, disodium pyrophosphate, monosodium phosphate and sodium chloride for use in food contact materials. EFSA Journal 2013;11(6):3245, 11 pp. doi:10.2903/j.efsa.2013.3245

EFSA CEF Panel (EFSA Panel on Food Contact Materials, Enzymes, Flavourings and Processing Aids), 2013b. Scientific Opinion on the safety evaluation of the active substances iron, sodium chloride, water, silica gel, activated carbon, monosodium glutamate, potassium acid tartrate, powdered cellulose, malic acid, chabazite, hydroxypropyl cellulose, potassium carbonate, sodium thiosulfate, propylene glycol, glycerin, polyethyleneglycol sorbitan monooleate, sodium propionate and clinoptilolite for use in food contact materials. EFSA Journal 2013;11(4):3155, 12 pp. doi:10.2903/j.efsa.2013.3155

EFSA CEF Panel (EFSA Panel on Food Contact Materials, Enzymes, Flavourings and Processing Aids), 2013c. Scientific Opinion on the safety assessment of the active substances iron, iron oxides, sodium chloride and calcium hydroxide for use in food contact materials. EFSA Journal 2013;11(10):3387, 9 pp. doi:10.2903/j.efsa.2013.3387

SCF (Scientific Committee of Food), 1990, First series of food additives of various technological functions, Report 25th Series http://ec.europa.eu/food/fs/sc/scf/reports/scf_reports_25.pdf.

GLOSSARY AND ABBREVIATIONS

Overall migration: The sum of the amounts of volatile and non volatile substances, except water, released from a food contact material or article into food or food simulant

Specific migration: The amount of a specific substance released from a food contact material or article into food or food stimulant

bw	body weight
CAS	Chemical Abstracts Service
CEF	Scientific Panel on food contact materials, enzymes, flavourings and processing aids
EU	European Union
EC	European Commission
EFSA	European Food Safety Authority
FCM	Food Contact Materials
Mw	Weight average molecular weight
PET	Poly(ethylene terephthalate)
REF No	Reference Number
SCF	Scientific committee on food
SML	Specific Migration Limit
w/w	Weight by weight

European Food Safety Authority

EFSA Journal 2014;12(5):3649

SCIENTIFIC OPINION

Scientific Opinion on the safety assessment of the active substances iron powder, activated carbon, calcined kaolin, sodium chloride, polyacrylic acid, sodium salt, crosslinked and calcium chloride, for use as active system in food contact materials[1]

EFSA Panel on Food Contact Materials, Enzymes, Flavourings and Processing Aids (CEF)[2,3]

European Food Safety Authority (EFSA), Parma, Italy

ABSTRACT

This scientific opinion of the EFSA Panel on Food Contact Materials, Enzymes, Flavourings and Processing Aids deals with the safety assessment of the active substances iron powder, activated carbon, calcined kaolin, sodium chloride, polyacrylic acid, sodium salt, crosslinked and calcium chloride, used in mixture which is packed into labels, for absorbing oxygen from the headspace surrounding packed food. All substances of this formulation have been evaluated and approved for use as additives in plastic food contact materials or as food supplements. Migration of substances from the labels and formation and release of volatile constituents are not expected under the intended conditions of use. The CEF Panel concluded that the use of substances iron powder, activated carbon, calcined kaolin, sodium chloride, polyacrylic acid, sodium salt, crosslinked and calcium chloride does not raise a safety concern when used in oxygen absorbers in labels, which prevent the physical release of their content into the food. When placed in the headspace of the packaging or when used in direct contact with foods, the labels should not intentionally or unintentionally come into direct contact with liquid foods or foods that have an external aqueous phase on the surface such as sliced fruits.

KEY WORDS

iron powder, activated carbon, calcined kaolin, sodium chloride, polyacrylic acid sodium salt crosslinked, calcium chloride, safety assessment

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[1] On request from the Bundesamt für Verbraucherschultz und Lebensmittelsicherheit, Germany, Question No EFSA-Q-2011-00241, adopted on 10 April 2014.

[2] Panel members: Ulla Beckman Sundh, Mona-Lise Binderup, Claudia Bolognesi, Leon Brimer, Laurence Castle, Alessandro Di Domenico, Karl-Heinz Engel, Roland Franz, Nathalie Gontard, Rainer Gürtler, Trine Husøy, Klaus-Dieter Jany, Martine Kolf-Clauw, Catherine Leclercq (until July 2013), Jean-Claude Lhuguenot (until November 2012), Wim Mennes, Maria Rosaria Milana, Maria de Fátima Poças, Iona Pratt †, Kettil Svensson, Fidel Toldrá and Detlef Wölfle. Correspondence: cef@efsa.europa.eu

[3] Acknowledgement: The Panel wishes to thank the members of the Working Group on Food Contact Materials: Mona-Lise Binderup, Laurence Castle, Riccardo Crebelli, Alessandro Di Domenico, Roland Franz, Nathalie Gontard, Ragna Bogen Hetland, Martine Kolf-Clauw, Eugenia Lampi, Maria Rosaria Milana, Maria de Fátima Poças, Philippe Saillard, Kettil Svensson and Detlef Wölfle for the preparatory work on this scientific opinion.

† Deceased

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Available online: www.efsa.europa.eu/efsajournal

SUMMARY

According to the Commission Regulation (EC) No 450/2009 of the Commission of European Communities of 29 May 2009 on active and intelligent materials and articles intended to come into contact with food, substances responsible for the active or intelligent function need first to be evaluated by EFSA before their inclusion into a positive Community list. The procedure of the evaluation and the tasks of EFSA are described in the Regulation (EC) No 1935/2004 of the European Parliament and of the Council of 27 October 2004 on materials and articles intended to come into contact with food.

In the context of this evaluation procedure, following a request from the Direction Générale de la Concurrence, de la Consommation et de la Répression des Fraudes, France, the EFSA Panel on Food Contact Materials, Enzymes and Processing Aids (CEF) was asked to deliver a scientific opinion on a mixture comprising iron powder, activated carbon, calcined kaolin, sodium chloride, polyacrylic acid, sodium salt, crosslinked and calcium chloride, for use as oxygen absorber in labels. Dossier was submitted on behalf of Atmosphère Control SAS, France.

According to the applicant, the substances constituting the oxygen absorber systems are mixed together and the active formulation is deposited on a multilayer film made from porous polyethylene terephthalate (PET) / nonwoven spunbonded high density polyethylene (HDPE) and covered by a multilayer film polyethylene terephthalate (PET) / polyethylene (PE). Both films are heat-sealed on 4 sides. Labels are stuck inside the packaging. The active ingredient responsible of the oxygen absorber function is iron which reacts with oxygen, removing the oxygen from the primary packaging. The other chemicals are used to provide adequate media to facilitate the reaction. The labels containing the oxygen absorber system can be used for various foods such as processed-meat products, precooked dishes, delicatessen, cheese, bakery, cakes and pastry products. These foods are generally stored at +4 °C. Shelf-lives vary from several days to several months.

The Panel concluded that under the intended conditions of use where there is no contact with liquid food or foods that have an external aqueous phase on the surface, the constituents of the mixture will not migrate because they are not volatile.

Considering the nature of these ingredients and their mode of action, the formation and release of volatile byproducts is not expected.

The CEF Panel concluded that the use of substances iron powder, activated carbon, calcined kaolin, sodium chloride, polyacrylic acid, sodium salt, crosslinked and calcium chloride does not raise a safety concern when used in oxygen absorbers in labels, which prevent the physical release of their content into the food. When placed in the headspace of the packaging or when used in direct contact with foods, the labels should not intentionally or unintentionally come into direct contact with liquid foods or foods that have an external aqueous phase on the surface such as sliced fruits.

Activated carbon should in addition comply with the same purity requirements as for Vegetable Carbon (E 153) set out by Commission Regulation (EU) No 231/2012 with exception of ash content which can be up to 10 % (w/w).

Iron is a natural constituent of foods. Iron compounds are also used as food additives, nutrient sources and for other purposes. The Commission may wish to take note of this if setting a restriction for iron.

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BACKGROUND AS PROVIDED BY THE LEGISLATION

Regulation (EC) No 450/2009[4] of the Commission of European Communities is a specific measure that lays down specific rules for active and intelligent materials and articles intended for contact with foodstuffs in addition to the general requirements established in Regulation (EC) No 1935/2004[5] of the European Parliament and of the Council on materials and articles intended to come into contact with food. Active materials and articles are intended to extend the shelf-life or to maintain or improve the condition of packaged food; they are designed to deliberately incorporate components that would release or absorb substances into or from the packaged food or the environment surrounding the food.

The substance(s) responsible for the active and/or intelligent function of the material should be included in a positive list by the Commission following a safety evaluation by EFSA according to the procedure described in the above mentioned regulations.

According to this procedure the industry submits applications to the Member States competent Authorities which transmit the applications to EFSA for evaluation. The application is supported by a technical dossier submitted by the industry following the EFSA guidelines on "submission of a dossier for safety evaluation by the EFSA of active or intelligent substances present in active and intelligent materials and articles intended to come into contact with food" (EFSA, 2009).

In this context, EFSA received an application from the Direction Generale De la Concurrence de la Consommation et de la Repression des Fraudes, France, requesting the evaluation of a mixture comprising iron powder, activated carbon, calcined kaolin, sodium chloride, polyacrylic acid, sodium salt, crosslinked and calcium chloride, for use as an oxygen absorbers in labels.

TERMS OF REFERENCE AS PROVIDED BY THE LEGISLATION

According to Regulation (EC) No 1935/2004 of the European Parliament and of the Council on materials and articles intended to come into contact with food EFSA is asked to carry out an assessment of the risks related to the intended use of the substances and to deliver a scientific opinion.

[4] Commission Regulation (EC) No 450/2009 of 29 May 2009 on active and intelligent materials and articles intended to come into contact with food. OJ L 135, 30.5.2009, pp.3–11

[5] Regulation (EC) No 1935/2004 of the European Parliament and of the Council of 27 October 2004 on materials and articles intended to come into contact with food and repealing Directives 80/590/EEC and 89/109/EEC. OJ L 338, 13.11.2004, pp. 4–17

ASSESSMENT

1. Introduction

The European Food Safety Authority was asked by the Direction Generale De la Concurrence de la Consommation et de la Repression des Fraudes, France to evaluate the safety of a mixture comprising iron powder (CAS No 7439-89-6, FCM Substance No 983), activated carbon (CAS No 7440-44-0, FCM Substance No 713), calcined kaolin (CAS No 92704-41-1, FCM Substance No 753), sodium chloride (CAS No 7647-14-5, FCM Substance No 985), polyacrylic acid, sodium salt, crosslinked (FCM substance No 1015) and calcium chloride (CAS 10043-52-4, FCM Substance No 585), for use as an oxygen absorber in labels. The request has been registered in the EFSA's register of questions under EFSA-Q-2011-00241. The dossier was submitted by the applicant, Atmosphère Contrôle SAS (ATCO), France.

2. General information

According to the applicant, the substances constituting the oxygen absorber systems (iron powder activated carbon, calcined kaolin, sodium chloride, polyacrylic acid, sodium salt, crosslinked and calcium chloride) are mixed together and the active formulation is a powder. The active formulation is deposited on a multilayer film made from porous polyethylene terephthalate (PET) / nonwoven spunbonded high density polyethylene (HDPE) and covered by a multilayer film polyethylene terephthalate (PET) / polyethylene (PE). Both films are heat-sealed on 4 sides. Labels are stuck inside the packaging.

According to the applicant, labels containing the oxygen absorber system can be used for various foods such as processed-meat products, precooked dishes, delicatessen, cheese, bakery, cakes and pastry products. These foods are generally stored at +4 °C. Shelf-lives vary from several days to several months.

According to the applicant, the oxygen absorber system needs a humid atmosphere (Aw > 0.8) to activate chemical reactions but must not be put in contact with liquids or acidic food (pH < 4.5) or entirely covered by food as the system loses its performance.

The mixture has not been evaluated by SCF or EFSA in the past. However, all substances constituting the oxygen absorber systems are either authorised for plastic materials and articles in contact with foods (Regulation (EU) No 10/2011[6]) and as food supplements (Regulation EC No 1170/2009[7]) or evaluated before, as follows:

- Iron powder is authorised as an additive for plastic materials and articles in contact with foods with a specific restriction of 48 mg iron/kg food based on a Provisional Maximum TDI (PMTDI) of 0.8 mg/kg bw set by JECFA/WHO (1983) and agreed by the SCF (1990) (FCM Substance No 983). The EFSA NDA Panel considered that data available are insufficient to establish a tolerable upper intake level for iron (EFSA, 2004a).

- Calcined kaolin is authorized as an additive for plastic materials and articles in contact with foods with no specific restriction (FCM Substance No 753).

- Sodium chloride is authorised as a food supplement with no specific restriction.

[6] Commission Regulation (EU) No 10/2011 of 14 January 2011 on plastic materials and articles intended to come into contact with food OJ L 12. 15.1.2011, p. 1-89

[7] Commission Regulation (EC) No 1170/2009 of 30 November 2009 amending Directive 2002/46/EC of the European Parliament and of Council and Regulation (EC) No 1925/2006 of the European Parliament and of the Council as regards the lists of vitamin and minerals and their forms that can be added to foods, including food supplements (Text with EEA relevance). OJ L 314, 01/12/2009, p. 36–42

- Calcium chloride is authorised as an additive for plastic materials and articles in contact with foods (Regulation (EU) No 10/2011) with no specific restriction (FCM Substance No 585).

- Activated carbon has been evaluated for use as additive for plastic materials and articles in contact with foods (EFSA, 2004b) and for use in oxygen scavenger mixtures (EFSA CEF Panel, 2012). For use in oxygen scavenger mixtures placed in sachets which would prevent the physical release of their contents into the food and placed in the headspace of the packaging or when used in direct contact with dry foods, the CEF Panel concluded that activated carbon does not raise safety concern if it complies with the same purity requirements as for Vegetable Carbon (E 153) set out by Commission Regulation (EU) No 231/2012[8] with exception of ash content which can be up to 10 % (w/w) (FCM Substance No 713).

- Polyacrylic acid, sodium salt, crosslinked, has been evaluated for use as a liquid absorber (EFSA CEF Panel, 2014). The CEF Panel concluded that the use of the substance does not raise a safety concern when used in absorbent pads in the packaging of fresh or frozen meat, poultry, and seafood as well as fresh fruits and vegetables. The absorbent pads must be used only under conditions in which the liquid absorption capacity is not exceeded and direct contact between the substance and the food is excluded.

3. Data available in the dossier used for this evaluation

The studies submitted for evaluation followed the EFSA guidelines on submission of a dossier for safety evaluation by the EFSA of active or intelligent substances present in active and intelligent materials and articles intended to come into contact with food (EFSA, 2009).

Non-toxicity data:

- Data on identity
- Data on physical and chemical properties
- Data on manufacturing process
- Data on function, intended use and authorisation
- Data on overall and specific migrations

Toxicity data:

- Gene mutations in bacteria on global migrants
- *In vitro* micronucleus test on global migrants

4. Evaluation

4.1. Non-toxicological data

The active powder used as an oxygen absorber, comprises iron powder, activated carbon, calcined kaolin, sodium chloride, polyacrylic acid, sodium salt, crosslinked and calcium chloride. The weight of powder mixture used and the design of each label depend on the final application and the needed capacity of oxygen absorption, the highest use of the active powder is up 12.4 g/kg packaged food. The active ingredient responsible for the oxygen absorber function is iron which reacts with oxygen, removing the oxygen from the primary packaging. The other chemicals are used to provide adequate media to facilitate the reaction.

Overall and specific migration were measured by total immersion of labels, with the highest weight of active formulation per unit of the sachet surface, up to 5.2 g/dm². Overall migration was determined in

[8] Commission Regulation (EU) No 231/2012 of 9 March 2012 laying down specifications for food additives listed in Annexes II and III to Regulation (EC) No 1333/2008 of the European Parliament and of the Council (Text with EEA relevance).OJ L 83, 22.3.2012, pp. 1-280

3 % acetic acid, distilled water and 95 % ethanol (each for 10 days, at 40 °C) and into isooctane (2 days at 20 °C) whereas specific migrations were performed only in 3 % acetic acid and distilled water under same contact conditions.

Due to the design of labels (perforated material) and the nature of the active principle, labels must not be placed in contact with a liquid fraction. Consequently, experiments by total immersion of labels are not appropriate. However the results submitted by the applicant have been summarised here for information.

The overall migration can be up to 3100 mg/kg in 3 % acetic acid, 478 mg/kg in water, 595 mg/kg in 95 % ethanol and 207 mg/kg in isooctane.

The specific migration of iron in 3 % acetic acid was up to 75 mg/kg, whereas there was no detectable migration (below 0.033 mg/kg) into water.

The specific migration of silicon, sodium, calcium in water was experimentally determined. Corresponding calculated migration of kaolin, sodium chloride and calcium chloride was respectively up to 0.4 mg/kg, 182 mg/kg and 2.1 mg/kg.

Under the intended conditions of use where there is no contact with liquid food or foods that have an external aqueous phase on the surface, these constituents will not migrate because they are not volatile.

Considering the nature of these ingredients and their mode of action, the formation and release of volatile byproducts is not expected.

4.2. Toxicological data

This oxygen absorber formulation is not intended for direct contact with liquid foods or foods that have an external aqueous phase on the surface or exudates. Therefore no migration of the constituents is expected. All ingredients of the oxygen absorber formulation have been evaluated and approved for use in food contact materials, and are expected to be stable in normal storage and handling conditions. Thus no toxicity studies on the formulation are required.

Nevertheless, two limited *in vitro* genotoxicity studies, namely a gene mutation test in bacteria and an *in vitro* micronucleus tests were performed on global migrants obtained under harsh conditions (10 days at 40 °C, by immersion in water), not representative of real conditions of use. In both tests no evidence of genotoxicity was observed.

The Panel concluded that under the intended conditions of use, the oxygen absorber formulation is toxicologically acceptable.

CONCLUSIONS

The CEF Panel concluded that the use of substances iron powder, activated carbon, calcined kaolin, sodium chloride, polyacrylic acid, sodium salt, crosslinked and calcium chloride, does not raise a safety concern when used in oxygen absorbers in labels, which prevent the physical release of their content into the food. When placed in the headspace of the packaging or when used in direct contact with foods, the labels should not intentionally or unintentionally come into direct contact with liquid foods or foods that have an external aqueous phase on the surface such as sliced fruits.

Activated carbon should in addition comply with the same purity requirements as for Vegetable Carbon (E 153) set out by Commission Regulation (EU) No 231/2012 with exception of ash content which can be up to 10 % (w/w).

Iron is a natural constituent of foods. Iron compounds are also used as food additives, nutrient sources and for other purposes. The Commission may wish to take note of this if setting a restriction for iron.

DOCUMENTATION PROVIDED TO EFSA

1. ATCO OS/DE. March 2011. Submitted by Atmosphère Contrôle SAS (ATCO), France.

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ABBREVIATIONS

CAS Chemical Abstracts Service

CEF Panel on Food Contact Materials, Enzymes, Flavourings and Processing Aids

EC European Commission

FAO Food and Agriculture Organization of the United Nations

FCM Food Contact Materials

EFSA European Food Safety Authority

EU European Union

HDPE High Density Polyethylene

JECFA The Joint FAO/WHO Expert Committee on Food Additiv

NDA Panel on Dietetic Products, Nutrition and Allergies

PE Polyethylene

PET Polyethylene terephthalate

PMTDI Provisional Maximum Tolerable Daily Intake

SCF Scientific Committee on Food

WHO World Health Organization

This report contains the collective views of an international group of experts and does not necessarily represent the decisions or the stated policy of the World Health Organization or of the Food and Agriculture Organization of the United Nations

Evaluation of certain food additives and contaminants

Thirty-first Report of the
Joint FAO/WHO Expert Committee on
Food Additives

World Health Organization
Technical Report Series
759

World Health Organization, Geneva 1987

Monographs containing summaries of relevant data and toxicological evaluations are available under the title:

Toxicological evaluation of certain food additives. Cambridge, Cambridge University Press, 1987 (WHO Food Additives Series, No. 22)

Specifications are issued separately by FAO under the title:

Specifications for the identity and purity of certain food additives
FAO Food and Nutrition Paper, No. 38

INTERNATIONAL PROGRAMME ON CHEMICAL SAFETY

The preparatory work for toxicological evaluations of food additives and contaminants by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) is actively supported by certain of the member States that contribute to the work of the International Programme on Chemical Safety (IPCS).

The International Programme on Chemical Safety (IPCS) is a joint venture of the United Nations Environment Programme, the International Labour Organisation, and the World Health Organization. One of the main objectives of the IPCS is to carry out and disseminate evaluations of the effects of chemicals on human health and the quality of the environment.

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EVALUATION OF CERTAIN FOOD ADDITIVES AND CONTAMINANTS

Thirty-first Report of the Joint FAO/WHO Expert Committee on Food Additives

CORRIGENDUM

Page 4:

Mr A. M. Humphrey, Bush Boake Allen, London, England (*FAO Consultant*), should be listed under *Secretariat* and not under *Members invited by FAO*.

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JOINT FAO/WHO EXPERT COMMITTEE ON FOOD ADDITIVES

Geneva, 16–25 February 1987

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EVALUATION OF CERTAIN FOOD ADDITIVES AND CONTAMINANTS

Thirty-first Report of the Joint FAO/WHO Expert Committee on Food Additives

The Joint FAO/WHO Expert Committee on Food Additives met in Geneva from 16 to 25 February 1987. The meeting was opened by Dr J.-P. Jardel, Assistant Director-General, WHO, on behalf of the Directors-General of the Food and Agriculture Organization of the United Nations and of the World Health Organization. Dr Jardel pointed out that this Committee provided a unique international mechanism for the toxicological evaluation and safety assessment of food chemicals, and that it had established a model of safety assessment that was widely accepted.

He announced that the document *Principles for the safety assessment of food additives and contaminants in food*, which was approved at the thirtieth meeting of the Committee, would soon be published (Annex 1, reference *76*). This document, which was the culmination of a project undertaken by the International Programme on Chemical Safety in response to recommendations from earlier committees, would then be available for use by the Committee, governments, and international agencies and organizations.

1. INTRODUCTION

As a result of the recommendations of the first Joint FAO/WHO Conference on Food Additives, held in September 1955[1], there have been 30 previous meetings of the Expert Committee (Annex 1). The present meeting was convened on the recommendation made at the thirtieth meeting (Annex 1, reference *73*).

The tasks before the Committee were: (*a*) to prepare specifications for the identity and purity of certain food additives and to carry out toxicological evaluations of them; (*b*) to review specifications for selected food additives; and (*c*) to undertake toxicological evaluations of certain food additives and contaminants.

[1] *Joint FAO/WHO Conference on Food Additives.* FAO Nutrition Meetings Report Series, No. 11, 1956; WHO Technical Report Series, No. 107, 1956.

2. GENERAL CONSIDERATIONS

2.1 Modification of the agenda

Glycerol esters of wood rosin were added to the agenda for consideration of specifications. Ferrous gluconate was added to the agenda for reconsideration of its inclusion in the group ADI for gluconic acid.

2.2 Principles governing the toxicological evaluation of compounds on the agenda

In making recommendations on the safety of food additives and contaminants, the Committee took into consideration the principles established and contained in *Principles for the safety assessment of food additives and contaminants in food* (Annex 1, reference *76*). This publication, developed in response to repeated recommendations by the Committee, embraces the major observations, comments, and recommendations on the safety assessment of food additives and contaminants contained in the previous reports of the Committee and other associated bodies. The Committee noted that the document reaffirms the validity of recommendations that are still appropriate, and points out the problems associated with those that are no longer valid in the light of modern technical advances.

2.2.1 *Coloration of food using animal feed additives*

The present Committee considered several substances that could enter into the human food supply as a result of their presence in animal feeds. The diets of animals feeding in the wild or in free-range conditions contain carotenoids of various types that impart the characteristic colour to food products obtained from these animals, such as the yolk of eggs and the flesh of salmonid species. When these foods are produced under intensive conditions using prepared animal feeds, carotenoids (see section 3.1.3) are deliberately added to impart colour to the food derived from these animals. These substances may be regarded as indirect food/colour additives that will be present in the human food.

A number of factors must be taken into account when evaluating the suitability of particular carotenoids or sources of carotenoids (e.g., plant extracts) as additives to animal feed. Some of the factors

are the same as those considered when evaluating carotenoids for direct use as food additives. These include information from toxicological studies as well as the levels occurring in the foods presented to the consumer and the implications for nutrition. However, there are other considerations to be taken into account when there is indirect colouring of food using animal feed additives, such as the presence of metabolites of the additive in the food and the toxicological and nutritional significance of any such metabolites. Another consideration arises in connection with the source of the carotenoids; are they natural products or extracts of natural products? When a natural product source is regarded as a normal food, the Committee has taken this into account in evaluating the material as a direct food additive (Annex 1, reference *76*, section 3.1.3). In the case of a colour additive to animal feed, the status of the natural product as a normal constituent of the animals' food supply in free-range conditions might be a more appropriate consideration.

2.2.2 *Mycotoxin-contaminated animal feed*

Animals may be fed mycotoxin-contaminated fodder as a result of mould growth on materials intended for use as feed. In addition, food materials originally intended for human use may be diverted for use as animal feed if they are affected by spoilage organisms. This practice can mitigate to some extent the losses to the food supply and the economic losses that would result from complete rejection of the contaminated materials. Whatever the source of the mycotoxin-contaminated animal feed, its use raises concern about the effects of mycotoxin residues and their metabolites in human food derived from the animals that have ingested the contaminated fodder. The presence of aflatoxin M_1 in milk from cows that have been fed on aflatoxin B_1-contaminated fodder is an example of this.

Because of the implications for human health (see section 3.2), the Committee agreed that every effort should be made to control the mycotoxin contamination of animal feed. To achieve this objective, the Committee therefore recommended the development of appropriate strategies, such as the education of farm workers and others involved in grain handling operations, the adoption of measures that could be taken to minimize the potential for toxin production, and the establishment of suitable surveillance programmes to monitor mycotoxin levels in animal feeds.

Information should also be collected on the mycotoxin levels in foodstuffs derived from animals that have ingested mycotoxin-contaminated fodder.

Methods to reduce the content of mycotoxin by the treatment of contaminated animal fodder should also be developed. Although ammoniation of animal feeds has been used commercially to eliminate aflatoxin contamination of such feeds, more information will be needed about this and other mycotoxin detoxification procedures for consideration by future committees. Some of the factors that would be helpful in evaluating the human health consequences of detoxifying animal feed material include specific information about the nature of the products formed as a result of the treatment, their toxicity, the possibility of metabolic reactivation, and the residues that appear in human food as a result of the treatment. In addition to potential adverse nutritional effects, the possibility should be considered that the treatment process itself may result in the *de novo* production of toxic substances.

The present Committee had been requested to consider specifically aflatoxins. However, the Committee was aware that other mycotoxins also pose potential threats to public health. When the mycotoxin-producing organisms themselves are present in human food there is obvious cause for concern. The Committee stressed that the less obvious potential risk of using mycotoxin-contaminated fodder for food-producing animals should not be overlooked. The Committee recommended, therefore, that information be collected about the use of mycotoxin-contaminated animal fodder on a broad basis, including not only aflatoxin contamination but also other mycotoxins, including the effects of these toxins on food for human consumption.

2.2.3 *Food additives in infant foods*

The issue of whether food additives should be used in infant foods arose at the present meeting with regard to monosodium glutamate (MSG) as a consequence of concern expressed at the seventeenth meeting of the Committee (Annex 1, reference *32*) and with regard to beet red, since this colouring agent may contain high levels of nitrate. The Committee referred to the report of an FAO/WHO meeting on "Additives in Baby Foods" (Annex 1, reference *26*) and reiterated the view that the use of additives in foods designed specifically for infants should be approached with caution where

specific data dealing with the intake and effect of additives on infants were not available. This Committee was reassured by information about the intake and effects of monosodium glutamate in infants since it shows that there is no cause for concern about health risks (see section 3.1). Nevertheless, the Committee concluded that additives should not be used in infant foods solely to accommodate the taste preferences of the adult as opposed to that of the infant. With regard to beet red, the Committee concluded that levels of nitrate arising from its use in infant foods could well be of concern.

2.2.4 *The need for adequate information on natural products*

A number of the substances evaluated by the Committee were natural products that are produced from normal edible materials or from materials not usually used as food. A full understanding of the source and chemical nature of such products was considered to be essential for an evaluation of their safety-in-use.

2.2.5 *Evaluation of food processing aids*

Some substances that have been considered at this and previous meetings of the Committee are used as food processing aids for specific technological purposes. Chemical and technological information on such substances, including effects on the food, fate of the substance during processing, and the nature and level of residues in the final product, were considered to be an essential part of the safety evaluation process.

2.2.6 *Evaluation of complex mixtures*

In evaluating complex mixtures, such as caramels, smoke flavours, and extracts of natural materials, the provision of sound analytical data, including variability of commercial products, is of major significance.

2.2.7 *Multiple sources of the same chemical substance*

Occasionally, the Committee is requested to evaluate different materials that are mixtures containing a common component for which an ADI has been allocated. Examples of such materials are β-carotene and α-tocopherol in natural extracts. When using such materials, the ADI for that component should not be exceeded.

2.3 Principles governing the establishment and revision of specifications

2.3.1 *Justification for changes in specifications*

The Committee considered several requests for the amendment of specifications to decrease the purity required. The Committee noted that there are specific instances where a decrease in the assay limits may result in a product containing lesser amounts of a hazardous impurity. In this regard, the Committee recalled its discussion at the twenty-eighth meeting relative to the food colour Brown HT, where a threefold reduction in the naphthionic acid content was accompanied by an increase in the combined salt and moisture content from 20% to 30% and a concomitant decrease in the assay of the main colouring component (Annex 1, reference *66*).

The Committee's specifications are intended to reflect and encourage good manufacturing practice (Annex 1, reference *76*, section 4.3). Therefore, the Committee cannot lower the degree of purity represented by the specifications without a technological justification explaining the effects on the assurance of purity for the food additive, keeping in mind that the safety implications of any change in specifications must be taken into account.

2.3.2 *Review of specifications for enzyme preparations*

The Committee had on its agenda for this meeting several enzyme preparations derived from fungal sources. The Committee observed that enzyme preparations from different strains of the same species may have different characteristics, and this difference should be taken into consideration when formulating specifications for these products. The Committee noted that microbial sources may be changed and new strains selected; such a selection of new strains has been an accepted practice of enzyme manufacturers. For the evaluation of enzyme preparations derived from microorganisms, the Committee had previously laid down principles that include a consideration of the natural occurrence and ingestion of those microorganisms (Annex 1, reference *76*, Annex 3).

The Committee reiterated the conclusion, reached at the twenty-ninth meeting, that an acceptable daily intake should be established for enzyme preparations derived from microorganisms not normally used as food or for enzyme preparations not removed from the food products to which they are added. In accordance with the

Committee's general principles (Annex 1, reference *76*, section 4.3), specifications for such materials are required to identify the substance that has been biologically tested. However, for the fungal enzymes reviewed by the present Committee, it was found that insufficient information was available to define or characterize adequately some preparations.

The present consideration of enzyme preparations included a review of the specifications with respect to the identification of the microbial source of enzyme preparations. The existing specifications for enzyme preparations place the responsibility for assuring the maintenance of pure cultures of microbial species on the manufacturer of those preparations. While the Committee recognizes that manufacturers are motivated to control precisely the purity of microbial species and strains, specifications are meant to define the materials subjected to toxicological testing and to reflect and encourage good manufacturing practice. In general, the Committee requests data on any chemical, physical or microbiological criterion that can be used to test enzyme preparations and identify the source material.

The Committee noted that source organisms may produce toxins under certain conditions of growth. The current specifications for enzyme preparations require manufacturers to test for chemical contaminants that are known to occur in a particular microbial species or that may occur during culture as a result of inadvertent microbial contamination with another organism or as impurities contained in the culture medium. The Committee's specifications should be updated regularly as new microbial sources are reviewed by the Committee and as new toxins are discovered.

The Committee discussed the need to define the non-enzymic components of enzyme preparations and how information on such components might relate to the definition and safety of the product, because in many cases the enzymic portion of these products is a minor component (by weight). Different fermentation conditions or the use of different strains of microorganism might change the non-enzymic components.

In view of such considerations and the important role of the *Specifications for enzyme preparations used in food processing* (Annex 1, reference *69*), the Committee concluded that the general specifications should be reviewed. The Committee agreed that the following information should be provided in order to define more clearly individual preparations:

—non-enzymic components, including hazardous contaminants;
—major and minor enzymic activities;
—international units of activity, where they have been defined;
—specific stabilizers and preservatives used in enzyme preparations;
—how fermentation processes are monitored to ensure a reproducible product;
—how the purity of microbial strains is controlled and how individual commercial strains might differ from naturally-occurring strains; and
—the utility of linking specific activity with some non-enzymic components (such as total organic solids, see section 3.1.1) to provide an index of purity.

2.3.3 *Review of specifications for substances derived from natural products*

The Committee had on the agenda of its present meeting several substances that are derived from natural products and are used to colour or flavour food.

The Committee recognized difficulties in establishing specifications for these substances that are as precise as those for synthetically manufactured chemicals because of the variability in the natural substance. For example, there will be substances that contain only a very small proportion of colouring or flavouring principles. Specifications prepared by the Joint FAO/WHO Expert Committee on Food Additives are minimum requirements for the composition and quality of food-grade additives, allowing for acceptable variation in their production (Annex 1, reference *38*). Specifications of some additives derived from natural sources, such as natural colours, specify the content of main active components, such as colouring principles, as "not less than declared" which takes into account the quality of these substances actually traded.

Some natural active principles are unstable, and the vendor adjusts the content or assay value at the time of trade. The Committee noted that some of these substances may be degraded during subsequent storage and then they do not meet the specifications. In such cases, it is necessary to give appropriate advice if the degradation can result in the production of potentially hazardous substances.

The Committee considered whether limits for certain impurities in substances derived from natural products should be established on

the basis of colour or flavour intensity. The Committee agreed that it would be appropriate to specify certain impurity limits based on colour or flavour intensity when as a result the amounts of such impurities in the finished food products would be more tightly controlled. For those impurities that are not directly proportional to colour or flavour intensity, or in those instances where data were unavailable to correlate colour or flavour intensity with impurity levels, the Committee agreed to specify limits based on the weight of material.

Several of the substances derived from natural products may contain other naturally-occurring, potentially hazardous components as well as environmental contaminants such as pesticide residues. The Committee strongly re-emphasized the importance of technical data related to manufacture and contaminant levels for substances brought before it for review of the specifications.

3. COMMENTS ON SPECIFIC FOOD ADDITIVES AND CONTAMINANTS

The Committee evaluated a number of food additives and contaminants for the first time and re-evaluated some substances considered at previous meetings. Information on the evaluations and on specifications is summarized in Annex 2. Details of further toxicological studies and information required or desired for certain substances are given in Annex 3.

3.1 Specific food additives

3.1.1 *Enzyme preparations*

Problems in evaluating the safety of enzymes in food processing were discussed at the fifteenth, eighteenth, and twenty-ninth meetings of the Expert Committee, when principles relating to their evaluation were elaborated (Annex 1, references *26, 35,* and *70*). At the present meeting, the Committee reaffirmed those principles, which have been consolidated in Annex III of *Principles for the safety assessment of food additives and contaminants in food* (Annex 1, reference *76*).

For the purpose of toxicological evaluation, the enzyme preparations considered by this Expert Committee can be grouped into the following classes:

Class III – Enzymes derived from *Aspergillus oryzae*;
Class IV – Enzymes derived from *Aspergillus niger*;
Class V – Enzymes derived from *Trichoderma reesei* and *Trichoderma harzianum*, and *Penicillium funiculosum* and *Aspergillus alliaceus*

The guidelines established by the Joint FAO/WHO Expert Committee on Food Additives for these classes of enzyme provide a basis for the toxicological studies required for their evaluation.

At the twenty-ninth meeting, the Committee concluded that when enzyme preparations from classes IV and V were added directly to food but not subsequently removed, an acceptable daily intake should be established to ensure that levels of enzyme preparation in the food are safe. In order to evaluate the information received on the estimate of the amount of enzyme preparation used in the toxicological studies and levels of consumption resulting from its use in food, the Committee adopted the concept of enzyme total organic solids (T.O.S.)[1, 2], defined as follows:

$$\%\text{T.O.S.} = 100-(A+W+D)$$

where A = % ash, W = % water, and D = % diluent and carrier.

This concept overcomes the problem that enzyme preparations of different activities and forms were used in the toxicological studies. It also takes into account the fact that most of the organic solids in this fraction are not the enzyme *per se*.

In establishing acceptable daily intakes for the enzymes in classes IV and V, the present Committee noting that the animal feeding studies were primarily short-term, concluded that it would be appropriate to use a safety factor greater than the usual 100.

Enzymes derived from Aspergillus oryzae

Enzymes from this source were considered at the fifteenth meeting of the Committee (Annex 1, reference *26*). A decision on the acceptable daily intake was postponed because of the concern that one of the known metabolites of *A. oryzae* is β-nitropropionic acid, which was suspected to be a potential carcinogen. Later, at the

[1] *Ad hoc* Enzyme Technical Committee. *The 1978 enzyme survey. Summarized data*, National Academy of Sciences/National Research Council/Food and Nutrition Board, Committee on GRAS List Survey, Phase III, National Academy Press, Washington, DC, 1981.

[2] Pariza, M.W. & Foster, E.M. Determining the safety of enzymes used in food processing. *Journal of food protection*, **46:** 453–468 (1983).

eighteenth meeting of the Committee, a lipase derived from *A. oryzae* was considered (Annex 1, reference *35*). It was determined at that time that there was no information to substantiate the suspicion of potential carcinogenicity of β-nitropropionic acid, and that analyses of foods have shown that the metabolite is present in very few foods and then only in minute amounts. The present Committee was also informed that different varieties of *A. oryzae* are used in certain parts of the world in the preparation of foods. The Committee restated its opinion that such enzymes should be considered as normal constituents of food (Annex 1, reference *26*).

α-*Amylase* (E.C. 3.2.1.1). The Committee examined the short-term studies in rats showing that there was no adverse effect from a dietary level equivalent to 7 g of the enzyme preparation per kg of body weight per day. Based on the lack of evidence of toxicity in this study and the general considerations, this enzyme was considered acceptable for use in food. The existing specifications for α-amylase and glucoamylase mixtures were revised and designated as tentative. New, tentative specifications were drawn up for α-amylase preparations.

Proteases (E.C. 3.4.21.14; 3.4.23.6). A short-term study in rats showed that a dietary level equivalent to 7 g of the enzyme preparation per kg of body weight per day was without effect. Based on this lack of toxicity and on the consideration in the general remarks, this enzyme was considered acceptable for use in food. The existing specifications were revised and designated as tentative.

A combined toxicological monograph was prepared.

Enzymes derived from Aspergillus niger

Aspergillus niger is a contaminant of food and was not considered in the same way as those organisms that are regarded as normal constituents of food. Data are required to ensure that the strains used in the preparation of enzymes do not produce mycotoxins (Annex 1, reference *26*).

Carbohydrases. Microbial carbohydrases prepared from some varieties of *A. niger* were evaluated at the fifteenth meeting and a temporary ADI ("not limited") was established (Annex 1, reference *26*). An adequate 90-day study in rats was requested. The present

Committee reviewed carbohydrases derived from *A. niger*. This group of enzymes was considered to include those carbohydrases evaluated at the fifteenth meeting, and studies on this group of enzymes would meet those requirements.

Amyloglucosidases (E.C. 3.2.1.3). The Committee examined the results available from short-term feeding studies in rats. One study in which the preparation comprised up to 10% of the diet (7 g of the enzyme per kg of body weight per day) was considered acceptable by current standards. No compound-related effects were observed. Duckling tests had been carried out on two preparations that showed an absence of aflatoxin-related effects.

β-*Glucanase* (E.C. 3.2.1.6). The Committee noted that the preparation was not genotoxic in microbial or mammalian test systems. Short-term studies in rats and dogs have been carried out. In both species, no compound-related effects resulted from treatment with dose levels of 5 ml of the enzyme preparation per kg of body weight (2.5 g per kg of body weight per day).

Hemi-cellulase. This enzyme was not genotoxic in microbial or mammalian test systems. In one limited 90-day study in rats, no effects were observed at the highest dose fed (1 g per kg of body weight per day). The enzyme preparation contained high levels of pectinase, and the safety data derived from this preparation provided additional information on the safety of that enzyme.

Pectinases (E.C. 3.1.1.11; 4.2.2.10; 3.2.1.15). In a short-term study in rats, no adverse effects were observed at dietary levels of the enzyme preparation equivalent to 7 g per kg of body weight per day. This enzyme preparation may be identical to the hemi-cellulase preparation discussed above, and data from that preparation provided additional information on the safety of this enzyme preparation.

Protease. No toxicity data were available.

Evaluation. Although the Committee was aware of possible strain differences in *A. niger* and the possibility that different culture conditions might be used to prepare the various enzymes, the available toxicity data indicated that all the enzyme preparations

considered had very low levels of toxicity. Based on this information, the Committee established a single ADI for each of the separate enzyme preparations of 0–1 mg T.O.S. per kg of body weight. This ADI should apply to each of the carbohydrases as well as to the proteases. A combined toxicological monograph was prepared. New tentative specifications were prepared for amyloglucosidase, β-glucanase, hemi-cellulase, and pectinase preparations. No specifications were prepared for the protease preparation.

Beta-glucanase derived from Trichoderma harzianum

Beta-glucanase (E.C. 3.2.1.6) from *Trichoderma harzianum* has not been previously evaluated by the Committee. The preparation was not mutagenic in bacterial or mammalian systems. The preparation caused no adverse effects in a reproduction study in rats at levels up to 5% of the diet, and was not teratogenic in a rat study at doses up to 1 g per kg of body weight per day. Short-term studies in rats and dogs showed no adverse effects at 3 g per kg of body weight per day in dogs, and 2 g per kg of body weight per day in rats. Based on the available information, the Committee established a temporary ADI of 0–0.5 mg T.O.S. per kg of body weight.

Because this enzyme is derived from a microorganism that is neither a normal constituent of food nor a common contaminant in food, in accordance with Annex III of *Principles for the safety assessment of food additives and contaminants in food* (Annex 1, reference *76*), it is required that by 1992 this preparation will undergo a long-term study in a rodent species and that specifications will be established to show that the organism does not produce antibiotics and is non-pathogenic to man.

A toxicological monograph and new tentative specifications were prepared.

Cellulase derived from Trichoderma reesei

Cellulase from *Trichoderma reesei* has not been previously evaluated by the Committee. The enzyme preparation is characterized by two activities, exo-cellobiohydrolase (E.C. 3.2.1.1) and 1,4-endo-glucanase (E.C. 3.2.1.4).

The preparation was not mutagenic in bacterial or mammalian systems. It caused no adverse effects in a reproduction study in rats at levels up to 5% of the diet, and it was not teratogenic in a rat study

at doses up to 7 g of preparation per kg of body weight. Short-term studies are available in dogs and rats, the no-adverse-effect levels being 3 g per kg of body weight per day in dogs, and 2 g per kg of body weight per day in rats. The Committee was also informed that tests have been performed to show that the strain of *T. reesei* used for the production of this enzyme does not produce any antibiotics and is not known to be a human pathogen. Based on the available information, the Committee established a temporary ADI of 0–0.3 mg T.O.S. per kg body weight.

Because this enzyme was derived from a microorganism that is neither a normal constituent of food nor a common contaminant in food, in accordance with Annex III of *Principles for the safety assessment of food additives and contaminants in food* (Annex 1, reference *76*), it is required that by 1992 this preparation will undergo a long-term study in a rodent species.

A toxicological monograph and new tentative specifications were prepared.

Cellulase derived from Penicillium funiculosum (E.C. 3.2.1.4; 3.2.1.21; 3.2.1.91)

No safety data were available to the Committee, so no ADI could be established for cellulase from *Penicillium funiculosum*. New tentative specifications were prepared.

Pectinase derived from Aspergillus alliaceus

No safety data were available to the Committee, so no ADI could be established for pectinase from *Aspergillus alliaceus*. No specifications were prepared.

3.1.2 *Flavouring agents.*

Trans-anethole. *Trans*-anethole was evaluated for acceptable daily intake at the eleventh and twenty-third meetings of the Committee (Annex 1, references *14* and *50*). At the twenty-third meeting, a temporary ADI of 2.5 mg per kg of body weight was established, with the requirement that an adequate long-term feeding study be performed. In 1983 the Committee extended the temporary ADI to 1987 pending completion of the long-term feeding study in rats that was then in progress.

The present Committee was aware of additional metabolic studies in rodents and man, and that the required long-term feeding study had been completed. However, there was not sufficient opportunity to evaluate fully the toxicological implications of a significant incidence of hepatoma observed in treated female rats. The Committee was of the opinion that the temporary ADI could be extended for an additional year to provide an opportunity for a full, in-depth review of this study. The existing temporary ADI for *trans*-anethole of 0–2.5 mg per kg of body weight was therefore retained until 1988 pending review of the new data.

A toxicological monograph was not prepared. The existing specifications were maintained.

Benzyl acetate

This compound was previously reviewed at the eleventh, twenty-seventh, and twenty-ninth meetings of the Expert Committee (Annex 1, references *14*, *62*, and *70*).

At the twenty-ninth meeting, the Committee extended the temporary ADI of 0–5 mg per kg of body weight until 1987 when lifetime gavage studies with benzyl alcohol, a normal metabolite of benzyl acetate, were expected to be available. In addition, a new study was planned that incorporated benzyl acetate into the diet of rats and mice. The present Committee decided to extend the temporary ADI because it was informed that the in-life phases of the benzyl alcohol studies have been completed, but that the histology studies are still in progress. The Committee requested that these data be submitted for review by the Committee in 1989.

A toxicological monograph was not prepared. The existing specifications were maintained.

Smoke flavourings

The Committee considered smoke condensates and liquid smoke at the nineteenth meeting (Annex 1, reference *38*). Inadequate information was available at that time for an evaluation to be made.

The present Committee reviewed both the specifications and safety data for this group of products. It noted that smoke flavourings are complex mixtures of varying composition, primarily prepared by the condensation of smoke generated by the pyrolysis of

certain hardwoods in the absence or presence of a limited amount of air. The initial smoke condensate separates into an aqueous phase and a tarry phase. The smoke condensate may be separated into fractions by physical separation techniques or solvent extraction. These fractions may be further purified, if necessary, to remove hazardous constituents known to be present in smoke. Smoke flavourings include smoke condensates, fractions thereof, and mixtures of such fractions.

Products contain different amounts of a whole spectrum of compounds such as alkyl carboxylic acids with carbon numbers 2 to 5, ketones with carbon numbers 2 to 5, furfural derivatives, lactones, and phenol derivatives. Smoke flavourings were studied for the presence of two groups of hazardous constituents: nitrosamines and polycyclic aromatic hydrocarbons. Nitrosamines were not detected in those smoke flavourings tested, while certain non-carcinogenic polycyclic aromatic hydrocarbons were detected in smoke flavourings. To ensure the absence of hazardous polycyclic aromatic hydrocarbons the Committee adopted a specification which required that the concentration of benzo(*a*)pyrene should not exceed 10 µg per kg, which is the lowest practicable level for measurement.

Short-term studies were available for several types of liquid smoke flavouring (aqueous extract), but extensive studies were available only for a single product derived from the tarry extract. The Committee viewed the use of smoke flavourings generically, keeping in mind that the use of smoke flavourings replaces traditional smoking practices, and this represents a definite improvement since a large number of potentially toxic compounds are eliminated during the production of the flavourings. A similar view has been expressed by the Council of Europe (Resolution AP185/2).

The Committee considered that it may not be possible to allocate an ADI to such a complex group of products, and concluded that smoke flavourings of suitable specifications could be used provisionally to flavour foods traditionally treated by smoking. However, since the available safety data for these products were limited, new or novel uses of smoke flavourings should be approached with caution. The Committee concluded that detailed information on the production and composition of smoke flavourings is required, as described in section 2.2.6, and that it would be desirable to have further safety studies carried out on a well-defined spectrum of smoke flavourings.

A toxicological monograph and new tentative specifications were prepared.

3.1.3 *Food colours*

Beet red and betanine. The Committee noted that previous committees had considered together beet red and betanine, its major colour component. This Committee decided that it would be appropriate to evaluate these food colours separately and pointed out that, for the compound betanine, there were insufficient data available to establish an ADI, since that information available to the Committee did not meet currently accepted standards.

In evaluating beet red, the Committee took into account the principles laid down at the twenty-first meeting (Annex 1, reference *44*) and endorsed in Annex III of *Principles for the safety assessment of food additives and contaminants in food* (Annex 1, reference *76*). Thus, when the concentrate is used to enhance the colour of beet products it could be considered as food. If, on the other hand, the concentrate is used more generally as a colourant, careful specifications need to be established. Since nitrate is a component of beet red, it is necessary to ensure that levels of nitrate do not exceed the specifications. Under these conditions beet red could be used according to good manufacturing practice with an ADI "not specified", keeping in mind the need to limit the nitrate content of foods produced for infants and young children (see section 2.2.3).

A toxicological monograph was prepared. The existing specifications for beet red were revised, and the Committee agreed to delete the "tentative" qualification. No specifications for betanine were prepared.

Canthaxanthin

The Committee was aware that canthaxanthin has been used as a direct food additive, as a feed additive, and as an orally-administered pigmenting agent for human skin in both pharmaceutical and cosmetic applications. It was evaluated for acceptable daily intake at the tenth and eighteenth meetings of the Committee (Annex 1, references *13* and *35*).

The present Committee was asked to review the safety of canthaxanthin as a food additive because of reports of crystalline deposition in the retina during its use as an orally-administered skin-

pigmenting agent. The dose that resulted in this deposition was within the ADI established by the Committee at the eighteenth meeting (Annex 1, reference *35*).

The Committee viewed the observation of crystal deposition in the retina as new data that warranted a complete review of this compound. Most of the new data from animal studies were available only as summaries, and therefore could not be used as a basis for evaluation. The Committee noted that, although pigment accumulation in the eye had been demonstrated analytically following oral administration of canthaxanthin to rats and dogs, no ophthalmoscopy had been carried out and no animal model for the human condition had been developed. In man, however, an estimate was made of the minimal level of exposure resulting in fundal pigment deposition in the retina.

In the light of all these considerations, the previous ADI was made temporary and reduced to 0–0.05 mg per kg of body weight on the basis of the minimal effect level for pigment deposition in the retina of human subjects, adjusted using a ten-fold safety factor.

When setting an ADI, the Committee does not consider therapeutic use, which is a matter for clinical judgement. The cosmetic use of canthaxanthin as an orally-administered skin-pigmenting agent was not anticipated when the ADI was established at the eighteenth meeting. Therefore, it is not included in the temporary ADI established at the present meeting; the temporary ADI applies only to the food and feed additive uses of canthaxanthin.

In allocating a temporary ADI to canthaxanthin, the Committee required that the following additional work be undertaken and the data submitted by 1989:

(*a*) Details of the long-term studies in mice and rats for which summary data had been submitted, including ophthalmological data where available;

(*b*) Clarification of the factors that influence deposition in the eye, including the establishment of the threshold dose, the influence of dose and duration of exposure, the reversibility of pigment accumulation, and the investigation of potential animal models; and

(*c*) Clarification of whether pigment deposition is causally related to impaired ocular function.

A toxicological monograph was prepared. The existing specifications were revised.

Carbon black

Activated vegetable carbon (food grade)[1], that is carbon black derived from vegetable material or lignites, was evaluated for an ADI for man at the fourteenth meeting of the Committee (Annex 1, reference *22*). An ADI "not limited", except that good manufacturing practice be followed, was established. This refers to its use as a clarifying agent, not as a food colour.

Carbon black colours

There are two main groups of carbon blacks used for colouring purposes, the first group are derived from hydrocarbons and the second group are derived primarily from peat and plant materials and are commercially described as vegetable black.

The food colouring uses of carbon blacks derived from both sources were evaluated by the Committee at the twenty-first meeting (Annex 1, reference *44*). No ADI was established for food colouring uses from either source. A major concern of that Committee related to the question of how strongly and irreversibly polynuclear aromatic hydrocarbons are adsorbed onto carbon black.

(*a*) *Carbon black (hydrocarbon sources)*. The present Committee considered data from studies involving carbon blacks derived from hydrocarbon sources. Benzene extracts of certain carbon blacks were found to be carcinogenic to mice. These carcinogenic extracts contain polynuclear aromatic hydrocarbons (PAHs) that were adsorbed onto the carbon black. Data were available to show that only small amounts of polynuclear aromatic hydrocarbons (less than 0.005% of the benzene-extractable PAHs) were eluted from carbon black by biological fluids. Carbon black was not mutagenic in bacterial or mammalian systems. Dietary carbon black was not carcinogenic in limited lifetime studies in rats and mice at levels up to 10% of the diet. Information was also presented to show that carbon black was able to adsorb some chemical carcinogens and, under certain experimental conditions, was shown to reduce their carcinogenic potential.

Based on the available information, the Committee provisionally accepted the use of carbon blacks from hydrocarbon sources in food

[1] This substance is now known as activated carbon (synonyms activated charcoal, decolorizing carbon).

contact materials, including wax coating for cheese. However, it emphasized that future specifications of these carbon blacks should include figures relating to residual polynuclear aromatic hydrocarbons. However, given the fact that carbon blacks from hydrocarbon sources are shown to contain different amounts of known carcinogens and the lack of knowledge on the ability of man to extract such carcinogens from carbon blacks upon ingestion, and considering the limited lifetime feeding studies in experimental animals with defined carbon blacks, the Committee concluded that it was unable to determine the suitability of carbon blacks from hydrocarbon sources as food additives at this time. Therefore, an ADI was not established for direct use as a food colourant. The Committee did not receive information on identity and purity of carbon blacks from hydrocarbon sources and therefore no specifications were prepared.

A toxicological monograph was prepared.

(*b*) *Carbon black (vegetable black)*. No toxicological data were available on carbon blacks derived from vegetable sources and therefore an ADI could not be established.

No toxicological monograph was prepared.

The existing specifications for carbon black (vegetable black) were revised but maintained as "tentative".

Carotenes (natural)

These substances were reviewed at the eighteenth meeting of the Committee (Annex 1, reference *35*) when it was concluded that further information was required before a specification could be developed. Therefore, no toxicological evaluation was possible for these materials at that time.

While there is a substantial toxicological data base relating to carotenes and an acceptable daily intake has been established for synthetic β-carotene (Annex 1, reference *35*), this could not be applied to carotenes (natural) since these substances did not comply with the specifications for β-carotene and differed significantly in composition with regard to materials other than carotenes.

The Committee considered three sources of carotenes, namely a hexane extract of carrots, a byproduct of the manufacture of chlorophyll from alfalfa/grass meal by a process of solvent extraction and fractionation, and algal extracts obtained by

supercritical carbon dioxide or vegetable oil extraction. These materials differed significantly from each other and from synthetic β-carotene such that separate evaluations were required. For the natural materials, carotenes comprised at maximum about 5% of the extract, further diluted with vegetable oil for standardization in some cases.

No toxicological data were available on these substances. Because of the origin and method of extraction, the Committee concluded that such data were necessary under the guidelines laid down in the twenty-first report of the Committee (Annex 1, reference *44*) and endorsed in Annex III of *Principles for the safety assessment of food additives and contaminants in food* (Annex 1, reference *76*). Accordingly, the Committee was unable to evaluate these materials for an ADI. However, with regard to extracts of carrots or alfalfa, the Committee felt that the need for toxicity tests may be obviated if detailed analytical data were supplied to confirm that natural toxicants occurring at low levels in food/feedstuffs are not concentrated in the extract and that levels of use would not materially exceed the levels of exposure that would result from their normal use.

A toxicological monograph was not prepared. New tentative specifications were prepared, one covering the two substances derived from vegetable sources, and the other covering products extracted from the alga *Dunaliella salina*. The Committee requested further information on these products, especially on possible levels of urethane in products obtained by extraction with supercritical carbon dioxide.

The existing tentative specifications for carotenes (natural) were withdrawn.

Citranaxanthin

The Committee was informed that the major present day use of this synthetic carotenoid is as an animal feed additive to impart a yellow colour to chicken fat and egg yolks. It may also be used as a colouring agent by adding it directly to foods.

If the substance were to be used as a direct food colouring agent, the data were not sufficiently comprehensive for evaluation (e.g., only one lifetime feeding study was available). The Committee concluded that further data of the type outlined in Annex III of *Principles for the safety assessment of food additives and contaminants*

in food for synthetic food colours are required before the substance can be fully evaluated for direct food use (Annex 1, reference *76*).

In the case of use as an animal feed additive, an evaluation could not be performed because the data base did not include sufficient information on the nature of residues to be found in animal-derived foodstuffs and because there was no information concerning the use levels that would constitute good animal husbandry practice.

A toxicological monograph was prepared. The existing tentative specifications were revised, and the Committee agreed to delete the "tentative" qualification.

Xanthophylls

Xanthophylls were considered at the twenty-first meeting of the Committee, when it was noted that two dry types were available, citranaxanthin produced synthetically or from dried *Tagetes* petals (*Tagetes erecta* L.) or algae (genus *Spongiococcum*) (Annex 1, reference *44*, page 23). At that time no toxicity data were available and no evaluation could be made.

The present Committee considered the uses of xanthophylls both as food additives and in poultry feed. The Committee was informed that commercial xanthophyll preparations were obtained by hexane extraction of *Tagetes* petals and contained primarily lutein, with variable amounts of antheraxanthin and other xanthophylls. In addition another product, designated mixed carotenoids, derived by solvent extraction of nettles, alfalfa, or grass meal consists of carotenoids with xanthophyll lutein accounting for the major part.

No toxicological data were available on the *Tagetes* extract or on lutein. The Committee was unable, on the basis of the information before it, to determine whether *Tagetes* petals were used as food. Such products would not require toxicological evaluation according to the guidelines contained in the twenty-first report of the Committee (Annex 1, reference *44*) and endorsed in Annex III of *Principles for the safety assessment of food additives and contaminants in food* (Annex 1, reference *76*). Therefore the Committee was unable to evaluate the safety of xanthophylls.

In noting that xanthophyll preparations were used as feed additives, the Committee concluded that it would be necessary to have qualitative and quantitative information on xanthophylls and metabolites in animal-derived foods before an evaluation could be made.

No toxicological monograph was prepared. New tentative specifications were prepared for *Tagetes* extract and for mixed carotenoids. The existing specifications for xanthophylls were withdrawn.

3.1.4 *Miscellaneous food additives*

Ferrous gluconate. At the nineteenth meeting, the Committee evaluated ferrous gluconate as a colouring adjunct (Annex 1, reference *38*). An ADI "not specified" was established, with the proviso that the contribution of ferrous gluconate to the total dietary gluconic acid intake from all sources should be included in the ADI for gluconic acid.

Because this is a soluble bioavailable ferrous salt, the iron moiety poses a greater potential threat of toxicity than does the gluconate moiety. Therefore, the present Committee concluded that it would be more appropriate to link the ADI for ferrous gluconate to the provisional maximum tolerable daily intake (PMTDI) for iron established at the twenty-seventh meeting (Annex 1, reference *62*) than to the ADI for gluconate. On this basis, the contribution of iron from the use of ferrous gluconate should be included with all other sources of iron, the total of which should not exceed the PMTDI for iron of 0.8 mg per kg of body weight.

A toxicological monograph was not prepared. Revision of the existing specifications was not considered.

L-Glutamic acid and its ammonium, calcium, magnesium, monosodium, and potassium salts

The above glutamates were evaluated at the fourteenth and seventeenth meetings of the Committee (Annex 1, references *22* and *32*). A toxicological monograph was prepared after the seventeenth meeting, when an ADI of 0–120 mg per kg of body weight (calculated as glutamic acid) was allocated.

The Committee was informed of dietary studies carried out in some Asian countries from which there is evidence that the consumption of monosodium glutamate has increased in recent years, and the effort of the Codex Committee on Food Additives to determine whether the intake of this compound exceeded the previously established ADI.

Monosodium glutamate is used in small quantities as a flavour enhancer in manufactured foods. A more significant dietary source of glutamate may be from the direct use of monosodium glutamate by the consumer and by restaurants as part of preparations used to season food. It would be desirable to obtain data on this use of monosodium glutamate and the probable intake of free glutamate from food preparations, such as soups and sauces, including appropriate intake studies, bearing in mind possible individual intolerance to single high intakes of this compound and other free glutamates. The intake studies should include data on the temporal distribution of intakes as well as on daily intakes.

The Committee considered information obtained since the seventeenth meeting including extensive metabolic studies relating dose regime to plasma levels of glutamic acid, endocrinological and neurotoxic effects, and studies of intolerance to monosodium glutamate.

The Committee concluded, based on the analysis of blood levels of glutamic acid in human subjects associated with various dietary regimens, that peak plasma levels are dependent on the food vehicle in which the compound is incorporated and that infants metabolize monosodium glutamate in a similar way to adults. In the light of all the data, the Committee allocated an ADI "not specified" to monosodium glutamate when incorporated into food or used as a condiment; this ADI applies to all glutamates, alone and in combination.

Caution should be used when ingesting monosodium glutamate as a large single dose rather than divided between several meals because high plasma levels may be reached under the former conditions.

In its previous evaluation, the Committee concluded that it would be prudent not to apply the ADI for glutamate to infants under 12 weeks of age (Annex 1, reference *32*). In view of the finding that infants metabolize monosodium glutamate in a similar way to adults, no additional hazard to infants was indicated. However, the present Committee expressed the general opinion in section 2.2.2 that the use of any food additives in infant foods should be approached with caution.

Substances given an ADI "not specified", such as glutamate salts in this instance, are of low toxicity. On the basis of the available data (chemical, biochemical, toxicological, and other), the total dietary intake of glutamates arising from their use at the levels necessary to

achieve the desired technological effect and from their acceptable background in food do not, in the opinion of the Committee, represent a hazard to health. For that reason, the establishment of an acceptable daily intake expressed in numerical form is not deemed necessary. The Committee reiterated the general principle expressed in its first report (Annex 1, reference *1*) that the amount of an authorized additive used in food should be the minimum necessary to produce the desired effect.

A toxicological monograph was prepared. The existing specifications for L-(+)-glutamic acid, monosodium L-glutamate, monopotassium L-glutamate, monoammonium L-glutamate, calcium di-L-glutamate, and magnesium di-L-glutamate were revised.

4-Hydroxymethyl-2,6-ditert-butylphenol

The Committee had before it for evaluation 4-hydroxymethyl-2,6-di*tert*-butylphenol. The compound was considered by the twenty-third meeting of the Committee (Annex 1, reference *50*), at which time additional data were requested. Since the requested data were not forthcoming, this Committee was unable to evaluate the compound. The Committee was unaware of commercial production of this antioxidant or of its use in food and the existing tentative specifications were therefore withdrawn (Annex 1, reference *56*).

Polydextroses

Polydextrose A and polydextrose N were evaluated by the twenty-fourth meeting of the Expert Committee, at which time an ADI of 0–70 mg per kg of body weight was allocated (Annex 1, reference *53*). The twenty-fifth Committee revised the specifications to include a limit of 0.05% for 5-hydroxymethyl-furfural in polydextroses (Annex 1, reference *56*).

Polydextroses showed no toxic effects in acute, subacute, or chronic studies in three species of animal at levels equivalent to 10% of the diet. Studies have shown that metabolism of these compounds is comparable in animals and man. Polydextroses are poorly absorbed and are metabolized by the gut flora to their normal metabolites, primarily carbon dioxide and volatile fatty acids.

Studies in man have demonstrated that polydextroses, when administered at very high doses, exert a laxative effect, with a mean

laxative threshold of 90 g per day or 50 g as a single dose. This factor should be taken into account when considering appropriate levels for the use of polydextroses alone or in combination with other substances causing laxative effects by osmotic action.

The Committee re-examined polydextroses on the basis of the above considerations and those expressed in *Principles for the safety assessment of food additives and contaminants in food*, sections 5.5.1 and 6.2 (Annex 1, reference *76*), and allocated an ADI "not specified".

A toxicological monograph was not prepared. The existing specifications were maintained.

Tannic acid

The substances previously evaluated at the tenth and fourteenth meetings of the Committee (Annex 1, references *13* and *22*) were hydrolysable gallotannins. The Committee changed the name used on the agenda "tannins (food-grade)" to "tannic acid" to separate the commercial products used as food additives and processing aids from chemically unrelated substances also called tannins.

Temporary ADIs for tannins of 0.6 mg per kg of body weight from Peruvian tara and of 0.3 mg per kg of body weight from Turkish aleppo, Chinese tara, and Sicilian sumac were allocated at the fourteenth meeting on the basis of the results of a multigeneration reproduction study and a long-term feeding study in rats performed with Peruvian tara. Studies in a second species and further information on the specifications for these tannins were requested at the fourteenth meeting (Annex 1, reference *23*).

New toxicological information available to the Committee demonstrated that a tannic acid product was not mutagenic in bacterial and yeast systems, even with metabolic activation. In addition, it was not teratogenic in rats and mice.

On the basis of the existing toxicological data on tannic acid (hydrolysable gallotannins) and considering that the use of tannic acid in food processing as a flocculant, under conditions of good manufacturing practice, results in very low levels in food and beverages, the Committee changed the previous temporary ADI to a temporary ADI "not specified" for tannic acid used as a filtering aid.

The data were not comprehensive enough to be used to evaluate the use of tannic acid as a flavouring agent added directly to food.

The Committee concluded that additional data on the composition of tannic acid from different sources and evidence that its use does not result in a significant increase in total intake of tannic acid (as hydrolysable gallotannins) are required to decide whether the substance should be subjected to further toxicity tests before it can be evaluated for direct food use.

The Committee revised the previous specifications for "tannins (food-grade)" and changed the title to "tannic acid" as described above. The Committee maintained the tentative designation.

3.2 Contaminants

3.2.1 *Aflatoxins*

The Committee noted that FAO and WHO had requested the evaluation of aflatoxins from the viewpoint of their impact on health when present as food contaminants. A specific request by the FAO Intergovernmental Group on Oilseeds, Oils and Fats[1] for the possible establishment of acceptable international maximum levels of aflatoxins had led to the need for the evaluation of aflatoxins from a toxicological point of view. The Committee was informed of the activities of the Joint UNEP/FAO/WHO Food Contamination Programme, where data are collected on levels of aflatoxin in groundnuts, tree nuts, maize, and other grains of major dietary importance, in milk and animal feed, and to some extent in total diets.[2,3] The Committee was informed that a conference was being planned in the near future to consider the various questions relating to food contamination by mycotoxins. Documents being prepared for this meeting included analyses of the current relevant regulations and a synopsis of national control measures, taken in relation to aflatoxin contamination. These documents are available from

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[1] *Recent developments concerning aflatoxins.* Committee on Commodity Problems, Intergovernment Group on Oilseeds, Oils and Fats, Nineteenth Session. Rome, Food and Agriculture Organization of the United Nations, 1985.

[2] Joint UNEP/FAO/WHO Food Contamination Monitoring Programme (1986): *Summary of 1980–1983 Monitoring Data*, Geneva (Unpublished document WHO/EHE/FOS/86.2).

[3] Joint UNEP/FAO/WHO Food Contamination Monitoring Programme (1986): *Chemical Contaminants in Foods: 1980–1983*, Geneva (Unpublished document WHO/EHE/FOS/86.5).

FAO.[1] Information on the available toxicity data is contained in a number of recent reviews.[2–5]

The present evaluation was concerned with the health effects of aflatoxin present in the human diet, although the Committee recognized the importance of aflatoxin in animal feed as a source of human exposure to aflatoxin and its metabolites (see section 2.2.2).

Four major aflatoxins (B_1, B_2, G_1, and G_2) occur in fungally contaminated plant products. The major aflatoxin-producing fungi are *Aspergillus flavus* and *A. parasiticus*. In addition, aflatoxins M_1 and M_2, the hydroxylated metabolites of aflatoxins B_1 and B_2, occur predominantly in the milk of cows fed rations containing aflatoxins B_1 and B_2. However, aflatoxin B_1 is usually found in the greatest concentration in the food supply, and most of the available toxicological data relate to this compound.

The Committee considered information from studies on the biochemistry and toxicology of aflatoxins, as well as the effects on human health and information on the possible relationship between aflatoxin ingestion and the occurrence of primary liver cancer in man. The acute toxic effect of aflatoxins B_1, B_2, and M_1 in all animal species studied is characterized by haemorrhagic necrosis of the liver. Many data exist on the carcinogenic effects of orally-administered aflatoxin B_1; it is a well known potent hepatocarcinogen in all mammalian species studied. Animal species exhibit a range of susceptibilities to the carcinogenic effects of aflatoxin B_1, ranging from the duck which is extremely sensitive, to adults of certain strains of mice and sheep which are relatively insensitive. Dose–response studies in rats show that dietary levels of aflatoxin as low as 0.005 mg/kg of purified aflatoxin B_1 result in an 80% incidence of liver tumours in 65–80 weeks. A number of factors, such

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[1] Second FAO/WHO/UNEP Conference on Mycotoxins, Bangkok, 1987. Unpublished working papers available from Food Quality and Standards Service, FAO, 00100 Rome, Italy.

[2] *Mycotoxins*. Geneva, World Health Organization, 1979 (Environmental Health Criteria, 11).

[3] *IARC monographs on the evaluation of the carcinogenic risk of chemicals to man: some naturally occurring substances*. Vol. 10, International Agency for Research on Cancer, Lyon, 1979, pp. 51–72.

[4] Busby, W.T. & Wogan, G.N. Aflatoxins. In: Scarle, C.E. ed. *Chemical carcinogens*, 2nd ed. Vol. 2. American Chemical Society, Washington, DC, 1984 (ACS Monograph 182).

[5] Tutelyan, B.A. & Kravchenko, P.B. *Mycotoxins (medical and toxicological aspects)*. USSR Medical Academy, Moscow, 1985 (in Russian).

as dietary content of protein, lipid, and vitamins and hormones, have been shown to modify the carcinogenic response of rats to aflatoxin B_1. Limited data are available on the carcinogenicity of some of the aflatoxin congeners or metabolites. The available information indicates a decreasing order of potency of $B_1 > G_1 > B_2 > G_2$. Aflatoxicol, a major metabolite of aflatoxin, may be as potent as aflatoxin B_1; aflatoxin M_1 appears to be at least an order of magnitude less potent than aflatoxin B_1. Information was also available on the effects of aflatoxin on man from cases of acute intoxication and death and on epidemiological studies relating intakes of aflatoxin and incidence rates of primary liver cancer.

The Committee considered a number of alternative ways of evaluating the risk associated with human exposure to aflatoxin B_1. It was noted that death had occurred following short-term exposure to aflatoxins at an estimated level of 6 mg/day.[1] The Committee considered that it was possible that the acute toxic effects might be eliminated by ensuring that the levels of aflatoxin in the diet were at least an order of magnitude lower than those causing the toxic effects.

The more difficult goal was the attempt to establish the possible carcinogenic risk resulting from chronic exposure to aflatoxin. Good animal data are available on the relationship between aflatoxin levels, duration of exposure, and carcinogenicity. The available human data on the association between aflatoxin exposure and primary liver cancer are difficult to evaluate because of the large number of uncertainties in the studies, which include inadequate data on the dietary intake of aflatoxins, contribution of hepatitis B virus to the etiology of cancer, and cultural and dietary status and habits. The Committee agreed that at present the available scientific information does not permit a determination of the extent to which exposure to aflatoxins contributed to the increased incidence of primary liver cancer in the populations that were studied.

The Committee considered aflatoxin to be a potential human carcinogen. There is not sufficient information available to establish a figure for a tolerable level of exposure. The Committee urged that the intake of dietary aflatoxin be reduced to the lowest practicable levels, so as to reduce, as far as possible the potential risk. It reiterated the view expressed at the twenty-second meeting of the

[1] *Mycotoxins*. Geneva, World Health Organization, 1979 (Environmental Health Criteria 11).

Committee that dealt with the problem of trace contaminants in food (Annex 1, reference *47*), namely: "A health hazard can be determined only by taking into account toxicological knowledge and information about potential exposure. However, in the case of potent carcinogens, for example certain mycotoxins, the Committee believed that efforts should be made to limit their presence in food to irreducible levels. It defined an irreducible level as that concentration of a substance which cannot be eliminated from a food without involving the discarding of that food altogether, severely compromising the ultimate availability of major food supplies".

Data on the occurrence of aflatoxins in various foods and estimated aflatoxin dietary intakes for various countries clearly demonstrate the wide ranging levels of aflatoxins in susceptible food commodities (e.g., peanuts, cereal grains) and confirmed that consumers throughout the world are being exposed to these substances albeit at different levels. In this latter regard, the limits enforced by different countries for aflatoxins in food undoubtedly contribute positively to minimizing consumer exposure. In the main, these limits have been based on the recognition that aflatoxins are undesirable from a human health standpoint, but at present there is no practical means of eliminating them completely without restricting the availability of otherwise nutritious commodities. In addition, these limits reflect technological developments that have resulted in the reduction of aflatoxin contamination of foods as well as analytical improvements permitting analysis and regulatory control at lower levels.

The Committee acknowledged the complexities of the problem of the reduction of aflatoxin exposure, but was aware that this could be achieved in a number of ways. In the first instance, it was noted that aflatoxin contamination can be controlled by minimizing mould growth. To do this, several pre-harvest control measures have been identified, e.g., selection of a resistant seed variety, prevention of physical damage to crops by insects, and appropriate crop rotation. Similarly, harvest precautions, e.g., proper handling to avoid physical damage and crop cleaning to remove field soil have been shown to minimize susceptibility to contamination. The effect of storage conditions has also been investigated by a number of researchers and moisture content together with temperature have been identified as the most important factors to be taken into account for the protection of stored grains against aflatoxin

contamination. Accordingly, continuous, adequate aeration and monitoring of moisture content and temperature are to be encouraged. In addition to harvesting and storage precautions, screening of crops prior to processing and sale has been shown to be an important way of minimizing exposure to aflatoxins. For example, manual, mechanical, and electronic methods have been used successfully to exclude damaged or discoloured peanuts. The Committee urged the application of these means to minimize aflatoxin contamination of food.

The Committee was also informed of research activities related to the detoxification of aflatoxin-contaminated produce. At the present time, the only treatment that the Committee was aware is used commercially is the ammoniation of animal feeds. It was stressed that detoxification procedures should not be regarded as an alternative to good agricultural practice and that such procedures should only be considered when preventive measures have failed. Furthermore, any detoxification treatment must not adversely affect the nutritional quality of the treated crop or result in the presence or formation of other toxic substances that could compromise the overall safety of the crop.

A toxicological monograph was not prepared.

4. ESTABLISHMENT AND REVISION OF CERTAIN SPECIFICATIONS

Twenty-four substances were considered for specifications only. Specifications for seventeen substances were revised and seven were maintained. In addition, the Committee was asked to consider the specifications for glycerol esters of wood rosin. However, the Committee noted that information on this substance had not been solicited from all sources and therefore it agreed to review these specifications at a future meeting.

4.1 Food colours

The Committee was asked to reconsider certain of the specifications for food colours drawn up at the twenty-eighth meeting.

Caramel colours

The Committee last evaluated caramel colours in 1985 when the specifications were made tentative pending receipt of further information on starting materials, methods of manufacture, and composition (Annex 1, reference *70* p. 28). At that time, limits for the various parameters in the specifications were set on the basis of the solids content. The Committee has since received limited information on starting materials, methods of manufacture, and composition. The Committee was asked to reconsider the basis for the limits on the grounds that limits set on an equivalent colour basis provide a better control for levels of 4-methylimidazole and 2-acetyl-4-tetrahydroxybutylimidazole in the final food product. The Committee agreed that for caramels with a low colour intensity limits set on an equivalent colour basis represented a tighter restriction on the levels of these components in the final food. However, such a method of expressing limits could be less restrictive for caramel colours with a high colour intensity. Furthermore, the ADI allocated in 1985 was set on an "as is" or equivalent solids basis in terms of total caramel colour. Therefore, the Committee agreed that limits for 4-methylimidazole and 2-acetyl-4-tetrahydroxybutylimidazole on an equivalent colour basis provided a valuable supplementary control, and the specifications were revised accordingly. Nevertheless, the Committee also maintained, for 4-methylimidazole and 2-acetyl-4-tetrahydroxybutylimidazole, an upper limit on the solids content and maintained all other limits on a solids basis. Limits for solids content and colour intensity were added. The existing tentative specifications were revised and the "tentative" qualification deleted.

Patent blue V

The Committee was informed that the manufacture of the calcium salt of this colour (which is provided for in the specifications) resulted in the unavoidable presence of calcium sulfate producing more water-insoluble matter. The Committee revised the specifications accordingly.

Brilliant black BN and Ponceau 4R

The Committee had been requested to reduce the assay levels of the specifications for Brilliant black BN and Ponceau 4R, although

it was informed that these levels could be met. The Committee reiterated the opinion expressed in section 2.3.1 that such amendments to the specifications should be fully justified in terms of a net improvement in quality. The existing specifications for Brilliant black BN and Ponceau 4R were maintained.

Paprika oleoresin

The Committee's tentative specifications for paprika oleoresin were revised to include an assay test based on colour value and to place a maximum limit on capsaicin content. The Committee had also received a request to include provisions for an additional processing solvent, 1,2-dichloroethane. However, the Committee could not include this solvent in its specifications without a toxicological review of the solvent.

4.2 Sweetening agents

Maltitol and xylitol. The Committee considered specifications for maltitol powders and xylitol.

The Committee was not aware that chemically-pure maltitol is used in food. Dry, food-grade maltitol is covered by the existing specifications for hydrogenated glucose syrups. The specifications for hydrogenated glucose syrups were revised to make it clear that they include the dried product.

Both hydrogenated glucose syrups and xylitol are added to foods as replacements for sugar. Since such foods may be consumed by children, the Committee felt that the lead content of these substances should be subject to more stringent control than that usually applied to food additives and agreed that a maximum limit of 1 mg per kg was called for. The specifications for xylitol were also revised and both specifications were made tentative pending confirmation that the lower limit for lead can be met. The Committee further recommended that at some future date the specifications for mannitol, sorbitol, sorbitol syrup, and isomalt should be reviewed with the aim of reducing the lead limit of these substances as well.

4.3 Miscellaneous food additives

Polyglycerol esters of fatty acids. The Committee received a request to amend the specifications to increase the range of average

polyglycerol chain lengths permitted from 3 to 10 glycerol units. The Committee concluded that the specifications could not be amended without a review of the toxicological data on these substances to ensure that the material tested included the range of polyglycerol units requested. The existing specifications were maintained.

Sucrose esters of fatty acids

The Committee received requests to permit three additional solvents to be used for the manufacture of this additive together with proposals for residual solvent limits. The Committee agreed not to add these solvents to those already permitted for the manufacture of this additive without a review of the toxicological data on these substances to determine the nature of the substances tested or an evaluation of the solvents themselves. The existing specifications were maintained.

Talc

The Committee was requested to review methods available for the determination of asbestos in talc. It was concluded that, because of the complexity and expense of instrumentation required for the quantification of asbestos in talc, the present test should not be revised. The existing specifications were maintained and the Committee agreed to delete the "tentative" qualification.

4.4 Establishment and revision of methods of analysis

4.4.1 *General methods*

New general methods were prepared for:

(*a*) method of assay for oil-soluble food colours;
(*b*) limit test for pyrrolidone-carboxylic acid in glutamic acid and its salts by thin-layer chromatography.

4.4.2 *Tentative methods of analysis*

In the course of revising a number of specifications, the Committee identified the need to update several of its analytical methods. The following tentative, alternative general methods were prepared as proposals for use in future revisions of specifications:

(*a*) general method for the determination of polyols by high pressure liquid chromatography;

(*b*) alternative method for the determination of the nominal molecular mass of polyethylene glycols by size exclusion chromatography;

(*c*) determination of the content of ethylene oxide and 1,4-dioxane in polyethylene glycols by gas–liquid chromatography.

5. FUTURE WORK

1. The Committee was informed of recent changes in the methods of manufacture of iron oxides used as food colours, which could result in increased levels of contaminants. Iron oxides should be reviewed as a group, taking into account the origin of raw materials and all methods of manufacture. Information on the current use of iron oxides in foods and intake data are desirable.

2. Glycerol esters of wood rosin should be reviewed taking into account data provided in reply to the request of the twentieth meeting.

3. Paprika oleoresin, polyglycerol esters of fatty acids, and sucrose esters of fatty acids should be toxicologically evaluated in light of proposed changes in specifications.

4. Lead limits in the specifications for all polyol sweetening agents should be reviewed (see section 4.2).

5. The General Specifications for enzymes used in food processing (Annex 1, reference *69*, Annex 1) should be reviewed.

6. Methods of analysis should be established to identify and assay the principal components of food colours prepared by the extraction of plant materials.

6. RECOMMENDATIONS TO FAO AND WHO

1. In view of the large number of food additives and contaminants requiring evaluation or re-evaluation, meetings of the Joint FAO/WHO Expert Committee on Food Additives should continue to be held at least once a year.

2. Every effort should be made to reduce aflatoxin levels in food to the lowest levels practicable.

3. FAO and WHO should encourage governments to investigate and implement preventive and control measures for limiting the levels of aflatoxin in the diet.

4. FAO and WHO should encourage international collaboration between governments so as to harmonize aflatoxin regulatory controls as far as is feasible.

5. FAO and WHO, in cooperation with other international organizations, should encourage the development of improved analytical methods for aflatoxins in order to enhance their usefulness as well as their application for regulatory control.

6. FAO and WHO should continue efforts aimed at establishing appropriate sampling procedures that take into account the non-homogeneous distribution of aflatoxin contamination.

7. The agencies concerned should consider strengthening the Joint UNEP/FAO/WHO Food Contamination Monitoring Programme to increase the value of the data collected as well as its usefulness as a basis upon which advice can be provided to Member States concerning food and feed surveillance programmes.

8. Since the available data on the intake of dietary aflatoxins are limited, intake studies should be carried out, especially in countries where climatic conditions are conducive to aflatoxin contamination of foods.

9. FAO and WHO together with other international organizations should encourage the conduct of adequate epidemiological studies concerning the health effects thought to be related to aflatoxin exposure, ensuring that confounding variables are accounted for.

10. Further information is required about aflatoxin and other mycotoxin detoxification procedures, including the nature of the products resulting from the treatment, their toxicity, the possibility of metabolic reactivation, residues in human food as a result of treatment, adverse nutritional effects, and the potential *de novo* formation of toxic substances by the treatment process.

11. Information submitted to the Committee to be used to set specifications should, whenever possible, be in accordance with internationally accepted rules for nomenclature. In particular:

—physical constants and chemical parameters should be expressed in SI units (Système international d'Unités);
—the chemical names of organic compounds should be in accordance with the IUPAC rules for nomenclature, and if official names are known these should be used.

ACKNOWLEDGEMENTS

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Annex 1

REPORTS AND OTHER DOCUMENTS RESULTING FROM PREVIOUS MEETINGS OF THE JOINT FAO/WHO EXPERT COMMITTEE ON FOOD ADDITIVES

1. *General principles governing the use of food additives* (First report of the Expert Committee). FAO Nutrition Meetings Report Series, No. 15, 1957; WHO Technical Report Series, No. 129, 1957 (out of print).
2. *Procedures for the testing of intentional food additives to establish their safety for use* (Second report of the Expert Committee). FAO Nutrition Meetings Report Series, No. 17, 1958; WHO Technical Report Series, No. 144, 1958 (out of print).
3. *Specifications for identity and purity of food additives (antimicrobial preservatives and antioxidants)* (Third report of the Expert Committee). These specifications were subsequently revised and published as *Specifications for identity and purity of food additives*, vol. 1. *Antimicrobial preservatives and antioxidants*, Rome, Food and Agriculture Organization of the United Nations, 1962 (out of print).
4. *Specifications for identity and purity of food additives (food colours)* (Fourth report of the Expert Committee). These specifications were subsequently revised and published as *Specifications for identity and purity of food additives*, vol. II. *Food colours*, Rome, Food and Agriculture Organization of the United Nations, 1963 (out of print).
5. *Evaluation of the carcinogenic hazards of food additives* (Fifth report of the Expert Committee). FAO Nutrition Meetings Report Series, No. 29, 1961; WHO Technical Report Series, No. 220, 1961 (out of print).
6. *Evaluation of the toxicity of a number of antimicrobials and antioxidants* (Sixth report of the Expert Committee). FAO Nutrition Meetings Report Series, No. 31, 1962; WHO Technical Report Series, No. 228, 1962 (out of print).
7. *Specifications for the identity and purity of food additives and their toxicological evaluation: emulsifiers, stabilizers, bleaching and maturing agents* (Seventh report of the Expert Committee). FAO Nutrition Meetings Report Series, No. 35, 1964; WHO Technical Report Series, No. 281, 1964 (out of print).
8. *Specifications for the identity and purity of food additives and their toxicological evaluation: food colours and some antimicrobials and antioxidants* (Eighth report of the Expert Committee). FAO Nutrition Meetings Report Series, No. 38, 1965; WHO Technical Report Series, No. 309, 1965 (out of print).
9. *Specifications for identity and purity and toxicological evaluation of some antimicrobials and antioxidants.* FAO Nutrition Meetings Report Series, No. 38A, 1965; WHO/Food Add/24.65 (out of print).
10. *Specifications for identity and purity and toxicological evaluation of food colours.* FAO Nutrition Meetings Report Series, No. 38B, 1966; WHO/Food Add/66.25.
11. *Specifications for the identity and purity of food additives and their toxicological evaluation: some antimicrobials, antioxidants, emulsifiers, stabilizers, flour-treatment agents, acids, and bases* (Ninth report of the Expert Committee). FAO Nutrition Meetings Report Series, No. 40, 1966; WHO Technical Report Series, No. 339, 1966 (out of print).

12. *Toxicological evaluation of some antimicrobials, antioxidants, emulsifiers, stabilizers, flour-treatment agents, acids, and bases.* FAO Nutrition Meetings Report Series, No. 40A, B, C; WHO/Food Add/67.29, 1967.
13. *Specifications for the identity and purity of food additives and their toxicological evaluation: some emulsifiers and stabilizers and certain other substances* (Tenth report of the Expert Committee). FAO Nutrition Meetings Report Series, No. 43, 1967; WHO Technical Report Series, No. 373, 1967.
14. *Specifications for the identity and purity of food additives and their toxicological evaluation: some flavouring substances and non-nutritive sweetening agents* (Eleventh report of the Expert Committee). FAO Nutrition Meetings Report Series, No. 44, 1968; WHO Technical Report Series, No. 383, 1968.
15. *Toxicological evaluation of some flavouring substances and non-nutritive sweetening agents.* FAO Nutrition Meetings Report Series, No. 44A, 1968; WHO/Food Add/68.33.
16. *Specifications and criteria for identity and purity of some flavouring substances and non-nutritive sweetening agents.* FAO Nutrition Meetings Report Series, No. 44B, 1969; WHO/Food Add/69.31.
17. *Specifications for the identity and purity of food additives and their toxicological evaluation: some antibiotics* (Twelfth report of the Expert Committee). FAO Nutrition Meetings Report Series, No. 45, 1969; WHO Technical Report Series, No. 430, 1969.
18. *Specifications for the identity and purity of some antibiotics.* FAO Nutrition Meetings Report Series, No. 45A, 1969; WHO/Food Add/69.34.
19. *Specifications for the identity and purity of food additives and their toxicological evaluation: some food colours, emulsifiers, stabilizers, anticaking agents, and certain other substances* (Thirteenth report of the Expert Committee). FAO Nutrition Meetings Report Series, No. 46, 1970; WHO Technical Report Series, No. 445, 1970.
20. *Toxicological evaluation of some food colours, emulsifiers, stabilizers, anticaking agents, and certain other substances.* FAO Nutrition Meetings Report Series, No. 46A, 1970; WHO/Food Add/70.36.
21. *Specifications for the identity and purity of some food colours, emulsifiers, stabilizers, anticaking agents, and certain other food additives.* FAO Nutrition Meetings Report Series, No. 46B, 1970; WHO/Food Add/70.37.
22. *Evaluation of food additives: specifications for the identity and purity of food additives and their toxicological evaluation: some extraction solvents and certain other substances; and a review of the technological efficacy of some antimicrobial agents* (Fourteenth report of the Expert Committee). FAO Nutrition Meetings Report Series, No. 48, 1971; WHO Technical Report Series, No. 462, 1971.
23. *Toxicological evaluation of some extraction solvents and certain other substances.* FAO Nutrition Meetings Report Series, No. 48A, 1971; WHO/Food Add/70.39.
24. *Specifications for the identity and purity of some extraction solvents and certain other substances.* FAO Nutrition Meetings Report Series, No. 48B, 1971; WHO/Food Add/70.40.
25. *A review of the technological efficacy of some antimicrobial agents.* FAO Nutrition Meetings Report Series, No. 48C, 1971; WHO/Food Add/70.41.
26. *Evaluation of food additives: some enzymes, modified starches, and certain other substances: toxicological evaluations and specifications and a review of the technological efficacy of some antioxidants* (Fifteenth report of the Expert

Committee). FAO Nutrition Meetings Report Series, No. 50, 1972; WHO Technical Report Series, No. 488, 1972.

27. *Toxicological evaluation of some enzymes, modified starches, and certain other substances.* FAO Nutrition Meetings Report Series, No. 50A, 1972; WHO Food Additives Series, No. 1, 1972.
28. *Specifications for the identity and purity of some enzymes and certain other substances.* FAO Nutrition Meetings Report Series, No. 50B, 1972; WHO Food Additives Series, No. 2, 1972.
29. *A review of the technological efficacy of some antioxidants and synergists.* FAO Nutrition Meetings Report Series, No. 50C, 1972; WHO Food Additives Series, No. 3, 1972.
30. *Evaluation of certain food additives and the contaminants mercury, lead, and cadmium* (Sixteenth report of the Expert Committee). FAO Nutrition Meetings Report Series, No. 51, 1972; WHO Technical Report Series, No. 505, 1972, and corrigendum.
31. *Evaluation of mercury, lead, cadmium, and the food additives amaranth, diethylpyrocarbonate, and octyl gallate.* FAO Nutrition Meetings Report Series, No. 51A, 1972; WHO Food Additives Series, No. 4, 1972.
32. *Toxicological evaluation of certain food additives with a review of general principles and of specifications* (Seventeenth report of the Expert Committee). FAO Nutrition Meetings Report Series, No. 53, 1974; WHO Technical Report Series, No. 539, 1974, and corrigendum (out of print).
33. *Toxicological evaluation of certain food additives including anticaking agents, antimicrobials, antioxidants, emulsifiers, and thickening agents.* FAO Nutrition Meetings Report Series, No. 53A, 1974; WHO Food Additives Series, No. 5, 1974.
34. *Specifications for identity and purity of thickening agents, anticaking agents, antimicrobials, antioxidants and emulsifiers.* FAO Food and Nutrition Paper, No. 4, 1978.
35. *Evaluation of certain food additives* (Eighteenth report of the Expert Committee). FAO Nutrition Meetings Report Series, No. 54, 1974; WHO Technical Report Series, No. 557, 1974, and corrigendum.
36. *Toxicological evaluation of some food colours, enzymes, flavour enhancers, thickening agents, and certain other food additives.* FAO Nutrition Meetings Report Series, No. 54A, 1975; WHO Food Additives Series, No. 6, 1975.
37. *Specifications for the identity and purity of some food colours, flavour enhancers, thickening agents, and certain food additives.* FAO Nutrition Meetings Report Series, No. 54B, 1975; WHO Food Additives Series, No. 7, 1975.
38. *Evaluation of certain food additives: some food colours, thickening agents, smoke condensates, and certain other substances* (Nineteenth report of the Expert Committee). FAO Nutrition Meetings Report Series, No. 55, 1975; WHO Technical Report Series, No. 576, 1975.
39. *Toxicological evaluation of some food colours, thickening agents, and certain other substances.* FAO Nutrition Meetings Report Series, No. 55A, 1975; WHO Food Additives Series, No. 8, 1975.
40. *Specifications for the identity and purity of certain food additives.* FAO Nutrition Meetings Report Series, No. 55B, 1976; WHO Food Additives Series, No. 9, 1976.

41. *Evaluation of certain food additives* (Twentieth report of the Expert Committee). FAO Food and Nutrition Series, No. 1, 1976; WHO Technical Report Series, No. 599, 1976.
42. *Toxicological evaluation of certain food additives.* WHO Food Additives Series, No. 10, 1976.
43. *Specifications for the identity and purity of some food additives.* FAO Food and Nutrition Series, No. 1B, 1977; WHO Food Additives Series, No. 11, 1977.
44. *Evaluation of certain food additives* (Twenty-first report of the Joint FAO/WHO Expert Committee on Food Additives). WHO Technical Report Series, No. 617, 1978.
45. *Summary of toxicological data of certain food additives.* WHO Food Additives Series, No. 12, 1977.
46. *Specifications for identity and purity of some food additives, including antioxidants, food colours, thickeners, and others.* FAO Nutrition Meetings Report Series, No. 57, 1977.
47. *Evaluation of certain food additives and contaminants* (Twenty-second report of the Joint FAO/WHO Expert Committee on Food Additives). WHO Technical Report Series, No. 631, 1978.
48. *Summary of toxicological data of certain food additives and contaminants.* WHO Food Additives Series, No. 13, 1978.
49. *Specifications for the identity and purity of certain food additives.* FAO Food and Nutrition Paper, No. 7, 1978.
50. *Evaluation of certain food additives* (Twenty-third report of the Joint FAO/WHO Expert Committee on Food Additives). WHO Technical Report Series, No. 648, 1980, and corrigenda.
51. *Toxicological evaluation of certain food additives.* WHO Food Additives Series, No. 14, 1980.
52. *Specifications for identity and purity of food colours, flavouring agents, and other food additives.* FAO Food and Nutrition Paper, No. 12, 1979.
53. *Evaluation of certain food additives* (Twenty-fourth report of the Joint FAO/WHO Expert Committee on Food Additives). WHO Technical Report Series, No. 653, 1980.
54. *Toxicological evaluation of certain food additives.* WHO Food Additives Series, No. 15, 1980.
55. *Specifications for identity and purity of food additives (sweetening agents, emulsifying agents, and other food additives).* FAO Food and Nutrition Paper, No. 17, 1980.
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58. *Specifications for identity and purity of food additives (carrier solvents, emulsifiers and stabilizers, enzyme preparations, flavouring agents, food colours, sweetening agents, and other food additives).* FAO Food and Nutrition Paper, No. 19, 1981.
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61. *Specifications for the identity and purity of certain food additives.* FAO Food and Nutrition Paper, No. 25, 1982.
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63. *Toxicological evaluation of certain food additives and contaminants.* WHO Food Additives Series, No. 18, 1983.
64. *Specifications for the identity and purity of certain food additives.* FAO Food and Nutrition Paper, No. 28, 1983.
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68. *Specifications for the identity and purity of food colours.* FAO Food and Nutrition Paper, No. 31/1, 1984.
69. *Specifications for the identity and purity of food additives.* FAO Food and Nutrition Paper, No. 31/2, 1984.
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75. *Specifications for the identity and purity of certain food additives.* FAO Food and Nutrition Paper, No. 37, 1987.
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Annex 2

ACCEPTABLE DAILY INTAKES, OTHER TOXICOLOGICAL INFORMATION, AND INFORMATION ON SPECIFICATIONS

Substance	Specifications[1]	ADI for man (and other toxicological recommendations)
A. Food additives		
Enzyme preparations		
α-Amylase from *Aspergillus oryzae*	N, T	Acceptable[2]
Protease from *Aspergillus oryzae*	R, T	Acceptable[2]
Amyloglucosidases from *Aspergillus niger*	N, T	0–1 mg/kg body weight[3]
β-Glucanase from *Aspergillus niger*	N, T	0–1 mg/kg body weight[3]
hemi-Cellulase from *Aspergillus niger*	N, T	0–1 mg/kg body weight[3]
Pectinases from *Aspergillus niger*	N, T	0–1 mg/kg body weight[3]
Protease from *Aspergillus niger*	O	0–1 mg/kg body weight[3]
β-Glucanase from *Trichoderma harzianum*	N, T	0–0.5 mg/kg body weight[3, 4]
Cellulase from *Trichoderma reesei*	N, T	0–0.3 mg/kg body weight[3, 4]
Cellulase from *Penicillium funiculosum*	N, T	No ADI allocated[5]
Pectinase from *Aspergillus alliaceus*	O	No ADI allocated[5]
Flavouring agents		
trans-Anethole	S	0–2.5 mg/kg body weight[4]
Benzyl acetate	S	0–5 mg/kg body weight[4]
Smoke flavourings	N, T	Provisional acceptance[6]
Food colours		
Beet red	R	ADI "not specified"[7]
Canthaxanthin	R	0–0.05 mg/kg body weight[4]
Carbon black	R, T	No ADI allocated[5, 8]
Carotenes (algae)	N, T[9]	No ADI allocated[5]
Carotenes (vegetable)	N, T[9]	No ADI allocated[5]
Citranaxanthin	R	No ADI allocated[5]
Xanthophylls (mixed carotenoids)	N, T[10]	No ADI allocated[5]
Xanthophylls (*Tagetes* extract)	N. T[10]	No ADI allocated[5]
Miscellaneous food additives		
Ferrous gluconate	S	0.8 mg/kg body weight[11]
Glutamic acid and its salts	R	ADI "not specified"[7, 12]
4-Hydroxymethyl-2,6-di*tert*-butylphenol	W	No ADI allocated[5]
Polydextroses	S	ADI "not specified"[7]
Tannic acid	R, T	ADI "not specified"[4, 7, 13]
B. Contaminants		
Aflatoxins	–	Lowest practicable level[14]

	Specifications only[1]
Activated carbon	R
α-Amylase and glucoamylase from *Aspergillus oryzae*	R, T
β-Carotene (synthetic)	R
Brilliant black BN	S
Caramel colours	R
Carthamus yellow	R

(continued)

	Specifications only[1]
Chlorophylls	R
Chlorophylls, copper complexes	R
Chlorophyllins, copper complexes, sodium and potassium salts	R
Hydrogenated glucose syrups	R, T[15]
Insoluble polyvinylpyrrolidone	S
Paprika oleoresin	R
Patent blue V	R
Polyethylene glycols	R
Polyglycerol esters of fatty acids	S
Ponceau 4R	S
Potassium bromate	R
Potassium dihydrogen citrate	R
Riboflavin	R
Riboflavin 5′-phosphate, sodium	R
Sucrose esters of fatty acids	S
Talc	S
Triammonium citrate	S
Xylitol	R, T

Notes to Annex 2

1. N, new specifications prepared; O, specifications not prepared; R, existing specifications revised; S, specifications exist, revision not considered or not required; T, the existing, new, or revised specifications are tentative and comments are invited; and W, previously established specifications withdrawn.
2. Acceptable for use in food processing. These enzymes are derived from microorganisms that are traditionally accepted as constituents of foods or are normally used in the preparation of foods. These products are regarded as foods and, consequently, considered acceptable, provided that satisfactory chemical and microbiological specifications can be established.
3. Based on the percentage of T.O.S. (total organic solids): % T.O.S. = 100 – (A+W+D), where A = % ash, W = % water, and D = % diluent and carrier.
4. Temporary acceptance (see Annex 3).
5. Insufficient information available on its toxicology and/or chemical composition to establish an ADI.
6. Analytical and compositional data, including data on variability, are required; further safety studies on a well-defined spectrum of smoke flavourings are desired. Benzo(*a*)pyrene should not exceed 10 µg per kg.
7. ADI "not specified" means that, on the basis of the available data (chemical, biochemical, toxicological, and other), the total daily intake of the substance, arising from its use at the levels necessary to achieve the desired effect and from its acceptable background in food, does not, in the opinion of the Committee, represent a hazard to health. For that reason, and for the reasons stated in the individual evaluations, the establishment of an acceptable daily intake (ADI) expressed in numerical form is not deemed necessary.
8. The use of carbon black from hydrocarbon sources in food contact materials is provisionally accepted.
9. The previous specifications for carotenes (natural) were withdrawn.
10. The previous specifications for xanthophylls were withdrawn.
11. Provisional maximum tolerable daily intake (PMTDI) for iron.

12. Group ADI for L-glutamic acid and its ammonium, calcium, magnesium, monosodium, and potassium salts.
13. For use as a processing aid.
14. Presence in food should be reduced to irreducible levels. An irreducible level is defined as that concentration of a substance that cannot be eliminated from a food without involving the discarding of that food altogether, severely compromising the ultimate availability of major food supplies.
15. This specification also covers dry, food-grade maltitol, which is the substance listed on the agenda of this meeting.

Annex 3

FURTHER TOXICOLOGICAL STUDIES AND INFORMATION REQUIRED OR DESIRED

Enzyme preparations

β-Glucanase from Trichoderma harzianum[1]

1. Submission of the results of a long-term study in a rodent species.
2. Specifications showing that this organism does not produce antibiotics and is not pathogenic to man.

Cellulase from Trichoderma reesei[1]

Submission of the results of a long-term study in a rodent species.

Flavouring agents

trans-Anethole[2]

Submission of the results of the long-term feeding study in rats that has been completed recently.

Benzyl acetate[3]

Submission of the results of lifetime gavage studies with benzyl alcohol, the lifetime phases of which have been completed recently.

Food colours

Canthaxanthin[3]

1. Submission of details of the long-term studies in mice and rats for which summary data have been submitted, including ophthalmological data where available.
2. Clarification of the factors that influence pigment deposition in the eye, including the establishment of the threshold dose and the influence of dose and duration of exposure, the reversibility of pigment accumulation, and the investigation of potential animal models.

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[1] Information required by 1992.
[2] Information required by 1988.
[3] Information required by 1989.

3. Clarification of whether pigment deposition is causally related to impaired ocular function.

Miscellaneous food additives

Tannic acid

Further data are required on the composition of tannic acid from different sources. Before it can be evaluated for direct food use, evidence must also be provided that its use does not result in a significant increase in total intake of tannic acid (as hydrolysable gallotannins); these data will be used to decide whether tannic acid should be subjected to further toxicity testing.

WORLD HEALTH ORGANIZATION TECHNICAL REPORT SERIES

Recent reports:

No.		Sw. fr.
705	(1984) **The role of food safety in health and development** Report of a Joint FAO/WHO Expert Committee on Food Safety (79 pages)	7.—
706	(1984) **The uses of epidemiology in the study of the elderly** Report of a WHO Scientific Group on the Epidemiology of Aging (84 pages)	8.—
707	(1984) **Recommended health-based occupational exposure limits for respiratory irritants** Report of a WHO Study Group (154 pages)	14.—
708	(1984) **Education and training of nurse teachers and managers with special regard to primary health care** Report of a WHO Expert Committee (54 pages)	6.—
709	(1984) **WHO Expert Committee on Rabies** Seventh report (104 pages)	9.—
710	(1984) **Evaluation of certain food additives and contaminants** Twenty-eighth report of the Joint FAO/WHO Expert Committee on Food Additives (44 pages)	5.—
711	(1984) **Advances in malaria chemotherapy** Report of a WHO Scientific Group (218 pages)	20.—
712	(1984) **Malaria control as part of primary health care** Report of a WHO Study Group (73 pages)	8.—
713	(1984) **Prevention methods and programmes for oral diseases** Report of a WHO Expert Committee (46 pages)	5.—
714	(1985) **Identification and control of work-related diseases** Report of a WHO Expert Committee (71 pages)	7.—
715	(1985) **Blood pressure studies in children** Report of a WHO Study Group (36 pages)	5.—
716	(1985) **Epidemiology of leprosy in relation to control** Report of a WHO Study Group (60 pages)	6.—
717	(1985) **Health manpower requirements for the achievement of health for all by the year 2000 through primary health care** Report of a WHO Expert Committee (92 pages)	8.—
718	(1985) **Environmental pollution control in relation to development** Report of a WHO Expert Committee (63 pages)	6.—
719	(1985) **Arthropod-borne and rodent-borne viral diseases** Report of a WHO Scientific Group (116 pages)	10.—
720	(1985) **Safe use of pesticides** Ninth report of the WHO Expert Committee on Vector Biology and Control (60 pages)	6.—
721	(1985) **Viral haemorrhagic fevers** Report of a WHO Expert Committee (126 pages)	10.—

722 (1985) **The use of essential drugs**
Second report of the WHO Expert Committee on the Use of Essential Drugs (50 pages) ..... 6.—

723 (1985) **Future use of new imaging technologies in developing countries**
Report of a WHO Scientific Group (67 pages) ..... 7.—

724 (1985) **Energy and protein requirements**
Report of a Joint FAO/WHO/UNO Expert Consultation (206 pages) 17.—

725 (1985) **WHO Expert Committee on Biological Standardization**
Thirty-fifth report (140 pages) ..... 11.—

726 (1985) **Sudden cardiac death**
Report of a WHO Scientific Group (25 pages) ..... 4.—

727 (1985) **Diabetes mellitus**
Report of a WHO Study Group (113 pages) ..... 9.—

728 (1985) **The control of schistosomiasis**
Report of a WHO Expert Committee (113 pages) ..... 10.—

729 (1985) **WHO Expert Committee on Drug Dependence**
Twenty-second report (31 pages) ..... 4.—

730 (1986) **Dementia in later life: research and action**
Report of a WHO Scientific Group (74 pages) ..... 10.—

731 (1986) **Young people's health—a challenge for society**
Report of a WHO Study Group on Young People's Health and "Health for All by the Year 2000" (117 pages) ..... 16.—

732 (1986) **Community prevention and control of cardiovascular diseases**
Report of a WHO Expert Committee (62 pages) ..... 9.—

733 (1986) **Evaluation of certain food additives and contaminants**
Twenty-ninth report of the Joint FAO/WHO Expert Committee on Food Additives (59 pages) ..... 9.—

734 (1986) **Recommended health-based limits in occupational exposure to selected mineral dusts (silica, coal)**
Report of a WHO Study Group (82 pages) ..... 12.—

735 (1986) **WHO Expert Committee on Malaria**
Eighteenth report (104 pages) ..... 14.—

736 (1986) **WHO Expert Committee on Venereal Diseases and Treponematoses**
Sixth report (141 pages) ..... 18.—

737 (1986) **Resistance of vectors and reservoirs of disease to pesticides**
Tenth report of the WHO Expert Committee on Vector Biology and Control (87 pages) ..... 12.—

738 (1986) **Regulatory mechanisms for nursing training and practice: meeting primary health care needs**
Report of a WHO Study Group (71 pages) ..... 10.—

739 (1986) **Epidemiology and control of African trypanosomiasis**
Report of a WHO Expert Committee (127 pages) ..... 16.—

740 (1986) **Joint FAO/WHO Expert Committee on Brucellosis**
Sixth report (132 pages) ..... 18.—

741 (1987) **WHO Expert Committee on Drug Dependence**
Twenty-third report (64 pages) ..... 9.—

742 (1987) **Technology for water supply and sanitation in developing countries**
Report of a WHO Study Group (38 pages) ..... 7.—

743 (1987) **The biology of malaria parasites**
Report of a WHO Scientific Group (229 pages) ..... 32.—

744 (1987) **Hospitals and health for all**
Report of a WHO Expert Committee on the Role of Hospitals at the First Referral Level (82 pages) ..... 12.—

745 (1987) **WHO Expert Committee on Biological Standardization**
Thirty-sixth report (149 pages) ..... 20.—

746 (1987) **Community-based education for health personnel**
Report of a WHO Study Group (89 pages) ..... 12.—

747 (1987) **Acceptability of cell substrates for production of biologicals**
Report of a WHO Study Group (29 pages) ..... 5.—

748 (1987) **WHO Expert Committee on Specifications for Pharmaceutical Preparations**
Thirtieth report (50 pages) ..... 9.—

749 (1987) **Prevention and control of intestinal parasitic infections**
Report of a WHO Expert Committee (86 pages) ..... 12.—

750 (1987) **Alternative systems of oral care delivery**
Report of a WHO Expert Committee (58 pages) ..... 9.—

751 (1987) **Evaluation of certain food additives and contaminants**
Thirtieth report of the Joint FAO/WHO Expert Committee on Food Additives (57 pages) ..... 9.—

752 (1987) **WHO Expert Committee on Onchocerciasis**
Third report (167 pages) ..... 24.—

753 (1987) **Mechanism of action, safety and efficacy of intrauterine devices**
Report of a WHO Scientific Group (91 pages) ..... 12.—

754 (1987) **Progress in the development and use of antiviral drugs and interferon**
Report of a WHO Scientific Group (25 pages) ..... 5.—

755 (1987) **Vector control in primary health care**
Report of a WHO Scientific Group (61 pages) ..... 9.—

756 (1987) **Children at work: special health risks**
Report of a WHO Study Group (49 pages) ..... 9.—

757 (1987) **Rational use of diagnostic imaging in paediatrics**
Report of a WHO Study Group (102 pages) ..... 14.—

758 (1987) **The hypertensive disorders of pregnancy**
Report of a WHO Study Group (114 pages) ..... 16.—

Safety Data Sheet

Section 01 Identification

Product Identifier

Carbon, Activated

Activated Carbon, CL500, Powdered Coal
Activated Carbon, CL830, Granular, Coal, 8x30 Mesh
Activated Carbon, CL850, Powdered Coal
Activated Carbon, CT830, Granular, Coconut, 8x30 Mesh
Activated Carbon Powdered Wood
Addsorb VQ1 Activated Carbon 4.0 mm Coal
Aquasorb BP2 Powder Activated Carbon Coal
Aquasorb BP2-F Powder Activated Carbon Coal
Aquasorb BP5 Powder Activated Carbon Coal
Aquasorb CS Granular Coconut Shell Activated Carbon, 12x40 Mesh
Aquasorb CX-MCA Granular Coconut Shell Activated Carbon 12x40 Mesh
Aquasorb Granular Activated Carbon 3500 8x30
Aquasorb Granular Activated Carbon AD-VA3 4 mm Pellet Coal
Aquasorb Granular Activated Carbon AS 1500 8x30 Coal
EcoSorb GXB 4 mm Pellet Carbon Coal
Haycarb Granular Cocnut Shell Activated Carbon HRO 12x30 Mesh
Haycarb Granular Cocnut Shell Activated Carbon HRO 4x10 Mesh

Other Means of Identification

Activated granular carbon, activated powdered carbon, pelleted activated carbon, activated charcoal animal bone black.

Product Use and Restrictions on Use

Water purfication, gold recovery and air scrubbing

Initial Supplier Identifier

ClearTech Industries Inc
1500 Quebec Avenue
Saskatoon, SK. Canada
S7K 1V7

Phone: 800.387.7503
Fax: 888.281.8109
www.cleartech.ca

Prepared By

ClearTech Industries Inc. technical writer

24-Hour Emergency Phone

306.664.2522

Section 02 Hazard Identification

GHS-Classification

This product has been assessed in accordance with the Hazardous Products Regulations and is not classified as a hazardous substance or mixture.

Hazards Not Otherwise Classified

May ignite if dispersed in air.

Supplemental Information

Not available

Section 03 Composition / Information on Ingredients

Ingredients:

Chemical name	Common name(s)	CAS number	Concentration (w/w%)
Carbon	Coal, charcoal	7440-44-0	>99%

Section 04 First-Aid Measures

Description of necessary first-aid measures

Inhalation Get medical advice / attention if you feel unwell or are concerned.

Ingestion Get medical advice / attention if you feel unwell or are concerned.

Skin contact Rinse skin with lukewarm, gently flowing water / shower for 5 minutes or until product is removed. If skin irritation occurs or if you feel unwell: Get medical advice / attention.

Eye contact Gently brush product off face. Do not rub eyes. Let the eyes water naturally for a few minutes. Look right and left, then up and down. If particle / dust does not come out, cautiously rinse eye with lukewarm gently flowing water for 5 minutes or until particle / dust is removed, while holding the eyelids open. If eye irritation persists: Get medical advice / attention. Do not attempt to manually remove anything from the eyes.

Most important symptoms and effects, both acute and delayed

Inhalation May cause respiratory irritation.

Ingestion May cause discomfort or nausea.

Skin contact Not available

Eye contact May cause eye irritation and redness.

Further information For further information see Section 11 Toxicological Information.

Section 05 Fire Fighting Measures

Suitable extinguishing media Extinguish fire using extinguishing agents suitable for the surrounding fire.

Unsuitable extinguishing media Water jets are not recommended in fires involving chemicals.

Specific hazards arising from the chemical In the event of a fire oxides of carbon may be released. Dust from this product may ignite. After a fire this product can smolder for a long time.

Special protective equipment for fire-fighters Wear NIOSH-approved self-contained breathing apparatus and protective clothing.

Section 06 Accidental Release Measures

Personal Precautions / Protective Equipment / Emergency Procedures Wear appropriate personal protective equipment (See Section 08 Exposure Controls and Personal Protection). Stay upwind, ventilate area.

Environmental Precautions Prevent material from entering waterways, sewers or confined spaces. Notify local health and wildlife officials. Notify operators of nearby water intakes.

Methods and Materials for Containment and Cleaning Up Dry sweeping is not recommended. Pre-damping the material or use of a vacuum is preferred. Shovel into clean, dry, labeled containers and cover. Flush area with water.

Section 07 Handling and Storage

Precautions for Safe Handling	Use proper equipment for lifting and transporting all containers. Use sensible industrial hygiene and housekeeping practices. Wash thoroughly after handling. Avoid all situations that could lead to harmful exposure. Inspect containers for damage or leaks before handling. If the original label is damaged or missing replace with a workplace label. Have suitable emergency equipment for fires, spills and leaks readily available.
Conditions for Safe Storage	Store in a cool, dry, well-ventilated area, away from heat sources and incompatible materials. Always store in original labeled container. Keep containers tightly closed when not in use and when empty. Protect label and keep it visible.
Incompatibilities	Oxidizing agents, such as oxygen, hydrogen peroxide, sulphuric and nitric acids, hypochlorites and permanganates. Solvents

Section 08 Exposure Controls and Personal Protection

Exposure limits

There are no known exposure limits for this product.

Engineering controls

Ventilation Requirements	Mechanical ventilation (dilution or local exhaust), process or personnel enclosure and control of process conditions should be provided in accordance with all fire codes and regulatory requirements. Supply sufficient replacement air to make up for air removed by exhaust systems.
Other	No specific recommendations beyond the required hygiene facilities at the place of work.

Protective equipment

The following are recommendations only. It is the responsibility of the employer / user to conduct a hazard assessment of the process in which this product being used and determine the proper engineering controls and PPE for their process. Additional regulatory and safety information should be sought from local authorities and, if needed, a professional industrial hygienist.

Eye and face protection	Where there is potential eye or face exposure, safety glasses are recommended. Contact lenses are not recommended; they may contribute to severe eye injury.
Hand and body protection	Where handling this product it is recommended that skin contact is avoided.
Respiratory protection	In case of insufficient ventilation wear suitable respiratory equipment.
Thermal hazards	Not available

Section 09 Physical and Chemical Properties

Appearance

Physical state	Solid (various states)
Colour	Black
Odour	Odourless
Odour threshold	Not applicable

Property

pH	Not available
Melting point / freezing point	Sublimes >4,000 °C
Initial boiling point and boiling range	Sublimes >4,000 °C

Flash point	Not applicable
Evaporation rate	Not available
Flammability	Flammable
Upper flammable limit	Not applicable
Lower flammable limit	Not applicable
Vapour pressure	<1 mm of Hg
Vapour density	Not available
Relative density	200-700 kg/m³
Solubility	Not soluble in water
Partition coefficient: n-octanol/water	Not available
Auto-ignition temperature	452-518 °C
Decomposition temperature	Not available
Viscosity	Not applicable
Specific gravity	Not applicable
Particle characteristics	Particle size: Not available Particle shape: Not available

Section 10 Stability and Reactivity

Reactivity	Not available
Stability	This product is stable if stored according to the recommendations in Section 07.
Possibility of hazardous reactions	Not available
Conditions to avoid	Avoid contact with incompatible materials. Do not heat.
Incompatible materials	Oxidizing agents, such as oxygen, hydrogen peroxide, sulphuric and nitric acids, hypochlorites and permanganates. Solvents
Hazardous decomposition products	Thermal decomposition may produce oxides of carbon.

Section 11 Toxicological Information

Acute Toxicity (LD50 / LC50 values)

Component	Route	Species	Value	Exposure time
Carbon	Oral	Rat	>10,000 mg/kg bw	
	Inhalation	Rat	>64.4 mg/l	

Toxic Health Effect Summary

Chemical characteristics	No known effects
Skin	Tested negative for skin irritation
Ingestion	May cause vomitting.
Inhalation	May cause mild irritation
Eye contact	Scored below 1 for OECD guidline 405 on corneal opacity, iritis, conjunctival redness, and conjunctival oedema.

Sensitization	This product and its components at their listed concentration have no known sensitizing effects.
Mutagenicity	This product and its components at their listed concentration have no known mutagenic effects.
Carcinogenicity	This product and its components at their listed concentration have no known carcinogenic effects.
Reproductive toxicity	This product and its components at their listed concentration have no known reproductive effects.
Specific organ toxicity	This product and its components at their listed concentration have no known effects on specific organs.
Aspiration hazard	Aspiration may cause pulmonary edema.
Synergistic materials	Not available

Section 12 Ecological Information

Ecotoxicity

there is no available toxicity data for this product.

Biodegradability	The domestic substance list categorizes carbon as persistent.
Bioaccumulation	The domestic substance list categorizes carbon as non-bioaccumulative.
Mobility	Not water soluble.
Other adverse effects	May absorb disolved oxygen from water.

Section 13 Disposal Considerations

Waste From Residues / Unused Products	Dispose in accordance with all federal, provincial, and local regulations including the Canadian Environmental Protection Act.
Contaminated Packaging	Do not remove label, follow label warnings even after the container is empty. Empty containers should be recycled or disposed of at an approved waste handling facility.

Section 14 Transport Information

UN number	UN1362 (See additional information)
UN proper shipping name and description	CARBON, ACTIVATED
Transport hazard class(es)	4.2
Packing group	III
Excepted quantities	0
Environmental hazards	Not listed as a marine pollutant under Canadian TDG Regulations, schedule III.
Special precautions	No special provisions
Transport in bulk	ERAP index: not available MARPOL 73/78 and IBC Code: This product is not listed in Chapter 17 of the IBC Code.
Additional information	TDG regulations do not apply to charcoal or carbons that are carbons made by steam activation process [1.48 (c) (iii)] Secure containers (full or empty) during shipment and ensure all caps, valves, or closures are secured in the closed position.

TDG PRODUCT CLASSIFICATION: This product has been classified on the preparation date specified at section 16 of this SDS, for transportation in accordance with the requirements of part 2 of the Transportation of Dangerous Goods Regulations. If applicable, testing and published test data regarding the classification of this product are listed in the references at section 16 of this SDS.

Section 15 Regulatory Information.

NOTE: THE PRODUCT LISTED ON THIS SAFETY DATA SHEET HAS BEEN CLASSIFIED IN ACCORDANCE WITH THE HAZARD CRITERIA OF THE CANADIAN HAZARDOUS PRODUCTS REGULATIONS. THIS SAFETY DATA SHEET CONTAINS ALL INFORMATION REQUIRED BY THOSE REGULATIONS.

All components of this product appear on the domestic substance list.

Section 16 Other Information

Date of latest revision: August 24, 2021

Note: The responsibility to provide a safe workplace remains with the buyer / user. The buyer / user should consider the health hazards and safety information contained herein as a guide and should take those precautions required in an individual operation to instruct employees and develop work practice procedures for a safe work environment. The information contained herein is, to the best of our knowledge and belief, accurate. However, since the conditions of handling and use are beyond our control, we make no guarantee of results, and assume no liability for damages incurred by the use of this material. It is the responsibility of the buyer / user to comply with all applicable laws and regulations regarding handling, using, reselling and shipping this product.

Attention: Receiver of the chemical goods / SDS coordinator

As part of our commitment to the RDC Responsible Distribution® initiative, ClearTech Industries Inc. and its associated companies require, as a condition of sale, that you forward the attached Safety Data Sheet(s) to all affected employees, customers, and end-users. ClearTech will send any available supplementary handling, health, and safety information to you at your request.

If you have any questions or concerns please call our customer service center.

References:

1) CHEMINFO
2) TOXNET
3) eChemPortal
4) ECHA
5) Transportation of Dangerous Goods Canada
6) HSDB
7) PAN

Scientific Committee on Consumer Safety

SCCS

SCIENTIFIC ADVICE

on the safety of nanomaterials in cosmetics

The SCCS adopted this Advice
by written procedure on 8 January 2021

Corrigendum of 8 March 2021

ACKNOWLEDGMENTS

Members of the Working Group are acknowledged for their valuable contribution to this Advice. The members of the Working Group are:

The SCCS members:
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Dr L. Bodin
Prof. Q. Chaudhry (Rapporteur)
Prof. P.J. Coenraads
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This Advice has been subject to a commenting period of the minimum four weeks after its initial publication due to legislative constraints (from 5 October until 2 November 2020). Comments received during this period were considered by the SCCS. The final version has been amended.

Corrigendum was done in the table of Annex I. Column 4 (Already assessed by the SCCS?) was updated with the SCCS opinion numbers.

1. ABSTRACT

The SCCS concludes the following:

1. *The SCCS is requested to determine the nanomaterials, as published in the recent catalogue of nanomaterials of 2019, for which specific concerns can be identified and justified in order to establish a priority list of nanomaterials for risk assessment (Article 16(4) Reg.1223/2009). More specifically, the SCCS is requested to provide a description of the specific concerns that have been identified for the nanomaterials mentioned above. This process should be based on the currently available scientific literature and SCCS' expert judgement.**

Through a review of the available information and expert judgment, the SCCS has identified certain aspects of nanomaterials that constitute a basis for concern over safety to consumers' health when used in cosmetic products. These include:

- Physicochemical aspects relating to: very small dimensions of the constituent particles; solubility/persistence; chemical nature and toxicity of the nanomaterial; physical/morphological features of the constituent particles; surface chemistry and surface characteristics (surface modifications/coatings);
- Exposure aspects relating to: the frequency and the amounts used, whether the number/type of consumer product(s) used is relatively high; and whether there is a potential for systemic exposure of the consumer to nanoparticles and potential accumulation in the body;
- Other aspects relating to: novel properties, activity or function, and specific concern arising from the type of application.

A detailed account of these aspects has been presented in this Advice. Also, the nanomaterials listed in the EC catalogue of nanomaterials of 2019 have been tabulated in an order of priority according to risk potential in Annex 1 of this Advice.

2. *For the nanomaterials with inconclusive SCCS opinions, such as [Colloidal Silver (nano) (SCCS/1596/18), Styrene/Acrylates copolymer (nano) + Sodium styrene/Acrylates copolymer (nano) (SCCS/1595/18) and Silica, Hydrated Silica, and Silica Surface Modified with Alkyl Silylates (nano form) (SCCS/1545/15)], the SCCS is requested to assess if a potential risk can be identified according to Article 16(6) Reg. 1223/2009. Such assessment, regardless of the data previously submitted by the respective applicants, should be based on the available scientific literature and SCCS' expert judgement (i.e. systemic or local availability; harmful effects specifically related to nano-form; surface catalysed reactions in nano-form, absorption (or potential absorption) from dermal and inhalation routes, potential of nano-form to deliver ionic forms, etc.).**

The SCCS has reviewed previous inconclusive opinions on three nanomaterials (SCCS/1596/18; SCCS/1595/18 and SCCS/1545/15), in conjunction with any further relevant information available in published literature to identify whether there is a scientific basis for concern over their safety to consumers' health when used in cosmetic products. The SCCS has identified certain aspects relating to each of the nanomaterials that raise a safety concern. These have been detailed in three separate annexes (2, 3 and 4) to this Advice.

* In the assessment of the above question and in order to avoid conflicting opinions with other bodies, SCCS is invited to consult SCHEER.

Keywords: SCCS, scientific advice, safety, nanomaterials, Regulation 1223/2009

The Scientific Advice to be cited as: SCCS (Scientific Committee on Consumer Safety), Scientific advice on the safety of nanomaterials in cosmetics, preliminary version of 6 October 2020, final version of 8 January 2021, SCCS/1618/20, Corrigendum of 8 March 2021

About the Scientific Committees

Two independent non-food Scientific Committees provide the Commission with the scientific advice it needs when preparing policy and proposals relating to consumer safety, public health and the environment. The Committees also draw the Commission's attention to the new or emerging problems which may pose an actual or potential threat.
They are: the Scientific Committee on Consumer Safety (SCCS) and the Scientific Committee on Health, Environmental and Emerging Risks (SCHEER) and are made up of scientists appointed in their personal capacity.

In addition, the Commission relies upon the work of the European Food Safety Authority (EFSA), the European Medicines Agency (EMA), the European Centre for Disease Prevention and Control (ECDC) and the European Chemicals Agency (ECHA).

SCCS

The Committee shall provide Opinions on questions concerning all types of health and safety risks (notably chemical, biological, mechanical and other physical risks) of non-food consumer products (for example: cosmetic products and their ingredients, toys, textiles, clothing, personal care and household products such as detergents, etc.) and services (for example: tattooing, artificial sun tanning, etc.).

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2. MANDATE FROM THE EUROPEAN COMMISSION

Background

Establishing the concerns

Article 16(4) of the Cosmetics Regulation provides that '*In the event that the Commission has **concerns** regarding the safety of a nanomaterial, the Commission shall, without delay, request the SCCS to give its opinion on the safety of such nanomaterial for use in the relevant categories of cosmetic products and on the reasonably foreseeable exposure conditions*'.

Thus far, the '*concerns*' of the Commission that gave origin to previous mandates to SCCS have been based on the intrinsic properties of nanomaterials, as a category, in light notably of their nano-scale dimension, bio-persistence and insolubility.

Establishing potential risk to human health

According to the Cosmetics Regulation, once a risk assessment for a nanomaterial has been performed, the Commission shall proceed with risk management measures provided that the risk assessment has established the presence of a potential risk to human health.

In this respect, Article 16(6) of the Cosmetics Regulation states that '*taking into account the opinion of the SCCS, and where there is a **potential risk to human health**, including when there is insufficient data, the Commission may amend Annexes II and III*'. The risk of having '*insufficient data*' materialised in the recent experience with the inconclusive SCCS opinions on nanomaterials (as notified through CPNP)[1]. In these cases, due to the lack of relevant information from the applicants both in the original notifications and in the additional information requested by the SCCS the '*potential risk to human health*' could not be established nor excluded by SCCS.

In the cases mentioned above, even if the '*insufficient data*' provision is fulfilled, the '*potential risk to human health*' is not fully established and the Commission is not in a position to take potential regulatory measures, in accordance with Article 16(6) of the Cosmetics Regulation.

The general principle of precaution allows the adoption of restrictive measures even when it is not possible to determine with certainty the existence and/or extent of an alleged risk, but the likelihood of a real harm persists should the risk materialise. Consequently, even if conclusive evidence is not required, the risk addressed by the measure shall be more than hypothetical and based on a scientific risk assessment as thorough as possible.

Therefore, a key question is to determine the minimum level of '*potential risk*', which could justify a restrictive regulatory measure for those substances with inconclusive opinions issued. In view of the current situation, the Commission considers that, regardless of the data submitted by the applicants, evidence in scientific literature could be used to assess if a '*potential risk*' to human health can, nevertheless, be identified and can reasonably justify the adoption of regulatory measures in accordance with Article 16(6) of the Cosmetics Regulation.

[1] Colloidal Silver (nano) (SCCS/1596/18), Styrene/Acrylates copolymer (nano) + Sodium styrene/Acrylates copolymer (nano) (SCCS/1595/18) and Silica, Hydrated Silica, and Silica Surface Modified with Alkyl Silylates (nano form) (SCCS/1545/15).

Such evidence at the level of substances or group of substances may include, but are not limited to the following:

- systemic or local availability;
- harmful effects specifically related to nano-form;
- surface catalysed reactions in nano-form;
- absorption (or potential absorption) from dermal and inhalation routes;
- potential of nano-form to deliver ionic forms.

Terms of reference

1. *The SCCS is requested to determine the nanomaterials, as published in the recent catalogue of nanomaterials of 2019, for which specific concerns can be identified and justified in order to establish a priority list of nanomaterials for risk assessment (Article 16(4) Reg.1223/2009). More specifically, the SCCS is requested to provide a description of the specific concerns that have been identified for the nanomaterials mentioned above. This process should be based on the currently available scientific literature and SCCS' expert judgement.**

2. *For the nanomaterials with inconclusive SCCS opinions, such as [Colloidal Silver (nano) (SCCS/1596/18), Styrene/Acrylates copolymer (nano) + Sodium styrene/Acrylates copolymer (nano) (SCCS/1595/18) and Silica, Hydrated Silica, and Silica Surface Modified with Alkyl Silylates (nano form) (SCCS/1545/15)], the SCCS is requested to assess if a potential risk can be identified according to Article 16(6) Reg.1223/2009. Such assessment, regardless of the data previously submitted by the respective applicants, should be based on the available scientific literature and SCCS' expert judgement (i.e. systemic or local availability; harmful effects specifically related to nano-form; surface catalysed reactions in nano-form, absorption (or potential absorption) from dermal and inhalation routes, potential of nano-form to deliver ionic forms, etc.).**

* In the assessment of the above question and in order to avoid conflicting opinions with other bodies, SCCS is invited to consult SCHEER.

3. SCIENTIFIC ADVICE

PREAMBLE

The very small size and other particle features of nanomaterials may confer certain distinctive characteristics to these materials compared to conventional forms. It was noted at early stages of the development and application of nanomaterials that the same nano-scale features, that make them desirable for a wide range of industrial and consumer applications, may also render them harmful for human health and/or the environment. Whilst the science of safety assessment of nanomaterials is still evolving, and there are several knowledge gaps, a number of characteristics have been identified as important in relation to the distinctive properties, behaviour and toxicological effects of nanomaterials. Since the use of any nanomaterial in a cosmetic product could potentially raise a concern over safety of the consumer, it is important to rationalise such concerns and identify the nanomaterials that require priority attention for safety assessment. In this regard, this Advice has briefly highlighted those key general aspects of nanomaterials that should raise a safety concern for a safety assessor/manager, so that the nanomaterial(s) in question could be subjected to appropriate safety assessment in the context of use in cosmetics to establish safety to the consumer.

It is worth noting that this Advice is not meant to provide a detailed review of literature, or a guidance on safety of nanomaterials, or a safety assessment of any specific nanomaterial. These aspects have been adequately covered elsewhere, and this Advice should be read in conjunction with the SCCS Guidance on nanomaterials (SCCS/1611/19), and the SCCS Opinions on the safety of nanomaterials that have been assessed so far[2].

As part of the approach used in this Advice, a scoring system has been used to assign a notional score to each nanomaterial listed in the EC catalogue to indicate the level of concern, and listed in a descending order of the scores so that the nanomaterials requiring priority attention for safety assessment could be identified. As such, the scoring system is also not an alternative to safety assessment, and has only been used to prioritise nanomaterials for a subsequent evidence-based safety assessment.

In order to address the mandated questions from the Commission, the SCCS has also revisited three of the previous opinions on nanomaterials that were inconclusive. This Advice has highlighted the basis for the concerns over the safety of these nanomaterials (Annexes 2-4) that merit further assessment.

[2] SCCS/1518/13 Addendum to the opinion SCCS/1489/12 on zinc oxide (nano); SCCS/1516/13 on titanium dioxide (nano); SCCS/1515/13 on carbon black (nano); SCCS/1566/15 on hydroxyapatite (nano); SCCS/1545/15 on silica, hydrated silica, and silica surface modified with alkyl silylates (nano); SCCS/1546/15 on 2,2'-methylene-bis-(6-(2H-benzotriazol-2-yl)-4-(1,1,3,3-tetramethylbutyl)phenol)(nano); SCCS/1580/16 on titanium dioxide (nano) coated with cetyl phosphate, manganese dioxide or triethoxycaprylylsilane as UV-filter in dermally applied cosmetic; SCCS/1583/17 on titanium dioxide (nano) as UV-filter in sprays; SCCS/1596/18 on colloidal Silver (nano); SCCS/1595/18 on styrene/acrylates copolymer (nano) and sodium styrene/acrylates copolymer (nano); SCCS/1606/19 on solubility of synthetic amorphous silica; SCCS/1624/20 Preliminary Opinion on hydroxyapatite (nano); SCCS/1621/20 Preliminary Opinion on copper (nano) and colloidal copper (nano)

3.1 DISCUSSION

3.1.1 PHYSICOCHEMICAL ASPECTS

3.1.1.2 VERY SMALL DIMENSIONS OF CONSTITUENT PARTICLES

The single common denominator amongst the vast array of nanomaterials is that they all have constituent particles in the size range of ≤100 nm in one or more dimensions. It has been known since 1950s that properties of particulate materials may change when they are manufactured at very small size dimensions (Feynman, 1959). It is also known that rules governing physicochemical properties of conventional (bulk) substances generally do not apply well to the same materials when they are in nano form (SCENIHR, 2010). However, although reducing the particle size may confer some fundamental shifts in the physicochemical properties of the materials, the nanoscale itself should not be considered as a threshold for such a phenomenon because, depending on the type of material, such changes may occur in a continuum over a wider range of particle sizes (SCENIHR, 2010).

Where lowering the particle size leads to changes in the physicochemical properties of a material, it could also lead to changes in the biokinetic behaviour, biological interactions and effects, compared to the bulk equivalents. For example, quantum effects are known to dominate on the properties of nanoparticles, especially when they are in the lower nm size range. It has been suggested that most physicochemical changes in inorganic nanoparticles occur at sizes around or below 30 nm (Auffan *et al.*, 2009a).

Another size-related aspect emanating from several studies relates to the ability of nano-sized particles to cross biological membrane barriers that protect vital organs from the entry of insoluble particles - e.g. cellular barrier, gastrointestinal barrier, blood-brain barrier, placental barrier (SCENIHR 2007, 2009). This means that nanoparticles can potentially enter those parts of the body, where larger-sized particles could not have reached. Nanoparticles are also claimed to have a greater uptake, absorption and bioavailability in the body compared to bulk equivalents (SCENIHR, 2007). For example, nano-sized carriers have been used for enhancing the delivery of nutrients and other substances in food supplements, nutraceuticals, cosmeceuticals and health-food products (e.g. Joye *et al*., 2014; EFSA Guidance, 2018).

The ability of nanoparticles to cross biological membranes and enter cells and tissues is an important factor for all toxicity endpoints, and more so for genotoxicity. The uptake of nanoparticles to the cellular nucleus appears to be more likely for smaller sized nanoparticles (Dawson *et al*., 2009; Kang *et al*., 2010; Wu *et al*., 2019). However, nanoparticles may also enter the nucleus during cell division (mitosis). It is an important consideration for understanding the mechanism of genotoxicity to establish whether it is due to direct contact and interaction of the particles with the genetic material, or through an indirect mechanism, e.g. via oxidative stress. In this regard, the cellular uptake of nanoparticles is not only influenced by the particle size but also by other features such as charge, surface properties, etc.

The very small size of the constituent particles also leads to a huge increase in ratio between surface area and volume of a nanomaterial, compared to conventional (bulk) form. Thus, on a weight per weight basis, surface reactivity of a nanomaterial can potentially be much greater than its conventional bulk equivalent. Particles at the nano-scale are also known to have large free energy at the surface (Simon and Joner, 2008). This not only increases the chances of agglomeration of nanoparticles, but may also lead other substances to bind to particle surfaces. The latter raises the possibility that nanoparticles may 'transport' other potentially harmful substances adsorbed on their surfaces into cells

and tissues – a phenomenon termed as 'Trojan horse' effect (EFSA Guidance, 2018). Such alterations in physicochemical properties and biokinetic behaviour may also result in changes in the interaction of a nanomaterial with its known biological target, or with a different target, that could lead to adverse effects, compared to bulk form of the same material.

The current scientific knowledge indicates that particulate materials composed or comprised of small particles may differ from conventional (bulk) form of the same materials in terms of certain physicochemical properties. For example, they may have much greater surface reactivity due to increased surface areas. Particles in the nanoscale (≤100 nm in one or more dimension), may also have a different biokinetic behaviour and may reach those organs that are normally protected from entry of the particles by membrane barriers. Such changes in physicochemical properties and biokinetic behaviour may lead to toxicological effects that are either atypical, or manifest in unexpected organs, compared to conventional (bulk) form of the same material. Therefore, composition of a particulate material in or around nanoscale should raise the trigger for a risk assessor in the first place to further evaluate safety data in consideration of the nano-scale properties of materials.

As a general rule, the lower the size of a nanoparticle is within the nano-scale, the higher the concern should be for its safety to the consumer health.

3.1.1.3 SOLUBILITY/PERSISTENCE/POTENTIAL ACCUMULATION IN THE BODY

A crucial aspect to consider when assessing the potential risk of nanomaterials is that they are composed or comprised of particles in the nanoscale. Any particle size related change in a material's properties, behaviour, or toxicity can only be expected with the existence of such a particle configuration. Where a nanomaterial loses particulate composition, e.g. due to immediate particle dissolution/breakdown, its subsequent risk will not be different from conventional form, and risk assessment for the dissolved chemical form is generally sufficient.

For partially or slowly dissolving nanomaterials, however, the risk of both the particles and the dissolved substance needs to be considered. The dissolution rate in relevant media can provide information on the forms and speciation in the nanomaterial, as well as toxicokinetics when it comes into contact with relevant areas of the human body (Dekkers *et al.*, 2016). This may also result in the particles delivering a relatively higher concentration of the solubilised material in certain organs, which would not occur if the material was fully solubilised. Thus, solubility and dissolution rate of a nanomaterial are important criteria that can help establish whether there is the likelihood of exposure to insoluble, biopersistent nanoparticles.

Due to the very small size, insoluble/poorly soluble and persistent particle nature, and potentially reactive particle surfaces, the interaction of nanoparticles with biological entities may take place close to the molecular level. Unlike conventional dissolved substances, the absorption and biokinetics of insoluble particles is not driven by a concentration gradient. Instead, nanoparticles are generally actively removed from systemic circulation by phagocytising cells of the mononuclear phagocytic system (MPS), and thus mainly end up in liver and spleen – the organs rich in phagocytic cells (De Jong *et al.*, 2013; Geraets *et al.*, 2014; Lankveld *et al.*, 2010; Lankveld *et al.*, 2011; Yuan *et al.*, 2019). Also, nanoparticles may be absorbed via different exposure routes (oral, dermal, inhalation) and their adverse effects may be at local and/or systemic levels. If elimination of nanoparticles from the body is limited, they may also accumulate in the body over time. As an example, the distribution

and accumulation of nano-iron can be different from that of non-nano-iron, which can result in altered toxicity (Brand *et al.*, 2017; Alphandery, 2019).

Solubility and dissolution rate of a nanomaterial in relevant media are important criteria for deciding whether a risk assessment carried out for the conventional chemical form would be sufficient, or whether it poses the risk of exposure to insoluble/poorly-soluble and persistent nanoparticles. In the latter case, consideration of the data on toxicokinetics becomes essential for risk assessment.

As a general rule, the lower the solubility and dissolution rate of a nanomaterial are, the higher the need should be for scrutiny of its safety to the consumer health.

3.1.1.4 CHEMICAL NATURE AND TOXICITY OF THE NANOMATERIAL

The chemical nature of nanomaterials can be as diverse as that of conventional chemicals, and they may comprise inorganic, organic, or composite/hybrid substances. It is therefore important that chemical nature of the substance(s) constituting a nanomaterial is also taken into consideration in safety assessment for any inherent toxicological hazard of the constituting chemical(s). The chemical nature of a nanomaterial is also important in considering the form of any ions/molecules that may be released as a result of particle dissolution/disintegration. The information on the potential toxicity of chemical components of a nanomaterial is generally obtained by searching different databases; for example, Risctox (https://risctox.istas.net/en/); ECHA database for REACH registered substances (https://echa.europa.eu/information-on-chemicals/registered-substances); TOXNET database (available as part of ChemIDPlus: https://chem.nlm.nih.gov/chemidplus/). A database of nanomaterial safety (eNanoMapper: https://data.enanomapper.net/) is also available that may provide relevant toxicity information on some of the already tested nanomaterials.

As discussed before, the properties/effects of nanomaterials are driven both by chemical nature and physical form of the constituent particles. The information on chemical toxicity therefore needs to be combined with any physical characteristics of the particles that may lead to a different biological outcome (e.g. toxicokinetics). It is also possible that the chemical nature of each of the components that make up a nanomaterial is safe individually, but may pose a hazard when put together in the form of a nanoparticle as such, or cause indirect effects by delivering the components to unintended places in the body.

It has been suggested that chemically stable metallic nanoparticles have no significant cellular toxicity, whereas nanoparticles that are able to undergo oxidation, reduction or dissolution can be cytotoxic and even genotoxic for cellular organisms (Auffan *et al.*, 2009b).

In regard to the potential toxicity of a nanomaterial, a particular focus is on identifying whether or not the nanomaterial or the constituting chemical(s) have CMR (carcinogen, mutagen or reproductive toxicant) properties. A nanomaterial should be assigned the highest priority for a further follow up for safety assessment if there are indications of potential CMR property from either chemical composition or the available data on the nanomaterial.

Especially when toxicity is evaluated in *in vitro* test systems specific considerations apply. One issue may be whether the tests had been carried out ensuring good stability of the test suspension and exposure of the test system to nanoparticles is established. Interactions of the nanomaterial with test media/environment can also pose problems when testing nanomaterials *in vitro* because potential interaction with the test systems may lead to

unreliable outcomes (Kroll *et al.*, 2012; Guadagnini *et al.*, 2015). The presence of the particles alone could be a source for interference with readout systems that use an optical method (e.g. light scattering and absorbance). In addition, nanomaterials may interfere and/or react with assay components. For example, colorimetric assays may be prone to interference due to the interaction between the dye and nanoparticles, and washout of the nanomaterials can be difficult due to such interactions (Guadagnini *et al.* 2015, Dusinska *et al.*, 2015). Guadagnini *et al.* (2015) showed that many nanoparticle characteristics (composition, size, coatings, and agglomeration) can interfere with a range of *in vitro* cytotoxicity assays (WST-1, MTT, LDH, neutral red, propidium iodide, 3H-thymidine incorporation, and cell counting), proinflammatory response evaluation (ELISA for GM-CSF, IL-6, and IL-8), and oxidative stress detection (monoBromoBimane, dichlorofluorescein, and NO assays). The interferences were found to be specific for both the assays, as well as the type of nanoparticle.

In vitro systems, generally used for testing conventional chemicals, may not be applicable to test nanomaterials, or may need to be modified for the purpose. For example, *in vitro* genotoxicity data are not acceptable if derived from AMES test, because nanoparticle uptake is not likely to take place in bacteria. Similarly, the timing of administration of cytokinesis blocking agent (cytochalasine B) is critical in the micronucleus test using the cytokinesis-blocked micronucleus (CBMN) method because as it can also block the cellular uptake of nanoparticles.

Data on chemical composition provide another trigger for safety concern to establish whether the constituent chemical(s) pose a toxicological hazard, either individually or when in the form of a nanomaterial. The toxicity data need to be assessed with consideration of the chemical nature as well as the potential changes in properties of the particles at the nano-scale. Testing of nanomaterials also needs to take into consideration the limitations of certain test methods and the potential interaction of nanoparticles with assay components or the test systems.

As a general rule, where chemical component(s) are toxic, as such or when put together in the form of a nanomaterial, they should constitute a trigger for concern over safety to the consumer health.

3.1.1.5 PHYSICAL/MORPHOLOGICAL FEATURES OF THE CONSTITUENT PARTICLES

Nanomaterials may be comprised of, or contain, free nanoparticles and/or larger-sized agglomerates and aggregates. Depending on the type of application, a nanomaterial may be present in the final product in the form of free nanoparticles, and/or larger sized clusters of particles. In the aggregated form, constituent particles are strongly bound together and are therefore not likely disaggregate under normal condition. Compared to this, the constituent particles are only held together by weak van der Waals forces in agglomerates, and may de-agglomerate under certain conditions of pH, ionic strength, etc. Therefore, nanomaterials that are composed of free nanoparticles or agglomerates (and nano-sized aggregates) are of more concern for safety than the same materials in which particles are present in the form of larger-sized aggregates.

Among the nanomaterial-containing products, those that can lead to inhalation exposure of nanoparticles are considered as being of the highest risk because particulate materials generally tend to induce more harm to the respiratory system (Donaldson and Seaton 2012). Among these, needle, tube and fibre shaped nanomaterials pose an even more severe risk due to the particular morphologies. Certain fibre characteristics like fibre length, rigidity and lack of degradation can result in the induction of inflammatory processes similar to those induced by asbestos (Donaldson *et al.* 2010).

It has been shown for carbon nanotubes, (CNT) that mechanistically, a number of mediators, signalling pathways, and cellular processes can be identified as major mechanisms that underlie the interplay among inflammation, fibrosis, and malignancy, and serve as pathogenic basis for such diseases in CNT-exposed animals. This also raises concern for similar disease conditions in humans (Dong and Ma, 2019).

Depending on the conditions during manufacturing, processing and handling, nanoparticles may exist in different physical and morphological forms in a nanomaterial. As a general rule, safety concerns should increase in the order from larger sized aggregates<agglomerates<free-nanoparticles. Also, certain morphological forms should raise more safety concerns than the others (e.g. needle shape, rigid long fibres, etc).

3.1.1.6 SURFACE CHEMISTRY

Due to the relatively large surface-to-volume ratio, the reactivity of nanomaterials can be enhanced compared to non-nanomaterials. The reactivity of such enlarged surfaces inside living cells may interfere with biological processes and trigger, for example, the generation of reactive oxygen species (ROS), which could lead to oxidative stress and inflammatory outcomes in biological tissues.

The surface redox state of metal oxide nanomaterials was considered relevant for induction of *in vitro* cytotoxicity. Nanomaterials with an overlap of conduction band energy (Ec) levels with the cellular redox potential were found to be cytotoxic while nanomaterials with a redox potential outside this level were less toxic (Zhang *et al.* 2012). The toxicity was ascribed to the induction of oxidative stress in the cells.

Nanomaterial surface chemistry has significant effect on interactions at the nano-bio interface, with important toxicological consequences. Recent data has shown complexity in the dynamic relationship between the composition of the biological environment and the physico-chemical properties of the nanomaterials (Lundqvist *et al*., 2008, Walkey *et al*, 2012, Wang *et al*., 2013; Yallapu *et al*., 2015, Lynch *et al*., 2015; Khan *et al*., 2020). Physiological environments, such as blood, interstitial fluid, and cellular cytoplasm, contain complex protein mixtures. When nanoparticles enter the physiological environment, they adsorb proteins to form protein corona (Cedervall *et al*., 2007a, b; Lundqvist *et al*., 2008). The protein corona that forms around nanoparticles alters the physicochemical properties of nanoparticles (Glancy *et al*., 2019; Marichal *et al*., 2019, Khan *et al*., 2020), and is a critical factor that affects their physiological response, influences the interactions between nanoparticles and biological systems and modulates the kinetics, transport, and reactivity of nanoparticles (Monopoli *et al*., 2011; Walkey *et al*., 2012; Clemments *et al*., 2017; Pallardy *et al*., 2017; Cai *et al*., 2020).

Surface characteristics of nanoparticles determine the reactivity of a nanomaterial, such as (photo)catalytic activity, potential for radical formation, biokinetic behaviour, and potential transport of other substances into the systemic circulation. Surface chemistry is a vital component which impacts the corona composition and subsequent distribution, uptake, toxicity and clearance of nanomaterials. These should be considered in conjunction with other confounding factors in safety assessment.

3.1.1.7 SURFACE CHARACTERISTICS (SURFACE MODIFICATIONS/COATINGS)

Particle surfaces can be chemically/biochemically modified to suit a particular function or property for some applications. For example, nanoparticles may be made more hydrophobic or hydrophilic through surface modification. This could have a profound effect on the ADME properties (e.g. increasing or decreasing systemic bioavailability) than the same nanoparticles without surface modification. The systemic availability of nanoparticles with surface modified with a protein or peptide may have immunological effects.

Any surface modification of a nanomaterial needs to be considered carefully in regard to potential changes in the biokinetic behaviour of the nanoparticles, in conjunction with other confounding factors in safety assessment.

3.2 EXPOSURE ASPECTS

3.2.1 SYSTEMIC EXPOSURE OF THE CONSUMER TO NANOPARTICLES

As mentioned above, due to nano-scale dimensions, the ADME (absorption, distribution, metabolism, excretion) characteristics of nanoparticles may be different from bulk equivalents. As a result, systemic exposure of the consumer to nano-form of a material may be different compared to bulk form of the same material. As a general rule, exposure to particles with sizes in the lower range (1-30 nm) of the nano-scale increases the chances of systemic exposure. The exposure assessment for such particles also need to consider other confounding factors, such as coatings or other surface modifications, solubility and dissolution rate in the exposure vehicle and the biological phases.

The route of exposure to nanomaterials is equally important in risk assessment. Studies have indicated that exposure to nanomaterials via inhalation route carries a relatively greater potential for risk to human health. However, depending on the absorption of nanoparticles and systemic availability, exposure from other routes (oral, dermal) may also be of similar safety concern.

As a general rule, safety concerns should by higher for those nanomaterials (or nanomaterial applications) that may lead to systemic exposure of the consumer to nanoparticles.

3.3 OTHER ASPECTS

3.3.1 NOVEL PROPERTIES, ACTIVITY OR FUNCTION

Another aspect that could lead to safety concerns is that a nanomaterial may be smart/functionalised to have a novel property, activity, or function that was not present in conventional form of the same material. Also, it is possible a nanomaterial is designed in such a novel way that it does not have a conventional comparator for assessment of changes in the properties, activity or function.

Novel nanomaterials designed for a specific activity or function should trigger a concern for safety as the activity/function may lead to adverse outcomes in an unintended part of body due to the altered biokinetic behaviour of nanoparticles.

3.3.2 SPECIFIC CONCERN ARISING FROM THE TYPE OF APPLICATION

The type and frequency of application of a nanomaterial containing product may also raise a safety concern. For example, application of a nanomaterial in loose powder or sprayable products may pose a risk of inhalation of respirable particles into the respiratory tract and expose the consumer's lung. Similarly, there will be more safety concerns if nanomaterials are used in products that are more frequently used, used in relatively large amounts, or intended for use by certain more vulnerable people or young children.

Certain type of products containing nanomaterials, and those used more frequently, or used by more vulnerable consumers may further increase the concerns over safety of the consumer's health. Especially possibilities for inhalation exposure raise a serious concern.

3.4 OVERALL SUMMARY

In regard to the safety of nanomaterials, in the first place, the presence of small particles (in the nanometer range) in an ingredient should draw attention of the risk assessors/managers to look more closely to the information on physicochemical characterisation of the nanomaterial. In particular, the presence of any significant proportion of nano-sized particles in consumer products should raise the first alert for potential concerns over safety.

Although there are currently no hard and fast rules for working out the safety concerns for nanomaterials, as a general principle, each of the following attributes should add a further degree of safety concern. For example, where:

1. The nanomaterial has constituent particles that have sizes in the lower range of the nano-scale (1-100 nm),

2. The nanomaterial is insoluble, or only partially-soluble,
3. The chemical nature of the nanomaterial suggests the potential for a toxicological hazard,
4. The nanomaterial has certain physical/morphological features (e.g. needle shape, rigid long fibres) that point to potential for harmful effects,
5. The nanomaterial has surface reactivity in terms of catalytic (including photocatalytic) activity, potential for radical formation, or other surface properties (e.g. that can enhance cellular uptake, or confer allergenicity due to proteinaceous surface),
6. The nanomaterial has a different biokinetic behaviour than the conventional equivalent. For example, on the surface a modification/coating (e.g. hydrophobic coatings, encapsulation) has been applied to the core nanoparticles to alter their ADME properties and as a result make them more accessible systemically, compared to the neat nanoparticles and/or their conventional chemical forms,
7. The nanomaterial is used as vehicle to carry other substances - which have not been assessed for safety as individual components, or together in the nano-scale entity,
8. There is a likelihood of systemic exposure of the consumer to nanoparticles through the use of final products, that enhance absorption in the skin (skin penetration) by a surface modification,
9. The frequency of use, and/or the amounts of the consumer product are relatively high,
10. There is evidence for persistence/accumulation of nanoparticles in the body,
11. Nanoparticles have other distinctive properties not present in conventional form of the same material or a new activity/function (e.g. a smart/functional nanomaterial),
12. The nanomaterial is so novel that it does not have a conventional comparator to allow assessment of changes in properties, behaviour or effects,
13. The nanomaterial is used in a product that is inhalable (taken up by inhalation into respiratory tract and lung), and the particles are respirable (can reach respiratory epithelium i.e. alveoli),
14. The assessment of genotoxicity is inadequate, e.g. *in vitro* studies are without information on stability of the test suspension, or evidence of cell exposure (internalisation).

The different aspects discussed above provide a basis for safety concerns that may arise from each individual aspect of nanomaterials. However, the overall concern for consumer safety will be a combination of all the aspects that are relevant to a specific nanomaterial.

In this regard, there are no agreed rules on how to combine all the individual 'alerts' to obtain an overall concern for safety. This is where expert judgement has been used to prioritise nanomaterials for safety assessment. Recently, a relevant scoring system has been proposed by Brand *et al.* (2019) that combines consideration of the key aspects of nanomaterials that can trigger a 'signal' for risk, which when combined with expert judgment can help assign an arbitrary score for prioritisation on the basis of risk potential for human health. Table-1 below has been adapted from Brand *et al.* (2019) in view of the potential usefulness in identifying priority nanomaterials for further action regarding safety assessment.

It needs to be noted that the outcome of such a scoring system is not meant to be an alternative to evidence-based safety assessment, but to provide a means for prioritising nanomaterials so that they can be subjected to proper safety assessment.

Table 1. Scoring system with key questions to assess a selected signal for prioritisation on risk potential for human health (adapted from Brand *et al.*, 2019).

Descriptor	Question	Answer[a] *(score)*		
		Yes *(3)*	No *(0)*	? *(1)*
Physico-chemical properties[b] *(max 12 pts)*	Indication of low or no dissolution or degradation rate in physiologically relevant media?			
	Indication of reactivity? E.g. due to surface area, type of chemical, surface treatment.			
	Indication of release of toxic ions or molecules?			
	Indication that the nanomaterial is persistent and rigid, e.g. a High Aspect Ratio Nanoparticle (HARN)[c] ?			
Hazard *(max 12 pts)*	Is the chemical itself a substance of very high concern, relating to human health hazard[d] ?			
	Indication of mutagenicity/carcinogenicity (of the material)?			
	Indication of immunotoxicity (of the material)?			
	Indication of other toxicity (of the material)?			
Kinetics *(max 12 pts)*	Indication of absorption?			
	Indication of distribution to brain or reproductive organs?			
	Indication of accumulation in any tissue?			
	Indication of change in kinetic profile compared to non-nano situation?			
Exposure[e] *(max 12 pts)*	Products used or likely to be used much or in many products and/or by wide population?			
	Is exposure of sensitive subgroups anticipated? (e.g. babies or elderly people)			
	Is exposure likely to occur frequently (more than a few incidental times)?			
	Is there potential for nanomaterial exposure likely, based on the product use description?			
	Total marks	…	…	…
		x 3	x 0	x 1
	Sub-score	…	0	…
	[3]Total score		…	

The scoring system uses descriptors relating to physicochemical properties, hazard, (toxico)kinetics and exposure aspects of nanomaterials. Expert judgement is needed to answer the questions (yes, no or unknown) to assign a score (3, 0, or 1, respectively).

3[a] An indication for a specific physicochemical property, hazard, (toxico)kinetic behaviour or exposure is sufficient to attribute the maximum score of 3. Unknown (=?) can also be interpreted as 'maybe', in case the indications are weak.

[b] Take into account that outer layers may not be stable and therefore consider changes in surface properties.

[c] HARN = a material that has a diameter <100 nm and a length many times greater than its diameter (aspect ratio greater than 3 or 5:1), as defined by ECHA (2017) [11].

[d] In the sense of Article 57 of Regulation EU 1907/2006 with respect to human health-related endpoints.

[e] Restricted to exposure of consumers.

It needs to be noted while considering such a scoring system that there will also be certain 'exit' routes for a nanomaterial from needing nano-specific safety assessment. For example, where the data indicate that:

1. a nanomaterial is completely dissolved or loses its nano-structure[4]
2. there is no systemic exposure to particulate form of the material
3. the nanoform of the material has been shown to be non-toxic

In such cases, nano-specific risk assessment may not be needed and conventional risk assessment should be sufficient.

4. CONCLUSION

1. *The SCCS is requested to determine the nanomaterials, as published in the recent catalogue of nanomaterials of 2019, for which specific concerns can be identified and justified in order to establish a priority list of nanomaterials for risk assessment (Article 16(4) Reg.1223/2009). More specifically, the SCCS is requested to provide a description of the specific concerns that have been identified for the nanomaterials mentioned above. This process should be based on the currently available scientific literature and SCCS' expert judgement.**

Through a review of the available information and expert judgment, the SCCS has identified certain aspects of nanomaterials that constitute a basis for concern over safety to consumers' health when used in cosmetic products. These include:

- Physicochemical aspects relating to: very small dimensions of the constituent particles; solubility/persistence; chemical nature and toxicity of the nanomaterial; physical/morphological features of the constituent particles; surface chemistry and surface characteristics (surface modifications/coatings);
- Exposure aspects relating to: the frequency and the amounts used, whether the number/type of consumer product(s) used is relatively high; and whether there is a potential for systemic exposure of the consumer to nanoparticles and potential accumulation in the body;
- Other aspects relating to: novel properties, activity or function, and specific concern arising from the type of application.

A detailed account of these aspects has been presented in this Advice. Also, the nanomaterials listed in the EC catalogue of nanomaterials of 2019 have been tabulated in an order of priority according to risk potential in Annex 1 of this Advice.

2. *For the nanomaterials with inconclusive SCCS opinions, such as [Colloidal Silver (nano) (SCCS/1596/18), Styrene/Acrylates copolymer (nano) + Sodium styrene/Acrylates copolymer (nano) (SCCS/1595/18) and Silica, Hydrated Silica, and Silica Surface Modified with Alkyl Silylates (nano form) (SCCS/1545/15)], the SCCS is requested to assess if a potential risk can be identified according to Article 16(6) Reg.1223/2009. Such assessment, regardless of the data previously submitted by the respective applicants, should be based on the available scientific literature and SCCS' expert judgement (i.e. systemic or local availability; harmful effects specifically related to nano-form; surface catalysed reactions in nano-form, absorption (or potential*

4 e.g. in a formulation, a test medium, or biological surface/environment, due to solubilisation, breakdown or degradation, or interactions with other substances (see SCCS/1611/19).

*absorption) from dermal and inhalation routes, potential of nano-form to deliver ionic forms, etc.).**

The SCCS has reviewed previous inconclusive opinions on three nanomaterials (SCCS/1596/18; SCCS/1595/18 and SCCS/1545/15), in conjunction with any further relevant information available in published literature to identify whether there is a scientific basis for concern over their safety to consumers' health when used in cosmetic products. The SCCS has identified certain aspects relating to each of the nanomaterials that raise a safety concern. These have been detailed in three separate annexes (2, 3 and 4) to this Advice.

* In the assessment of the above question and in order to avoid conflicting opinions with other bodies, SCCS is invited to consult SCHEER.

5. MINORITY OPINION

None.

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ANNEX 1: THE LIST OF PRIORITY NANOMATERIALS IN THE EC CATALOGUE OF NANOMATERIALS (2019) ON THE BASIS OF RISK POTENTIAL

For reasons of consistency, this table includes entries listed in the EC catalogue of nanomaterials and therefore includes also the nanomaterials previously assessed by SCCS, i.e. already listed in Annex IV and/or VI to the Cosmetic Regulation.

Category/ Nanomaterial	**CAS Number**	**CosIng Entry**	**Already assessed by the SCCS?**	**SCCS Concerns over Potential Risk to the Consumer**	**Priority for Risk Potential** (according to Brand *et al.*, 2019)*
Colloidal Copper **(Other Functions)**	7440-50-8		SCCS preliminary Opinion available – SCCS/1621/20	Copper (Cu) is an insoluble material that may degrade to ionic copper under certain conditions. Colloidal copper is apparently toxic by oral route, and there are indications that it leads to the formation of reactive oxygen species. Dermal penetration and systemic availability of copper nanoparticles is currently unclear. Oral uses are also reported in the EC catalogue (mouth wash). The SCCS has recently assessed the available information on Copper (nano) and Colloidal Copper (nano). Although no conclusions could be drawn because of the lack of adequate data, Annex II of the Preliminary Opinion (SCCS/1621/20) has detailed the SCCS concerns over consumer safety from the use of copper nanomaterials in cosmetic products. The concerns relate to possible systemic uptake of Cu nanoparticles (and/or ionic Cu), which may lead to accumulation in certain organs - notably the liver and spleen. In addition, there are indications in the available literature data of the potential mutagenic/ genotoxic and immunotoxic/ nephrotoxic effects of copper nanomaterials. These aspects raise an alert that warrants further safety evaluation of copper nanomaterials used as cosmetic ingredients.	40
Colloidal Platinum **(Other**	7440-06-4		SCCS evaluation ongoing	Platinum (Pt) is an insoluble and persistent material, which in non-nano form is inert and is	36

Functions)				not likely to degrade/ionise under physiological conditions. However, due to surface reactivity, Pt nanoparticles may surface-catalyse oxidative reactions, which under biological conditions may lead to harmful effects. Colloidal platinum is currently under safety evaluation by the SCCS. Non-nano form of Pt is also used as antimicrobial in cosmetics. Due to insoluble, persistent and surface-reactive nature, the use of colloidal platinum in cosmetic product is of concern in regard to consumer safety due to the potential for systemic exposure to Pt nanoparticles.	
Platinum/ platinum powder **(Other Functions)**	7440-06-4		SCCS evaluation ongoing	Platinum (Pt) is an insoluble, and persistent material, which in non-nano form is inert and is not likely to degrade/ionise. However, Pt nanoparticles may surface-catalyse oxidative reactions, which under biological conditions may lead to harmful effects. Colloidal platinum is currently under safety evaluation by the SCCS. Non-nano form is also used as antimicrobial in cosmetics. Due to insoluble, persistent and surface-reactive nature, the use of nano-form of platinum in cosmetic product is of concern in regard to consumer safety due to the potential for systemic exposure to Pt nanoparticles.	36
Methylene Bis Benzotriazolyl Tetramethylbutyl phenol **(UV Filter)**	103597-45-1	Nano: VI/23a Specific use conditions (column h and i)	SCCS Opinions available – SCCS/1460/11 and SCCS/1546/15	Methylene bis benzotriazolyl tetramethylbutylphenol (MBBT) is an insoluble and persistent/bioaccumulative material. There is a positive SCCS Opinion for the use of uncoated form of MBBT as a UV filter with certain specified characteristics in dermally-applied products, mainly on the basis of a lack of dermal absorption in insoluble particulate form. However, the Opinion noted inflammatory effects via the inhalation route, and also a lack of clarity in regard to potential genotoxicity/ carcinogenicity. Some applications of MBBT listed in the EC catalogue may	34

				lead to oral or inhalation exposure, which raises concern over safety of the consumer from the use of such applications.	
Colloidal Silver **(Other Functions)**	7440-22-4		SCCS Opinion available – SCCS/1596/18	Silver (Ag) is a slowly solubilising material under physiological conditions with the release of silver ions. Depending on the concentration and site of release, silver ions may be harmful because of the ability to bind with other moieties (e.g. proteins, enzymes). There are indications for genotoxicity, immunotoxicity, developmental toxicity of nano silver. Oral applications of colloidal silver are also listed in the catalogue (toothpaste, mouth wash, oral hygiene products). Such uses are of concern in regard to safety of the consumer due to potential for systemic exposure to silver nanoparticles.	34
Silver **(Other Functions)**			SCCS Opinion available – SCCS/1596/18	Silver (Ag) is a slowly solubilising material under physiological conditions with the release of silver ions. Depending on the concentration and the site of release, silver ions may be harmful because of the ability to bind with other moieties (e.g. proteins, enzymes). There are indications for genotoxicity, immunotoxicity, developmental toxicity of nano silver. Oral applications of silver are listed in the EC catalogue (toothpaste, mouth wash, oral hygiene products). Such uses are of concern in regard to safety of the consumer due to the potential for systemic exposure to silver nanoparticles.	34
Tris-Biphenyl Triazine **(UV Filter)**	31274-51-8	VI/29	SCCS Opinion available – SCCS/1429/11	Tris-biphenyl triazine (ETH50) is an insoluble material that is not absorbed via dermal or oral routes. There is a positive SCCS Opinion on the use of uncoated form of ETH50 with a median particle size > 80 nm as UV filter in dermally-applied products, mainly on the basis of a lack of dermal absorption of the material in insoluble particulate form. However, the	30

				Opinion does not recommend use in products that could lead to inhalation exposure because of the potential to cause strong inflammatory response in the lung. Therefore, the use of ETH50 in products that could lead to inhalation exposure, as listed in the catalogue, raise concern over safety of such applications to the consumer.	
Styrene/Acrylate Copolymer **(Other Functions)**			SCCS Opinion available – SCCS/1595/18	There is an inconclusive SCCS opinion on the safety of styrene/acrylate copolymer, which contained other cosmetic ingredients packaged inside the encapsulates. Such a nano-scale packaging of bioactive substances is of a concern regarding consumer safety because of the potential for nano-scale delivery and the resulting effect of the encapsulated substances to unintended parts of the body.	30
CI 77891 (Titanium dioxide) **(Colorant)**	13463-67-7 1317-70-0 1317-80-2	Non-Nano: IV/143	Assessed as UV-Filter	Titanium dioxide (TiO2) is a practically insoluble and persistent material that is inert in non-nano form. There is a positive SCCS Opinion for the use of its nano-form as a UV filter in dermally applied products, mainly on the basis of a lack of dermal absorption of TiO2 nanoparticles. However, the Opinion did not recommend use of nano forms of TiO2 in cosmetic products that could lead to inhalation exposure because of the potential to cause inflammatory response in the lung. There is also a safety concern (potential carcinogenicity) when exposure is via the inhalation route. The non-nano form of TiO2 (that contain a significant fraction in the nano-scale) as pigment/colorant in cosmetic products is currently under assessment by the SCCS.	29
Titanium Dioxide **(UV Filter)**		Nano: VI/27a Specific use conditions (column h and i)	SCCS Opinions available – SCCS/1516/13 SCCS/1580/16	Titanium dioxide (TiO2) is a practically insoluble and persistent material that is inert in non-nano form. There is a positive SCCS Opinion for the use of its nano-form as a UV filter in dermally applied products, mainly on the basis of a lack of dermal absorption of	29

				TiO2 nanoparticles. However, the Opinion did not recommend use of nano forms of TiO2 in cosmetic products that could lead to inhalation exposure because of the potential to cause inflammatory response in the lung. There is also a safety concern (potential carcinogenicity) when exposure is via the inhalation route. The non-nano form of TiO2 (that contain a significant fraction in the nano-scale) as pigment/colorant in cosmetic products is currently under assessment by the SCCS.	
Silica Dimethyl Silylate **(Other Functions)**	68611-44-9		SCCS Opinion available – SCCS/1545/15	Same concerns as under silica, except that with hydrophobic modification to make dimethylated particle surface, the absorption and systemic availability may be higher compared to neat silica and this raises a concern over consumer safety due to greater risk of internal exposure to the nanoparticles.	29
Silica Dimethicone Silylate **(Other Functions)**	CAS not given		Covered in SCCS/1606/19	According to CosIng, this is a reaction product of silica with polydimethylsiloxane. There are same concerns associated with this nanomaterial as under silica above, except that, with surface modification with simethicone silylate, the absorption and systemic availability may be higher compared to neat silica and this raises a concern over consumer safety due to greater risk of internal exposure to the nanoparticles.	29
Silica Silylate **(Other Functions)**	68909-20-6		SCCS Opinion available – SCCS/1545/15	Same concerns as under silica, except that with hydrophobic modification to make trimethylated particle surface, the absorption and systemic availability may be higher compared to neat silica and this raises a concern over consumer safety due to greater risk of internal exposure to the nanoparticles.	28
Fullerenes **(Other Functions)**	99685-96-8			Fullerene is composed of extremely small particles (around 1 nm) made of carbon lattice. Due to the extremely small size, fullerene particles	26

				have the potential to penetrate biological membrane barriers when exposed via dermal, oral or inhalation routes. The use of fullerenes as antimicrobial in cosmetics has been reported but it has not yet been evaluated for safety of the SCCS. Due to the extremely small particle size and persistent nature, the use of fullerene in cosmetic products is of concern in regard to consumer safety due to the potential for systemic exposure to fullerene nanoparticles.	
Silica **(Other Functions)**	7631-86-9 112945-52-5		SCCS Opinions available – SCCS/1545/15 SCCS/1606/19	Silica (SiO_2) is an insoluble and potentially persistent material, which in non-nano form is inert and is not likely to degrade/ionise. Different forms of the nano-structured synthetic amorphous silica (SAS) have been evaluated by the SCCS. The Opinion (SCCS/1545/15) however could not draw any firm conclusion either for or against the safety of SAS materials because of the inadequacy of safety data. Another SCCS opinion (SCCS/1606/19) assessed the solubility of SAS materials to conclude that hydrophobic and hydrophilic SAS materials could be regarded as insoluble and very-slightly-soluble respectively. In the absence of conclusive evidence for safety, the use of nano-structured forms of silica in cosmetic products, especially those that may lead to oral or inhalation exposure to nanoparticles, raises concern over safety of the consumer.	26
Hydrated Silica **(Other Functions)**	7631-86-9 112926-00-8		SCCS Opinion available – SCCS/1545/15	Same concerns as under silica, except that hydrated silica particles are likely to be relatively larger in size than other silica particles.	26
Gold Thioethylamino-Hyaluronic Acid **(Other Functions)**	CAS/Identity unclear		SCCS evaluation ongoing (Feb 2021)	Gold thioethylamino-hyaluronic acid is an insoluble and persistent material. Several studies are available that point to dermal penetration of colloidal/nano gold, and surface modification with thioethylamino-hyaluronic acid may further increase absorption	25

				of the nanoparticles through skin and other exposure routes than neat gold nanoparticles. This material has yet not gone through SCCS evaluation for safety. Some applications mentioned in the catalogue (hair relaxer/hair straightener products) may lead to inhalation exposure. Thus, consumer safety concerns from the use of gold thioethylamino-hyaluronic acid is the same as for colloidal gold – i.e. due to the potential for systemic exposure to the nanoparticles.	
Carbon Black/ CI 77266 **(Colorant)**	1333-86-4, 7440-44-0	Nano: IV/126a Specific use conditions (column h and i)	SCCS Opinion available – SCCS/1515/13	Carbon black is an insoluble nanostructured material that is used as a colorant in many cosmetic products. There is a positive SCCS Opinion for its use in dermally-applied products. However, the opinion did not recommend applications that might lead to inhalation exposure of the consumer to carbon black nanoparticles due to the likelihood of harmful effects, including the potential to induce genotoxic effects. The Opinion also did not cover oral uses (such as tooth whitener) that are listed in the EC catalogue. Therefore, there is a safety concern over the use of carbon black in applications that may give rise exposure of the consumer to nanoparticles via oral or inhalation routes. The SCCS also noted in the Opinion SCCS/151/13 that the lowest particle size for which data were available was 20 nm. Additional information would be required on the use of any carbon black material intended for use in cosmetic products with particles size smaller than 20 nm. Furthermore, the Opinion specified that the purity of carbon black nanomaterials used in cosmetic products should be >97%, with a comparable impurity profile with the material(s) tested for toxicity in the submission, and the material(s) should comply with FDA specifications with respect to carbon black produced by furnace method.	25
Colloidal Gold	7440-57-5		SCCS	Gold (Au) is an insoluble and	24

(Other Functions)			evaluation ongoing (Feb 2021)	persistent material, which in non-nano form is inert and is not likely to significantly degrade/ionise under physiological conditions. Colloidal gold is currently under evaluation by the SCCS. Several studies are available that point to dermal penetration of colloidal/nano gold. Some *in vivo* information on toxicity of colloidal/nano gold is also available. Some applications mentioned in the EC catalogue (hair relaxer/hair straightener products) may lead to inhalation exposure to gold nanoparticles, which raises a concern over the safety of colloidal gold due to the potential for systemic exposure of the consumer to gold nanoparticles.	
Gold **(Other Functions)**			SCCS evaluation ongoing (Feb 2021)	Gold (Au) is an insoluble and persistent material, which in non-nano form is inert and is not likely to degrade/ionise under physiological conditions. Colloidal gold is currently under evaluation by the SCCS. Several studies are available that point to dermal penetration of colloidal/nano gold. Some *in vivo* information on toxicity of colloidal/nano gold is also available. Some applications mentioned in the catalogue (hair relaxer/hair straightener products) may lead to inhalation exposure, which raises concern over safety of the consumer due to the potential for systemic exposure to gold nanoparticles.	23
Alumina (Aluminium oxide, Al_2O_3) **(Other Functions)**				Alumina (Al_2O_3) is an insoluble and potentially biopersistent material, which is not likely to degrade/ionise easily. In non-nano form, the material is considered relatively inert. However, the use of a nano form of alumina in cosmetic products has not yet gone through SCCS evaluation. Like other insoluble/persistent nanomaterials, the use of nano-forms of alumina in cosmetic products raises a concern over safety of the consumer due to the potential for systemic	23

				exposure to the nanoparticles.	
Hydroxyapatite **(Other Functions)**			SCCS Opinion available - SCCS/1566/15 and SCCS/1624/20	Hydroxyapatite in non-nano form is a natural material that is a component of bones and teeth. The nano-form of hydroxyapatite is currently under safe ty evaluation by the SCCS for oral applications (mouthwash, toothpaste). There are concerns in relation to the potential absorption of hydroxyapatite nanoparticles in the oral mucosa and the potential for harmful effects in the consumer.	21
Lithium Magnesium Sodium Silicate **(Other Functions)**	CAS 53320-86-8			Little relevant information is available in published literature regarding both non-nano and nano forms of lithium magnesium sodium silicate. Therefore, the same safety concerns apply to this nanomaterial as described under silica.	20
Sodium Propoxyhydroxyp ropyl Thiosulfate Silica **(Other Functions)**	CAS unclear			Little information is available in published literature regarding both non-nano and nano forms of sodium propoxyhydroxypropyl thiosulfate silica. Therefore, the same concerns apply to this nanomaterial as described under silica, except that, with such a surface modification, the absorption and systemic availability may be higher compared to neat silica particles, which raises a concern over consumer safety due to greater risk of internal exposure to the nanoparticles.	20
Sodium Magnesium Fluorosilicate **(Other Functions)**	85085-18-3			Sodium magnesium fluorosilicate is a soluble material that in non-nano form has low/no toxicity. The nano-form of the material has not yet been safety assessed by the SCCS.	17
Sodium Magnesium Silicate **(Other Functions)**	101659-01-2			Sodium magnesium silicate is a soluble materials, that in non-nano form has low/no toxicity. The nano-form of the material has not yet been safety assessed by the SCCS.	17
CI 77947 (Zinc Oxide)		Non-Nano:	Assessed as UV-filter	Zinc oxide (ZnO) is an insoluble material, which under non-	15

(Colorant)		IV/144		static biological environments keeps on releasing Zn ions until the particles are completely solubilised. At low concentrations Zn ions are not considered of any concern because of the essential biological function of zinc, and the existence of a large pool of Zn in the body. There is a positive SCCS Opinion on the use of certain nanoforms as UV filter in dermally-applied products on the basis of a lack of dermal absorption in insoluble particulate form. Oral applications are also mentioned in the EC catalogue (lipstick and lip care products). The use of nanoforms of ZnO with different coatings as UV filter is currently being assessed by the SCCS.	
Zinc Oxide **(UV Filter)**	1314-13-2	Nano: VI/30a Specific use conditions (column h and i)	SCCS Opinion available - SCCS/1489/12	Zinc oxide (ZnO) is an insoluble material, which under non-static biological environments keeps on releasing Zn ions until the particles are completely solubilised. At low concentrations Zn ions are not considered of any concern because of the essential biological function of zinc, and the existence of a large pool of Zn in the body. There is a positive SCCS Opinion on the use of certain nanoforms as UV filter in dermally-applied products on the basis of a lack of dermal absorption in insoluble particulate form. Oral applications are also mentioned in the EC catalogue (lipstick and lip care products). The use of nanoforms of ZnO with different coatings as UV filter is currently being assessed by the SCCS.	13

Note: The order of priority in this Table is meant to provide a comparison of the overall scores for different nanomaterials. As such, the nanomaterials with the same score carry the same level of concern, and their order in the list is not meant to reflect a higher/lower level of concern than other nanomaterials with the same score.

* subject to change due to availability of new information

ANNEX 2: SAFETY CONCERNS ON NANOMATERIALS – COLLOIDAL SILVER (NANO)

The SCCS has recently evaluated the safety of colloidal silver (nano) when used in cosmetics including toothpastes and skin care products with a maximum concentration limit of 1%, taking into account the reasonably foreseeable exposure conditions (SCCS/1596/18). From this evaluation, and other relevant information from published literature, the SCCS has concluded that there is a basis for concern that the use of colloidal silver (nano) in cosmetic products can pose a risk to the consumer because of the following considerations:

PHYSICOCHEMICAL ASPECTS

1. Colloidal silver (nano) is comprised of constituent particles that are in the nano-scale. The particle sizes are reported to range from the lowest cut-off size of 1.56 nm to 100 nm (Table 2, SCCS/1596/18).

2. Colloidal silver is a slow dissolving material, composed of particles that liberate silver ions dependent on the conditions of the media/environment. In the 2018 evaluated dossier, the solubility was reported by the Applicants as either 'unlimited solubility', or 'solubility below 0.01 mg/l and no further dissolution in aqueous media' (Section 3.1.6, SCCS/1596/18).

TOXICOLOGICAL ASPECTS

3. The chemical and particulate nature of colloidal silver (nano) suggests a potential for toxicological hazard, as detailed below:

Genotoxicity: The SCENIHR, 2014 Opinion indicates that several *in vitro* studies have reported genotoxic effects of nanosilver. Any contradicting results may be explained by differences such as in coating of silver nanoparticles (AgNPs), cell type used, the cellular uptake, intracellular dissolution, the genotoxicity endpoint chosen, and the way the cells were exposed. For example, pre-dispersion in a medium before cellular exposure may result in initial dissolution of the AgNP, so that Ag+ is present from the beginning, contributing to (geno)toxic effect, especially in short-term exposure assays (e.g. for two hours).

Literature on AgNP genotoxicity published after the SCENIHR 2014 opinion confirms these conclusions. There are many positive results on genotoxicity which cannot be ignored although there are variations in the results from different studies (Rodriguez-Garraus *et al.*, 2020). Published studies with positive results generally show that the cytotoxic and genotoxic effects of AgNPs *in vitro* depend on size, shape, coating, concentration, duration of treatment and cell type. Some *in vitro* and *in vivo* studies also show that the effects are not size-dependent but more related to surface properties (Huk *et al.*, 2014, Li *et al.*, 2014, Nallanthighal *et al.*, 2017). There are several mechanisms that could lead to genotoxicity: direct damage by AgNPs (several studies show their presence in the cell nucleus); AgNP-induced oxidative stress and inflammatory response; release of ions from the NPs surface. A 'Trojan-horse' effect may also explain the genotoxic effects of AgNPs, where their uptake would be followed by a release of silver ions. The extent of silver ion release from the nanosilver however depends on the type of AgNP. Some studies show that silver ion release does not significantly impact the genotoxicity of AgNPs (Huk *et al.*, 2015, Li *et al.*, 2017) but rather the surface properties of AgNPs and coating are important. Although it is likely that the genotoxicity associated with AgNPs toxicity occurs either directly, or indirectly via oxidative stress, AgNPs also have high affinity for thiol groups, which are important for protein folding and for function as ROS (reactive oxygen species) scavengers (Chen *et al.*, 2020). As currently many different AgNPs have been tested for genotoxicity under highly

variable test settings and conditions it is not possible to group AgNPs with respect to genotoxicity. Rather, each material needs to be evaluated individually.

General toxicity: The SCENIHR, 2014 Opinion states that silver and nanosilver are clearly shown to have toxic potential, although toxicity in general seems to be low in humans. In in-vitro studies, AgNPs have been shown to be cytotoxic and with genotoxic DNA-damaging capacity. Although Ag uptake and possible persistence in the testes has been observed, histopathology did not reveal specific testicular toxicity. Liver toxicity is indicated by the effect of AgNPs on various liver enzymes. *In vivo* effects on the immune system were observed both regarding allergy to Ag itself, but also in repeated dose toxicity studies in terms of effects on cytokine production and on non-specific immune responses like natural killer cell activity. SCENIHR (2014) stated that these immune effects warrant further studies to the functionality of the immune system after exposure to AgNPs.

Literature published after the SCENIHR 2014 opinion confirms the persistence in testes after oral administration of nano-silver and indicate effects on Leydig cells, spermatogenesis, sperm quality as well as histopathological changes in testes. However, male fertility was not affected (Ema *et al.*, 2017). In addition, the review paper by Ema *et al.* (2017) indicated that maternal oral exposure might lead to apoptosis and neuronal degeneration in the brain of the offspring via oxidative stress and that nano-silver might affect embryonic/fetal survival and growth. However, such effects were reported to have not led to adversity in regard to morphological development of the offspring.

A further study focussed on kidney effects after repeated (60 d) oral administration of nano-silver to female Wistar rats. Nano-silver treatment led to a decrease in kidney weights, some loss of renal functions and ultrastructural changes in the kidneys (Tiwari *et al.*, 2017).

Dabrowska-Bouta *et al.* (2018) have reported that both nano-silver and ionic silver induce morphological disturbances in myelin ultrastructure and alter the expression of myelin-specific proteins, suggesting that the CNS may be a target of low-level toxicity of nano-silver. There are other reports that nano-silver might alter gut microbiota (Dahiya *et al.*, 2018), and that nano-silver might damage epithelial cell microvilli and intestinal glands (Duran *et al.*, 2020).

Bianco *et al.* (2015) investigated the skin penetration of Ag nanoparticles using intact skin. The Ag nanoparticles were derived from soaking three different textiles in a synthetic sweat solution in the donor fluid of the Franz diffusion cell for 24h. The resulting aggregates consisted of silver and silver chloride, indicating that the silver was released from the textiles mostly in ionic form. Released Ag concentrations in the soaking solutions (i.e. exposure concentration) ranged from 0.7 to 4.7 µg/mL (0.6–4.0 µg/cm2), fitting the bactericidal range. Silver and silver chloride aggregates at sizes of up to 1 µm were identified both in the epidermis and dermis. The large size of these particles suggests that the aggregation had occurred in the skin.

Another study by the same group with the same experimental set up confirmed that silver percutaneous absorption occurs after exposure to polyvinylpyrrolidone coated silver (~19 nm) in three human skin graft samples (fresh, glycosylated and cryopreserved skin) (Bianco *et al.*, 2014). The silver particles aggregated significantly in the artificial sweat, but silver content was detected in the receptor fluid. After 24 h, the silver penetration was 0.2 ng/cm2,h for fresh skin, 0.3 ng/cm2,h for cryopreserved skin, and 3.8 ng/cm2,h for glycerolized skin. Since there were no differences between fresh and cryopreserved skin, silver permeation through the skin could be through passive diffusion rather than active uptake.

EXPOSURE ASPECTS

4. The frequency of use of the products containing colloidal silver (nano) can be relatively high as it is in widespread use as antimicrobial agent in a variety of consumer products (clothing, food container, refrigerators, environmental exposure, cosmetics, etc)

5. The material poses the likelihood of systemic exposure of the consumer through the use of final products:

Oral:

'bioavailability of silver after oral administration of AgNPs was shown in one rat study; it was suggested that 1-4 % of the oral dose of silver was taken up systemically.' (SCENIHR, 2014).

Dermal:

Experimental data on intact and damaged skin *in vitro* using the Franz diffusion method has shown that silver nanoparticle absorption was very low but detectable (Larese *et al.*, 2009). The experiment was performed with full thickness human skin obtained as surgical waste using electro-thermal AAS for Ag determination. Silver nanoparticles were observed by TEM in the stratum corneum of the skin (SCHENIHR, 2014). The absorption of silver through damaged skin has been reported as a result of application as an antimicrobial agent in wound dressings (Trop *et al.* 2006, Vlachou *et al.* 2007, Larese *et al.* 2009).

George *et al.* (2014) studied dermal application of Acticoat® dressings with silver crystal particles (10-40 nm) to 16 patients for 4-6 days. Skin samples were obtained from 8 patients, serum samples obtained from all samples. The results showed staining throughout the superficial stratum corneum, and in 25% of the samples, staining of deeper layers of the epidermis. Ag nanoparticle could penetrate as deep as the reticular dermis. In skin, Ag most probably reacts with tissue components or precipitates. There may also be diffusion of Ag+ ions and secondary aggregation in the dermis. However, there was no increase in serum silver levels after application of the dressings containing silver crystal particles with a size of 10-40 nm.

Tak *et al.*, 2015 used a stable colloidal dispersion of rod-, spherical- and triangle shaped Ag nanoparticles to study skin penetration *in vivo* in hairless mice as well as *in vitro* in the skin from hairless mice. The results showed that, amongst the tested materials, the *in vitro* and *in vivo* penetration was the highest for rod shaped nanoparticles. After *in vivo* dermal application the presence of silver could be detected in blood by ICP-MS and the amount of silver detected was dependent on particle shape.

Kraeling *et al.* (2018) investigated skin penetration of commercially available 20 nm silver nanoparticles with three different coatings from an aqueous solution or simple cosmetic oil-in-water (O/W) emulsion formulation at two consumer relevant dosing concentrations. Skin penetration studies were conducted for 24 h in viable weanling pig skin, and excised human cadaver skin using an *in vitro* flow through diffusion cell system. The three surface coatings were chosen for their electrical charges: citrate (CIT, negative; 19.9 ± 2.4 nm, median particle size distribution of 21 nm), polyethylene glycol (PEG, neutral; 22.87 ± 2.8 nm, median particle size distribution of 24 nm), and branched polyethyleneimine (bPEI, positive; 21.5 ± 2.12 nm, median particle size distribution of 21 nm; 22.3 ± 3.5 nm, median particle size distribution of 22.5 nm). Human full thickness skin from 3 caucasian female donors, age 28-75 years was used. After application the procedure used tape stripping, separation of epidermis and dermis, and analysis of fractions by ICP-MS. The results indicated penetration of very low amounts into viable epidermis. It was however not determined whether the amounts referred to were Ag nanoparticles or silver ions.

6. As noted by SCENIHR (2014), the bioavailability of silver after oral administration of Ag nanoparticles has been shown in one rat study, which suggested that 1-4% of the oral dose of silver may be taken up systemically. The main target organs for Ag nanoparticle distribution after systemic availability were the spleen, liver and kidney while there was less distribution to other organs. Also in the testes, high levels of silver were sometimes noted. Recent studies have indicated that some persistence of Ag may occur in the brain and testes

(SCENIHR, 2014; Ema *et al.*, 2017), although it is not clear whether the silver was present in the brain tissue or limited to the endothelium of the brain. There is also some evidence that ionic Ag may also form silver structures at the nanoscale *in vivo*. Presence of Ag in faeces after intravenous and subcutaneous administrations indicates biliary excretion of Ag originating from parentally administered Ag nanoparticles.

Although most toxicokinetic studies have used chemical analyses to detect silver in different organs, without establishing its ionic or particulate nature, there is evidence to suggest that systemically available nano-silver could be distributed to, and might accumulate in, kidneys, liver, spleen, brain, lungs, and testes, and persist in some organs for several weeks (Mercier-Bonin *et al.*, 2018). A gender-specific difference in nano-silver accumulation has been observed in a 90-day oral exposure study with ~60 nm nano-silver, where it was found that female Fischer 344 rats accumulated twice the amount of silver in their kidneys as male rats (reported in Cameron *et al.*, 2018).

It appears from these studies that, compared to conventional silver compounds, AgNPs release Ag+ ions slowly, and may thus act as a reservoir releasing silver ions inside the body over long periods if taken up and transported to distant tissues (e.g. brain, testes).

CONCLUSION

With a collective consideration of the physicochemical, toxicological and exposure aspects noted above, the SCCS is of the view that there is a basis for concern that the use of colloidal silver (nano), as notified through CPNP for use in cosmetic products, can pose a health risk to the consumer. The SCCS will be ready to assess any evidence provided to support safe use of the material in cosmetic products.

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ANNEX 3: SAFETY CONCERNS ON NANOMATERIALS – STYRENE/ACRYLATES COPOLYMER (NANO)

The SCCS has previously evaluated the safety of styrene/acrylate copolymer (nano) intended for use in leave-on cosmetics products up to a concentration of 0.06% (SCCS/1595/18). The material was notified as a nanomaterial in the form of nano beads that contained different encapsulated substances (e.g. methylsilanol mannuronate and dimethylsilanol hyaluronate), meant to be antistatic, humectant, moisturising and skin conditioning.

The SCCS has found that the published literature is scarce on the safety aspects of nano-scale styrene/acrylates as such or when used as a carrier for other (bioactive) substances. The SCCS therefore considered other relevant information on micro/nanoplastics as such and when used for encapsulating other substances.

On the basis of evaluation of the available information, the SCCS has concluded that the use of nano beads made of styrene/acrylate copolymer, containing other encapsulated substances for use in cosmetic products, constitutes a concern for consumer safety on the basis of the following:

PHYSICOCHEMICAL ASPECTS

1. The styrene/acrylate copolymer (nano beads) containing other substances is comprised of particles that are in the nano-scale (20-160 nm) (SCCS/1595/18).

2. The styrene/acrylate co-polymer is composed of non-dissolving particles in the nanoscale, with the reported solubility of less than 0.01 mg/L and no further dissolution in aqueous media (SCCS/1595/18).

3. Due to the insoluble polymeric nature, styrene/acrylate co-polymer bears similarities with other micro/nano plastics that are generally insoluble, non-degradable and persistent in nature (Ganesh Kumar *et al.*, 2020). The SCCS has therefore also looked into the available data on physiochemical and toxicological aspects of other micro/nano plastics for possible use in the safety assessment of styrene/acrylate co-polymer.

TOXICOLOGICAL ASPECTS

4. As detailed below, micro/nano plastics (including styrene/acrylate copolymer) have been reported for potential toxicological hazards:

Genotoxicity:

Polystyrene nanoparticles (100 nm) have been shown to induce DNA damage in the cytokinesis-block micronucleus (CBMN) assay *in vitro* in human fibroblast cells (Poma *et al.*, 2019). The presence of protein corona on the surface of polystyrene nanoparticles (~100 nm) has been reported to increase DNA damage in lymphocytes in a Comet assay (Gopinath *et al.*, 2019). However, negative results have also been reported from micronucleus assay of polystyrene nano- (47-64 nm) and micro- (565-597 nm) particles in CHO-K1 cells (Hesler *et al.*, 2019).

General Toxicity:

Most concerns regarding nanoplastics are related to their persistence and effects on the environment (Ng *et al.* 2018, Alimba and Faggio 2019, Stapleton 2019, Yong *et al.* 2020, Ganesh Kumar *et al.*, 2020). More recently concerns for mammalian and human toxicity

have gained more attention, although data are generally scarce (reviewed in Lehner *et al.* 2019, Chang *et al.* 2020, Stapleton 2019, Yong *et al.* 2020, Allan *et al.* 2020). The possible toxic effects of plastic particles have been attributed to the potential toxicity of plastics themselves, and their combined toxicity with leachable additives and adsorbed contaminants (Chang *et al.*, 2020).

In an *in vitro* study, polystyrene particles were not acutely toxic for a coculture of Caco-2 and HT29-MTX-E12 or BeWo b30 cells, and did not cross intestinal and placental barriers, but both the polystyrene nano- (47-64 nm) and micro- (565-597 nm) particles showed cellular uptake and intracellular accumulation (Hesler *et al.*, 2019). In the same studies, cytotoxicity of polystyrene microparticles was observed at doses above 25 µg/mL for NIH/3T3 and murine embryonic stem cells, and myocard cell differentiation in embryonic stem cells was hampered after exposure to doses at 1 µg/mL. The microparticles were found to be more toxic than the nanoparticles, both in terms of cytotoxicity and embryotoxicity (nanoparticles IC50 >100 µg/mL, microparticles IC50 >12.6 µg/mL), although both were indicated as weakly toxic.

Considerable cytotoxicity and hemolysis was observed for polystyrene nanoplastics (particle size ~100 nm) at an exposure dose of 10 µg/mL that was dramatically increased after protein corona formation on the particle surface (Gopinath *et al.*, 2019).

5. Toxicity data on the two substances assessed in SCCS/1595/18 (methylsilanol mannuronate and dimethylsilanol hyaluronate) are not available. However, silanols consist of compounds of variable complexity in which a silanol group ((≡Si-OH; =Si (OH)2) has been incorporated in the chemical structure. Silanols are present as chemical functionalities on the surface of silica particles determining the hydrophilicity of silica nanoparticles (Napierska *et al.* 2010). Long chain silanol terminated compounds were found to be more toxic than short chain silanol terminated compounds for corneal toxicity (Green *et al.* 1992).

EXPOSURE ASPECTS

6. The purpose of the use of styrene/acrylate co-polymer nano beads loaded with other compounds is stated to offer slow release of the compounds at cutaneous level with controlled diffusion. The SCCS considers it a test case for the novel way of using a substance at the nano-scale in cosmetics products. This type of application can potentially open up the opportunity for the use of numerous other (bioactive) substances in a large number of applications resulting in a wider exposure of the consumers to nano-encapsulated materials, the safety of which has not yet been assessed.

OTHER ASPECTS

7. Although the information on the substances encapsulated in styrene/acrylate co-polymer nano beads is virtually non-existent, it can be envisaged that encapsulation of a substance in a nano-sized carrier, made of a hydrophobic plastic, may alter its properties and biokinetic behaviour that may further alter its toxicological effects, compared to the same substance in non-encapsulated form. Because of the potential of such a nano-carrier to deliver substances deeper into the skin or other systemic organs, this type of application may be used for encapsulating a multitude of other substances for a variety of cosmetic applications. It is however important to note that, even if safety of a polymer and the encapsulated substance can be shown individually, this cannot be taken as an evidence for the safety of the two when put together in the form of a nano-scale entity. In this context, the SCCS is of the view that, in the absence of sufficient data to demonstrate the safety of compounds nano-encapsulated in the polymer matrix, such an application constitutes a concern for the safety of the consumer.

CONCLUSION

With a collective consideration of the physicochemical, toxicological and exposure aspects noted above, the SCCS is of the view that there is a basis for concern that the use of nano beads of styrene/acrylate copolymer encapsulating other substances, as notified through CPNP for use in cosmetic products, can pose a health risk to the consumer. The SCCS will be ready to assess any evidence provided to support safe use of the material in cosmetic products.

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ANNEX 4: SAFETY CONCERNS ON NANOMATERIALS – SILICA, HYDRATED SILICA, AND SILICA SURFACE MODIFIED WITH ALKYL SILYLATES (NANO)

In 2015, the SCCS evaluated the safety of synthetic amorphous silica (SAS) materials intended for use in cosmetic products (SCCS/1545/15, Revision of 29 September 2015). The Opinion considered the available evidence to be insufficient to allow drawing a conclusion on the safety of any of the SAS materials evaluated (i.e. silica, hydrated silica, and silica surface modified with alkyl silylates).

In 2019, the SCCS evaluated the solubility aspects of SAS materials intended for use in cosmetic products (SCCS/1606/19). The Opinion concluded that none of the SAS materials (hydrophilic or hydrophobic) could be regarded as soluble to merit exclusion from the definition of nanomaterial as provided in Cosmetic Regulation.

Although the SAS materials are amorphous and largely comprise of aggregated particles, they are composed of primary nanoparticles of very small dimensions (as low as 10 nm). They also contain a fraction of small sized aggregates and potentially free particles that are below 100 nm in size. In view of this, the SCCS considers it relevant to look into the potential toxicological effects of nanoparticles (in addition to the data on SAS materials) to identify the risk potential of the nano-scale fraction of the SAS materials.

In consideration of all the relevant information provided in safety dossiers, and from published literature, the SCCS is of the view that the use of SAS materials in cosmetic products constitutes a concern for consumer safety on the basis of the following:

PHYSICOCHEMICAL ASPECTS

1. SAS materials are comprised of constituent particles that are in the nano-scale, ranging between 10 and 50 nm in size (SCCS/1545/15; SCCS/1606/19). Depending on the manufacturing process, nanoparticles in the SAS materials may exist in the form of larger sized agglomerates and aggregates, but also as free particles as well as agglomerates and aggregates that are within the nano-scale (i.e. 1-100 nm) (Fruijtier-Polloth, 2012; Fruijtier-Polloth, 2016).

2. The solubility of hydrophilic SAS materials in water is reported to range from 22 mg/L to 225 mg/L, and that of hydrophobic SAS materials from 0.4 up to 180 mg/L. According to the definitions of solubility terms provided in the USP 38/USP 38–NF33 and the European Pharmacopeia, these materials can only be regarded as being very slightly soluble and insoluble, respectively (SCCS/1606/19).

3. Although no data were provided for the previous SCCS evaluations, the physicochemical nature of the SAS materials suggest that they are likely to be persistent in biological environments. This is underlined by the conclusions of a nano-specific risk assessment, which highlighted SAS as a biopersistent material prone to accumulation in tissues upon long-term exposure with daily consumption (Van Kesteren *et al.*, 2015).

5. The SAS materials are produced by different processes and surface treatments, and may exist in hydrophilic, hydrophobic or colloidal form - each with a different surface characteristics (SCCS/1545/15; SCCS/1606/19). The physicochemical properties and biokinetic behaviour of these different SAS materials is likely to differ depending on the type of surface characteristics.

6. The SAS materials could potentially adsorb other chemical moieties that have an affinity towards hydroxyl groups on the surface of SAS particles. Therefore, formulation of SAS materials with other chemical and biochemical moieties may further modulate their toxicokinetics, or this may lead to unexpected effects due to nano-scale delivery of other substances.

TOXICOLOGICAL ASPECTS

7. The chemical and insoluble particulate nature of SAS nanoparticles suggests a potential for toxicological hazard, as detailed below:

In vitro toxicity:

In general, aggregation of primary nanoparticles can be expected to reduce the chances of systemic toxic effects of a nano-structured material. However, a review of the published studies has indicated that all types of SAS nanoparticles (SAS NPs) can induce cytotoxicity (Murugadoss *et al.*, 2017), and that cytotoxicity of the aggregates of >100 nm size is not always less than that of the nano-sized counterparts (Murugadoss *et al.*, 2020). The *in vitro* toxic effects of SAS NPs have been reported in several cell types lines to be through the induction of oxidative stress and/or pro-inflammatory responses and mediation of apoptosis, mainly via the intrinsic or mitochondrial pathway (caspase-dependent pathway) in a size- and dose-dependent manner.

Nanoparticle mediated production of reactive oxygen species (ROS) is believed to be an important mechanism of toxicity, including the nano forms of silica. Cytotoxicity and genotoxicity induced by Stöber-manufactured and colloidal SAS NPs have been strongly correlated with the induction of oxidative stress. Precipitated SAS NPs have also been associated with cytotoxicity due to oxidative stress but not with genotoxicity. Interestingly, pyrogenic SAS NPs have been shown to cause cytotoxicity, mostly without involving oxidative stress (Murugadoss *et al.*, 2017). In contrast, other studies have shown that pyrogenic SAS NPs are biologically more reactive than colloidal SAS NPs (Zhang *et al.*, 2012) and precipitated SAS NPs (Di Cristo *et al.*, 2016) of the same composition and size.

Genotoxicity:

An overview on the genotoxicity of SAS materials has been given in SCCS/1545/15 (section 3.3.6.3), leading to the conclusion that 'There is evidence for *in vitro* and *in vivo* genotoxicity of SAS nanomaterials in the open literature as demonstrated by several studies in terms of positive Comet and micronucleus assays. It has also been noted by the SCCS that the particles used in most of these studies were probably different from those intended for use in cosmetic products. Nevertheless, these studies indicate the potential mutagenic/genotoxic effects of SAS materials if there is an internal exposure.'

Genotoxicity of amorphous silica nanoparticles has recently been reviewed by Yazdimamaghani *et al.* (2019). The authors analysed 106 publications describing experimental studies on SAS NPs genotoxicity. Although there were negative and inconsistent reports on genotoxicity, a number of studies showed that exposure to SAS NPs could lead to genotoxicity through direct or indirect mechanisms.

Immunotoxicity:

Chen *et al.* (2018) reviewed *in vitro* and *in vivo* studies on the effects of silica nanoparticles to the immune system. Proinflammatory responses, ROS formation and autophagy were considered as the main mechanisms for the immunotoxicity of SAS NPs, which can also induce autophagy even at subtoxic levels (Kretowski *et al.*, 2017, Wang *et al.*, 2017).

A recent review by Sharma and Jha (2020) has summarised the possible toxic mechanisms of SAS NPs on the cellular and biochemical processes as well as on the innate immune responses, inflammation, and immune related dysfunctions.

In vivo toxicity:

Based on the available literature, and unpublished studies reviewed by OECD (2016) and ECHA (2019), there are no indications for an association between dermal exposure and adverse effects of amorphous or crystalline form of silica either in humans or animals (ATSDR, 2019). The same ATSDR review also reported that no adverse effects were associated with oral amorphous silica exposures ranging from acute to chronic duration. However, other recent publications have indicated systemic toxicity (mainly liver fibrosis or vacuolisation of tubular epithelial cells in kidney) after repeated oral exposures to pyrogenic silica (Zande *et al.*, 2014; Tassinari *et al.*, 2020) and precipitated SAS (Boudard *et al.* 2019, 2020).

EXPOSURE ASPECTS

8. SAS materials are used in a wide range of consumer and industrial applications. Synthetic amorphous silica (as well as crystalline forms) is found in many commercial products (e.g., bricks, mortar, plaster, caulk, granite and engineered stone kitchen counter tops, roofing granules, wallboard, concrete cleansers, art clays and glazes, talcum powder) (NTP 2009, SCCS, 2015). The frequency of use of the products containing SAS materials can also be relatively high. The general population is therefore exposed to silica (crystalline and amorphous) through air, indoor dust, food, water, soil, and various consumer products (ATSDR, 2019).

9. SAS is an authorised food additive (E551) in 22 categories of food and food supplements (in solid or liquid form), as well as in a number of food-grade components (additives, enzymes, flavorings, nutrient sources) at levels ranging from 2000 to 30,000 mg/kg or quantum satis (Younes *et al.*, 2018). Exposure of the general public to silica is also expected to occur through the diet. In addition to use as a food additive, E551 is also used in cosmetics (notably as an abrasion additive in toothpastes), in pharmaceuticals (as a free-flow additive, carrier, retardant agent and tableting aid) (Fruijtier-Polloth, 2016), and in food packaging. Typical cosmetic uses of SAS materials are in leave-on skin products (skin care and make-up), rinse-off skin products, as well as hair and lip products (SCCS/1545/15).

10. The widespread use of SAS materials poses the likelihood of consumer exposure via food and use of consumer products through different routes:

Dermal Uptake:

The dermal uptake of SAS materials has been discussed in the SCCS Opinion (SCCS/1545/15). A number of studies in the published literature have indicated the possibility of penetration of amorphous silica particles through skin after repeated applications (Nabeshi *et al.*, 2011; Hirai, *et al.*, 2012) – especially when skin barrier is damaged (Rancan *et al.*, 2012). One study (Boonen *et al.*, 2011) has indicated the possible skin penetration of even larger (micron) sized silica particles when applied in ethanolic formulations. Therefore, where SAS materials are intended for use in ethanolic formulations for cosmetic applications, the penetration potential of the nanoparticles should also be assessed in ethanolic media.

The SCCS noted in the Opinion (SCCS/1545/15) that the particles used in many of the published studies were different from those intended for use in cosmetic products; for example, some were labelled with fluorescent dyes that might have changed their properties/behaviour. A review by Nafisi *et al.* (2014) has also highlighted the need for more, properly designed, studies on the dermal penetration of silica nanoparticles. The situation with the use of such products on flexed, cut, compromised and diseased skin also remains to be clarified in this context. Having considered all the aspects, the SCCS concluded in SCCS/1545/15 that the evidence for the lack of skin penetration of silica

nanoparticles/clusters was insufficient and inconclusive and there was a need for further evidence from more properly designed studies.

Oral uptake:

Oral toxicokinetic studies in rat reported in OECD (2016) have pointed to a very low absorption of silica from the gastrointestinal tract as indicated by the slightly increased levels in liver, spleen and kidneys. Two other more recent *in vivo* studies, focusing on longer term exposure (3–18 months) at doses in the expected range of dietary intake, have reported adverse effects in the liver, kidney and thyroid (Boudard *et al.*, 2019); Boudard *et al.*, 2020, Tassinari *et al.*, 2020), indicating systemic exposure. Furthermore, systemic availability of particulate SiO_2 has recently been reported from post-mortem tissue samples from 15 deceased persons (Peters *et al.*, 2020). All tissue samples investigated (liver, spleen, kidney and the intestinal tissues - jejunum and ileum) contained particles consisting of SiO_2 (and silicates) as confirmed by electron microscopy analysis. The SiO_2 particle mass concentrations in the tissues ranged from 0.2 to 25 mg Si/kg tissue with an average of 1.2 ± 3.1 mg Si/kg tissue, with a particle size ranging between 150–850 nm.

Influence of Coating:

Some SAS materials used in cosmetic products are also surface-treated to confer hydrophobic properties. Examples include silica dimethyl silylate, silica silylate, silica dimethicone silylate, silica caprylyl silylate and silica cetyl silylate (SCCS, 2019). The hydrophobic surface treatments have been found to strongly decrease solubility of the materials, and consequently increase the likelihood of greater persistence of the SAS materials (Hardy *et al.*, 2018; SCCS, 2019). In addition, such surface modifications can also affect ADME (absorption, distribution, metabolism, and excretion) behaviour of the particulate materials – especially of the nano-scale particles (Hardy *et al.*, 2018).

CONCLUSION

With a collective consideration of the physicochemical, toxicological and exposure aspects noted above, the SCCS is of the view that there is a basis for concern that the use of SAS materials, as notified through CPNP for use in cosmetic products, can pose a health risk to the consumer. The SCCS will be ready to assess any evidence provided to support safe use of the material in cosmetic products.

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SAFETY DATA SHEET

according to Regulation (EC) No. 1907/2006

Version 6.6
Revision Date 12.09.2023
Print Date 20.11.2023
GENERIC EU MSDS - NO COUNTRY SPECIFIC DATA - NO OEL DATA

SECTION 1: Identification of the substance/mixture and of the company/undertaking

1.1 Product identifiers

Product name	:	Activated charcoal
Product Number	:	242276
Brand	:	SIGALD
REACH No.	:	A registration number is not available for this substance as the substance or its uses are exempted from registration, the annual tonnage does not require a registration or the registration is envisaged for a later registration deadline.
CAS-No.	:	7440-44-0

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses	:	Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet

Company	:	Merck Life Science Sp.z.o.o. Szelągowska 30 PL-61-626 POZNAN
Telephone	:	+48 61 8290-100
Fax	:	+48 61 8290-120
E-mail address	:	TechnicalService@merckgroup.com

1.4 Emergency telephone

Emergency Phone #	:	+(48)-223988029 (CHEMTREC) 112 (numer alarmowy)

SECTION 2: Hazards identification

2.1 Classification of the substance or mixture

Not a hazardous substance or mixture according to Regulation (EC) No 1272/2008.

2.2 Label elements

No hazard pictogram, no signal word, no hazard statement(s), no precautionary statement(s) required

2.3 Other hazards

This substance/mixture contains no components considered to be either persistent, bioaccumulative and toxic (PBT), or very persistent and very bioaccumulative (vPvB) at levels of 0.1% or higher.

Ecological information:
The substance/mixture does not contain components considered to have endocrine disrupting properties according to REACH Article 57(f) or Commission Delegated regulation (EU) 2017/2100 or Commission Regulation (EU) 2018/605 at levels of 0.1% or higher.

Toxicological information:
The substance/mixture does not contain components considered to have endocrine disrupting properties according to REACH Article 57(f) or Commission Delegated regulation (EU) 2017/2100 or Commission Regulation (EU) 2018/605 at levels of 0.1% or higher.

May form explosible dust-air mixture if dispersed.

SECTION 3: Composition/information on ingredients

3.1 Substances

Synonyms	:	Charcoal activated
Formula	:	C
Molecular weight	:	12,01 g/mol
CAS-No.	:	7440-44-0
EC-No.	:	231-153-3

No components need to be disclosed according to the applicable regulations.

SECTION 4: First aid measures

4.1 Description of first-aid measures

If inhaled
After inhalation: fresh air.

In case of skin contact
In case of skin contact: Take off immediately all contaminated clothing. Rinse skin with water/ shower.

In case of eye contact
After eye contact: rinse out with plenty of water. Remove contact lenses.

If swallowed
After swallowing: make victim drink water (two glasses at most). Consult doctor if feeling unwell.

4.2 Most important symptoms and effects, both acute and delayed

The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed

No data available

SECTION 5: Firefighting measures

5.1 Extinguishing media

Suitable extinguishing media
Water Foam Carbon dioxide (CO2) Dry powder

Unsuitable extinguishing media
For this substance/mixture no limitations of extinguishing agents are given.

5.2 Special hazards arising from the substance or mixture

Carbon oxides
Combustible.
Risk of dust explosion.
Development of hazardous combustion gases or vapours possible in the event of fire.

5.3 Advice for firefighters

In the event of fire, wear self-contained breathing apparatus.

5.4 Further information

none

SECTION 6: Accidental release measures

6.1 Personal precautions, protective equipment and emergency procedures

Advice for non-emergency personnel: Avoid inhalation of dusts. Evacuate the danger area, observe emergency procedures, consult an expert.
For personal protection see section 8.

6.2 Environmental precautions

No special precautionary measures necessary.

6.3 Methods and materials for containment and cleaning up

Observe possible material restrictions (see sections 7 and 10). Take up dry. Dispose of properly. Clean up affected area. Avoid generation of dusts.

6.4 Reference to other sections

For disposal see section 13.

SECTION 7: Handling and storage

7.1 Precautions for safe handling

Advice on protection against fire and explosion
Keep away from open flames, hot surfaces and sources of ignition.Take precautionary measures against static discharge.

Hygiene measures
Change contaminated clothing. Wash hands after working with substance.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities

Storage conditions
Tightly closed. Dry.

Storage class
Storage class (TRGS 510): 11: Combustible Solids

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

SECTION 8: Exposure controls/personal protection

8.1 Control parameters

Ingredients with workplace control parameters

8.2 Exposure controls

Personal protective equipment

Eye/face protection
Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU). Safety glasses

Skin protection
This recommendation applies only to the product stated in the safety data sheet, supplied by us and for the designated use. When dissolving in or mixing with other substances and under conditions deviating from those stated in EN 16523-1 please contact the supplier of CE-approved gloves (e.g. KCL GmbH, D-36124 Eichenzell, Internet: www.kcl.de).

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0,11 mm
Break through time: 480 min
Material tested:KCL 741 Dermatril® L

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0,11 mm
Break through time: 480 min
Material tested:KCL 741 Dermatril® L

Respiratory protection
required when dusts are generated.
Our recommendations on filtering respiratory protection are based on the following standards: DIN EN 143, DIN 14387 and other accompanying standards relating to the used respiratory protection system.
Recommended Filter type: Filter type P1

The entrepeneur has to ensure that maintenance, cleaning and testing of respiratory protective devices are carried out according to the instructions of the producer. These measures have to be properly documented.

Control of environmental exposure
No special precautionary measures necessary.

SECTION 9: Physical and chemical properties

9.1 Information on basic physical and chemical properties

a)	Physical state	powder
b)	Color	black
c)	Odor	No data available
d)	Melting point/freezing point	Melting point/range: 3.550 °C - lit.
e)	Initial boiling point and boiling range	No data available
f)	Flammability (solid, gas)	May form combustible dust concentrations in air.
g)	Upper/lower flammability or explosive limits	No data available
h)	Flash point	Not applicable
i)	Autoignition temperature	No data available
j)	Decomposition temperature	No data available
k)	pH	No data available
l)	Viscosity	Viscosity, kinematic: No data available Viscosity, dynamic: No data available
m)	Water solubility	insoluble
n)	Partition coefficient: n-octanol/water	No data available
o)	Vapor pressure	1 hPa at 25 °C
p)	Density	1,8 - 2,1 g/cm3
	Relative density	No data available
q)	Relative vapor density	No data available
r)	Particle characteristics	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	none

9.2 Other safety information

No data available

SECTION 10: Stability and reactivity

10.1 Reactivity
The following applies in general to flammable organic substances and mixtures: in correspondingly fine distribution, when whirled up a dust explosion potential may generally be assumed.

10.2 Chemical stability
The product is chemically stable under standard ambient conditions (room temperature) .

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
no information available

10.5 Incompatible materials
Strong oxidizing agents

10.6 Hazardous decomposition products
In the event of fire: see section 5

SECTION 11: Toxicological information

11.1 Information on toxicological effects

Acute toxicity
Oral: No data available
Inhalation: No data available
Dermal: No data available

Skin corrosion/irritation
No data available

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitization
No data available

Germ cell mutagenicity
No data available

Carcinogenicity
No data available

Reproductive toxicity
No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

11.2 Additional Information

Endocrine disrupting properties

Product:

Assessment	The substance/mixture does not contain components considered to have endocrine disrupting properties according to REACH Article 57(f) or Commission Delegated regulation (EU) 2017/2100 or Commission Regulation (EU) 2018/605 at levels of 0.1% or higher.

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

SECTION 12: Ecological information

12.1 Toxicity
No data available

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
This substance/mixture contains no components considered to be either persistent, bioaccumulative and toxic (PBT), or very persistent and very bioaccumulative (vPvB) at levels of 0.1% or higher.

12.6 Endocrine disrupting properties

Product:

Assessment	:	The substance/mixture does not contain components considered to have endocrine disrupting properties according to REACH Article 57(f) or Commission Delegated regulation (EU) 2017/2100 or Commission Regulation (EU) 2018/605 at levels of 0.1% or higher.

12.7 Other adverse effects
No data available

SECTION 13: Disposal considerations

13.1 Waste treatment methods
No data available

SECTION 14: Transport information

14.1 UN number

ADR/RID: - IMDG: - IATA: -

14.2 UN proper shipping name

ADR/RID: Not dangerous goods
IMDG: Not dangerous goods
IATA: Not dangerous goods

14.3 Transport hazard class(es)

ADR/RID: - IMDG: - IATA: -

14.4 Packaging group

ADR/RID: - IMDG: - IATA: -

14.5 Environmental hazards

ADR/RID: no IMDG Marine pollutant: no IATA: no

14.6 Special precautions for user

No data available

Further information

Not classified as dangerous in the meaning of transport regulations.

SECTION 15: Regulatory information

15.1 Safety, health and environmental regulations/legislation specific for the substance or mixture

This material safety data sheet complies with the requirements of Regulation (EC) No. 1907/2006.

Authorisations and/or restrictions on use

15.2 Chemical Safety Assessment

For this product a chemical safety assessment was not carried out

SECTION 16: Other information

Full text of other abbreviations

ADN - European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways; ADR - Agreement concerning the International Carriage of Dangerous Goods by Road; AIIC - Australian Inventory of Industrial Chemicals; ASTM - American Society for the Testing of Materials; bw - Body weight; CMR - Carcinogen, Mutagen or Reproductive Toxicant; DIN - Standard of the German Institute for Standardisation; DSL - Domestic Substances List (Canada); ECx - Concentration associated with x% response; ELx - Loading rate associated with x% response; EmS - Emergency Schedule; ENCS - Existing and New Chemical Substances (Japan); ErCx - Concentration associated with x% growth rate response; GHS - Globally Harmonized System; GLP - Good Laboratory Practice; IARC - International Agency for Research on Cancer; IATA - International Air Transport Association; IBC - International Code for the Construction and Equipment of Ships carrying Dangerous Chemicals in Bulk; IC50 - Half maximal inhibitory concentration; ICAO - International Civil Aviation Organization; IECSC - Inventory of Existing Chemical Substances in China; IMDG - International Maritime Dangerous Goods; IMO - International Maritime Organization; ISHL - Industrial Safety and Health Law (Japan); ISO - International Organisation for Standardization; KECI - Korea Existing Chemicals Inventory; LC50 - Lethal Concentration to 50 % of a test population; LD50 - Lethal Dose to 50% of a test population (Median Lethal Dose); MARPOL - International Convention for the Prevention of Pollution from Ships; n.o.s. - Not Otherwise Specified; NO(A)EC - No Observed (Adverse) Effect Concentration; NO(A)EL - No Observed (Adverse) Effect Level; NOELR - No Observable Effect Loading Rate; NZIoC - New Zealand Inventory of Chemicals; OECD - Organization for Economic Co-operation and Development; OPPTS - Office of Chemical Safety and Pollution Prevention; PBT - Persistent, Bioaccumulative and Toxic substance; PICCS - Philippines Inventory of Chemicals and Chemical Substances; (Q)SAR - (Quantitative) Structure Activity Relationship; REACH - Regulation (EC) No 1907/2006 of the European Parliament and of the Council concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals; RID - Regulations concerning the International Carriage of Dangerous Goods by Rail; SADT - Self-Accelerating Decomposition Temperature; SDS - Safety Data Sheet; TCSI - Taiwan Chemical Substance Inventory; TECI - Thailand Existing Chemicals Inventory; TSCA - Toxic Substances Control Act (United States); UN - United Nations; UNRTDG - United Nations Recommendations on the Transport of Dangerous Goods; vPvB - Very Persistent and Very Bioaccumulative

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

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