**Supplement – Dunn et. al. Control Banding Tools for Engineered Nanoparticles: What the Practitioner Needs to Know**

**Table S-1. Examples of Occupational Exposure Limits (OELs) for Nanomaterials Examined and Related Bulk Materials.**

|  |  |  |
| --- | --- | --- |
| **Material name (chemical formula)** | **OEL (µg/m3, unless otherwise stated) (8-hr TWA)** | |
| **Nanoscale** | **Microscale or unspecified** |
| **Silica** (SiO2) |  |  |
| *Crystalline* | NA | 50 (resp) b |
| *Amorphous* | 300 a | 6,000 (total) b |
| **Titanium dioxide** (TiO2) | 17 c  100 d  300 e,f  610 g | 2,400 (resp) h  15,000 (total) i |
| **Silver** (Ag) |  |  |
| *Metal dust, fume, and/or soluble compounds* | 0.33, 0.67 j  0.19 k | 10 (total) l, m |
| *Metal dust and fume* |  | 100 (total) m |
| **Carbon nanotubes** (C) |  |  |
| *MWCNT*  *CNT & CNF, including**SWCNT* | 0.67 n  1 o |  |
| *MWCNT* | 1, 2 p | NA |
| *CNT, including SWCNT* | 30 q |  |
| *MWCNT (Baytubes®)* | 50 r |  |
| **Graphene** (C) | NA | NA |
| Graphite (C) – chemically-related material |  |  |
| *Synthetic* | NA | 15,000 (total) s |
|  |  | 5,000 (resp) s |
| *Natural* |  | 2,500 (resp) t |
| Carbon black (C) – chemically-related material | NA | 3,500 (resp) u |
| **Cellulose** |  | 15,000 (total) w |
|  | 0.01 fibers/ml v | 10,000 (total) x |
|  |  | 5,000 (resp) w,x |
| Particles not otherwise regulated (PNOR) | NA | 5,000 (resp) y |

**Footnotes on next page.**

**Footnotes to Table S-1:**

**Silica**: a Stockmann-Juvala et al. 2014; b NIOSH 2007.

**Titanium dioxide**: c Aschberger et al. 2011; d Stockmann-Juvala et al. 2014; e NIOSH 2011; f JSOH 2013;

g Gamo 2011; Nakanishi 2011; h NIOSH 2011; i OSHA [29 CFR 1910.1000].

**Silver**: j Aschberger et al. 2011, Stone et al. 2009;  k Weldon et al. 2016; l NIOSH 2007, OSHA [29 CFR 1910]

(metal dust, fume, and soluble compounds); m ACGIH 2001: 10 µg/m3 (soluble compounds); 100 µg/m3 (metal

dust and fume).**Carbon nanotubes**: n Stone et al. 2009; o NIOSH 2013; p Aschberger et al. 2010, 2011; q Nakanishi 2011;

r Pauluhn 2010.

Graphite: s OSHA [29 CFR 1910]; t NIOSH 2007.

Carbon black: u NIOSH 2007, OSHA [29 CFR 1910].

Cellulose: v Stockmann-Juvala et al. 2014; w OSHA [29 CFR 1910]; x NIOSH 2007.

PNOR: y OSHA [29 CFR 1910.1000].

***Abbreviations:***TWA: time-weighted average concentration; Resp: respirable particle size fraction; Total: total airborne particle mass; NA: not available or not applicable.

***Note:*** Additional specific inhalation OELs for these ENMs reported in Mihalache et al. (2017) that are not shown in Table S-1 include: acute inhalation OELs (Table 2 of Mihalache et al. 2017); risk estimates, vs. OELs (Kuempel et al. 2006); OEL derivation methods could not be confirmed from information in reference cited (Warheit 2013) or were not in English (Swidwinska-Gajewska and Czerczak 2014, 2015); another reference was cited for TiO2 (Ogura et al. 2011). Weldon et al. (2016) is included here, but was not cited in Mihalache et al. (2017).

**Table S-2. Summary of characteristics of the various nanomaterial-specific control banding tools.**



Adapted from Brouwer (2012).





**References cited in Supplement**

ACGIH. (2001). Silver and compounds. In: Documentation of threshold limit values and biological exposure indices. 7th ed. Vol. 1. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

Aschberger K, Johnston HJ, Stone V, Aitken RJ, Hankin SM, Peters SA. (2010) Review of carbon nanotubes toxicity and exposure — Appraisal of human health risk assessment based on open literature. Crit Rev Toxicol 40(9):759–790.

Aschberger K, Micheletti C, Sokull-Klüttgen B, Christensen FM. (2011) Analysis of currently available data for characterising the risk of engineered nanomaterials to the environment and human health — Lessons learned from four case studies. Environ Int 37(6):1143–1156.

Brouwer DH. (2012) Control banding approaches for nanomaterials. Annals of Occupational Hygiene; 56 506-14.

Gamo M, ed. (2011) Risk assessment of manufactured nanomaterials: Titanium dioxide (TiO2). Final report issued on July 22, 2011. New Energy and Industrial Technology Development Organization (NEDO) project (P06041) “Research and Development of Nanoparticle Characterization Methods.” National Institute of Advanced Industrial Science and Technology (AIST). Available from http://en.aist-riss.jp/assessment/2721/

JSOH (The Japan Society for Occupational Health). (2013) Recommendation of occupational exposure limits (2013–2014). J Occup Health, pp. 421–439.

Kuempel ED, Tran CL, Castranova V, Bailer AJ. (2006) Lung dosimetry and risk assessment of nanoparticles: evaluating and extending current models in rats and humans. Inhal Toxicol 18:717–24.

Mihalache R, Verbeek J, Graczyk H, Murashov V, van Broekhuizen P. (2017) Occupational exposure limits for manufactured nanomaterials, a systematic review. Nanotoxicology; 11 7-19.

Nakanishi J ed. (2011) Risk assessment of manufactured nanomaterials: “Approaches” - Overview of approaches and results. Final report issued on August 17, 2011. New Energy and Industrial Technology Development Organization (NEDO) project (P06041) “Research and Development of Nanoparticle Characterization Methods.” National Institute of Advanced Industrial Science and Technology (AIST). Available from http://en.aist-riss.jp/assessment/2721/

NIOSH. (2007) Pocket guide to chemical hazards. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2005-149.

NIOSH. (2011) Current Intelligence Bulletin 63: Occupational exposure to titanium dioxide. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2011-160.

NIOSH. (2013) Current Intelligence Bulletin 65: Occupational Exposure to Carbon Nanotubes and Nanofibers. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2013-145.

Ogura I, Gamo M, Kobayashi N, Ema M, Adachi K, Yamada N, Yamamoto O. (2011) Risk assessment of manufactured nanomaterials, TiO2. Tsukuba, Japan: NEDO reports.

Pauluhn J. (2010). Subchronic 13-week inhalation exposure of rats to multiwalled carbon nanotubes: toxic effects are determined by density of agglomerate structures, not fibrillar structures. Toxicol Sci 113(1):226-242.

Stockmann-Juvala H, Taxell P, Santonen T. (2014) Formulating occupational exposure limits values (OELs) (Inhalation & Dermal). Helsinki: Finnish Institute of Occupational Health. Scaffold Public Documents - SPD7.

Stone V. (2009) Engineered nanoparticles: review of health and environmental safety. Edinburgh: ENRHES EU project report.

Swidwinska-Gajewska AM, Czerczak S. (2014) Titanium dioxide nanoparticles: occupational exposure limits. Medycyna Pracy 65:407 [in Polish].

Swidwinska-Gajewska AM, Czerczak S. (2015) Nanosilver-Occupational exposure limits. Med Pr 66:429–442 [in Polish].

Warheit DB. (2013) How to measure hazards/risks following exposures to nanoscale or pigment-grade titanium dioxide particles. Toxicol Lett 220:193–204

Weldon BA, Faustman EM, Oberdorster G, Workman T, Griffith WC, Kneuer C, Yu IJ. (2016) Occupational exposure limit for silver nanoparticles: considerations on the derivation of a general health-based value. Nanotoxicology 10(7):945-956.