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1 VIEWPOINT IN PREPARATION FOR  
2 ENVIRONMENTAL SCIENCE & TECHNOLOGY  
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4 Risk assessments show engineered nanomaterials to  
5 be of low environmental concern

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12 Concerns about environmental risks related to engineered nanomaterials (ENMs) have spurred  
13 research into these risks that has been ongoing since the early 2000s. A valid question at this  
14 point is what the results indicate so far – do ENMs seem to be an environmental concern or not?  
15 The final answer to this question can arguably not be answered yet. There still remain a number  
16 of data gaps and challenges related to the production of ENMs, the release of ENMs from  
17 products, the measurement of ENMs in environmental media, the assessment of ENMs exposure

18 to different organisms and the ecotoxicity testing of ENMs. However, an early indication might  
19 be obtained by considering the environmental risk assessments of ENMs conducted so far. In  
20 particular, a parameter called the risk characterization ratio (RCR, sometimes called risk  
21 quotient) might offer guidance. RCR is calculated by dividing the estimated exposure of an ENM  
22 (often quantified as a predicted environmental concentration, PEC) by a presumed safe  
23 concentration below which no adverse effects are believed to occur for that ENM (often  
24 quantified as a predicted no-effect concentration, PNEC). The RCR thus tells whether the  
25 presumed safe concentration is exceeded by the exposure concentration by taking values above 1  
26 in such cases. Although RCRs are generally derived from quantitative risk modeling rather than  
27 measurements, they might provide some guidance while experimental methods are still under  
28 development.

29 Most ENM modeling studies provide estimates of release and/or concentrations in the  
30 environment. Only seven studies presenting RCRs for ENMs have been identified. From these  
31 studies, best estimates of RCRs for commonly studied ENMs were obtained for fresh/surface  
32 water, freshwater sediment, sewage treatment plant (STP) effluent and soil. Blaser et al. <sup>1</sup>  
33 calculated RQs for silver nanomaterials (nano-Ag) in the Rhine river, although they used  
34 ecotoxicological data for other forms of silver than nano-sized. ‘Realistic scenario’ RCRs  
35 calculated for nano-Ag, titanium dioxide nanomaterials (nano-TiO<sub>2</sub>) and carbon nanotubes (CNT)  
36 in Switzerland were obtained from the study by Mueller and Nowack <sup>2</sup>. RCRs for the same ENMs  
37 plus zinc oxide nanomaterials (nano-ZnO) and fullerenes were obtained from Gottschalk et al. <sup>3</sup>,  
38 representative for Switzerland, the United States (US) and the European Union (EU). RCRs for  
39 nano-TiO<sub>2</sub> and nano-Ag representative for Johannesburg City were obtained from Musee <sup>4</sup>. His  
40 scenario with no dilution of STP effluent was assumed to represent STP effluent and his scenario

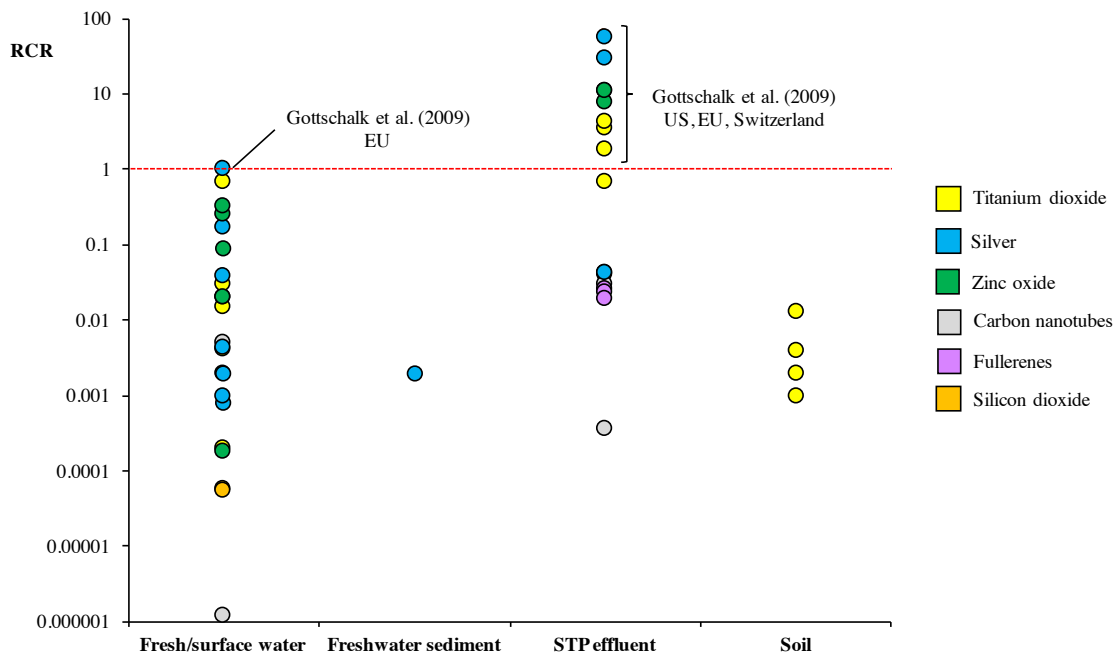
41 with the highest (ten-fold) dilution of the STP effluent was assumed to represent freshwater.  
42 RCRs for silicon dioxide nanomaterials (nano-SiO<sub>2</sub>) were obtained from Wang et al. <sup>5</sup>,  
43 representing Switzerland and the EU. Coll et al. <sup>6</sup> provided EU-wide RCRs for nano-TiO<sub>2</sub>, nano-  
44 Ag, nano-ZnO, CNT and fullerenes. Finally, Kjølholt et al. <sup>7</sup> presented RCRs for several ENMs  
45 in Denmark. Those for nano-TiO<sub>2</sub>, nano-Ag, nano-ZnO and CNT were obtained. For studies  
46 providing RCRs in the form of probability distributions, most likely (i.e. mode) values were  
47 considered to represent best estimates.

48 Figure 1 shows the results of this mini review for different compartments. Freshwater and  
49 STP effluent are the most considered compartments in these studies, while a few RCRs exist for  
50 freshwater sediment and soil as well. Clearly, the most common result is that RCR<1. For the  
51 freshwater compartment, only one in one case was RCR>1 obtained, namely for nano-Ag in the  
52 EU according to Gottschalk et al. <sup>3</sup> (RQ=1.1). However, several other studies obtained RCR<<1  
53 for nano-Ag, including the more recent EU-wide study by Coll et al. <sup>6</sup> (RCR=0.038). For STP  
54 effluent, Gottschalk et al. <sup>3</sup> again obtained RCR>1 for nano-Ag, but also for nano-ZnO and nano-  
55 TiO<sub>2</sub>. Their RCR=61 for nano-Ag in STP effluents in the EU is the highest RCR found in the  
56 review. However, it must be remembered that the STP effluent is not in itself a habitat for  
57 organisms, and becomes diluted when reaching environmental media.

58 Figure 1 shows best estimates of RCRs, which means that higher RCRs have been  
59 obtained in worst-case scenarios in the reviewed studies. It is still notable that so few realistic  
60 modeling results show RCR>1 and that nano-Ag is the only ENM for which RCR>1 was  
61 obtained in an environmental compartment given a realistic scenario. In particular, the ENMs  
62 CNT, fullerenes and nano-SiO<sub>2</sub> show very low RCRs, even in STP effluents ( $\leq 0.03$ ). Kjølholt et  
63 al. <sup>7</sup>, who included some additional ENMs to those reviewed here in their Danish study, write in

64 concordance with this review: “With the current scientific knowledge, and current use patterns  
65 and volumes, none of the ENMs selected for this study appear to constitute a general  
66 environmental risk or to be of significant environmental concern (i.e. they do not at the same  
67 time show high toxicity to aquatic organisms and occur at significant levels in the environment).”  
68 Current evidence from risk modeling studies thus suggests that many ENMs often included in  
69 risk assessments seem to be of minor environmental concern. If these modeling results are  
70 accurate, it warrants a shift in the focus of environmental risk research unless production and use  
71 of the well-studied ENMs increase drastically. It might be time to ask whether other ENMs  
72 would be more interesting to study? The development of new ENMs is ongoing. Examples of  
73 more recently developed ENMs include the two-dimensional materials graphene and boron  
74 nitride. Another example is the functionalization of ENMs for specific applications, such as the  
75 fullerene-based material [6,6]-phenyl-C<sub>61</sub>-butyric acid methyl ester (PCBM) used as electron  
76 acceptor molecule in organic solar cells. Investigations of more novel ENMs might reveal ENMs  
77 of higher environmental concern.

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 80 **Figure 1.** Review of risk characterization ratios for engineered nanomaterials. RCR=risk  
 81 characterization ratio, EU=European Union, US=United States, STP=sewage treatment plant.

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