Published in final edited form as:
Risk Anal. 2010 November ; 30(11): 1645–1662. doi:10.1111/j.1539-6924.2010.01521.x.

Nanotechnology Risk Communication Past and Prologue

Ann Bostrom[1,*] and **Ragnar E. Löfstedt**[2]

[1]Daniel J. Evans School of Public Affairs, University of Washington, Seattle, WA, USA

[2]Department of Geography and King's Centre for Risk Management, King's College London, London, UK

Abstract

Nanotechnologies operate at atomic, molecular, and macromolecular scales, at scales where matter behaves differently than at larger scales and quantum effects can dominate. Nanotechnologies have captured the imagination of science fiction writers as science, engineering, and industry have leapt to the challenge of harnessing them. Applications are proliferating. In contrast, despite recent progress the regulatory landscape is not yet coherent, and public awareness of nanotechnology remains low. This has led risk researchers and critics of current nanotechnology risk communication efforts to call for proactive strategies that do more than address facts, that include and go beyond the public participation stipulated by some government acts. A redoubling of nanotechnology risk communication efforts could enable consumer choice and informed public discourse about regulation and public investments in science and safety.

Keywords

Nanotechnology; public participation; risk communication; risk perception; risk policy

1. INTRODUCTION

> *In all honesty, this is the first time I have ever heard of nanotechnology, so I simply cannot comment on it.*
>
> *–From a 39-year-old U.S. respondent to an Internet survey of the science-attentive*(1)

Risk communication protects public health and welfare by raising awareness and informing personal and public decisions and actions.(2-4) If effective, nanotechnology risk communication will contribute to healthy innovation and sustainable development. This article provides a critical perspective on nascent nanotechnology risk perception and communication in the context of evolving nanotechnology innovation and policy. Achieving a broad overview comes at the cost of depth in the particulars, all of which are changing faster by the day.

Three pivotal questions emerge from our analyses of nanotechnology risk communication practices and prospects. These structure the rest of this article. First, what are the frames of reference for nanotechnology, and how do they shape risk communication efforts and the effects of these? Second, how have these frames of reference influenced public decisions and the conceptualization of risk regulation for emerging nanotechnologies, and what does

*Address correspondence to Ann Bostrom, Daniel J. Evans School of Public Affairs, Parrington Hall, University of Washington, Seattle, WA 98195-3055, USA; tel: 1.206.685.8198; abostrom@uw.edu.

this imply for new ways of thinking about risk regulation? We explore how this plays out currently for the cases of sunscreen and no-stink socks. Third, public engagement has emerged as the cutting edge of risk communication research and practice to address seemingly intractable issues. Are current forms of public engagement adequate, or does the rapid evolution of nanotechnology require new forms of public engagement? The emerging picture suggests an urgent need for more in-depth understanding of perceptions of nanotechnology across the spectrum of stakeholders, increased regulatory engagement and reporting requirements, and stepping up the pace of social engagement.

2. FRAMES, DECISIONS, AND REGULATIONS

2.1 Frames of Reference

2.1.1 Perception, Awareness, and Exposure to Information—Public awareness of nanotechnology remains low (Fig. 1). In 2004 only 29% of the U.K. public had heard of nanotechnology and only 19% could offer any definition.[5,6] Over 40% of survey respondents in the United States say they have heard nothing about it, and only 6% report having heard a lot[7] with similar findings in 2005 in the United States and Canada.[8] While awareness has risen in Australia (from 51% reporting in 2005 that they had heard the term "nanotechnology," to 66% in 2008), of those about a third (28% in 2005; 29% in 2008) profess not to know what it means.[9] Tokyo respondents were similarly unaware in 2004, with 55% reporting they had heard about nanotechnology, but only 34% claiming they understood the term.[10] A 2009 meta-analysis of survey studies conducted between 2002 and 2007 (including some but not all of those reviewed here) estimated that 51% of respondents had heard nothing about nanotechnology.[11]

Attitudes tend to be fairly balanced between perceived benefits and risks of nanotechnology, with benefits or uncertainty about the balance of risks and benefits dominating.[11,12] In 2005, 30% of a U.K. sample felt nanotechnology was a good thing, 13% a bad thing, and 28% did not have an opinion,[13] though gauging from other studies most of the latter had probably never heard of nanotechnology. In 2004, although 84% of those polled in the United States had heard nothing or little about nanotechnologies, 40% of those interviewed thought that nanotechnology would produce more benefits than risks, while only 22% said the risks would outweigh the benefits.[14] Kahan *et al.*'s[15] 2007 findings nearly mirror these. When a 2002–2003 cross-country study asked whether nanotechnology will improve our way of life in the future, responses in the United Kingdom reflected less technological optimism than those from the United States. In Europe 29% responded "Yes," while 53% said "Do not know." In contrast, in the United States 50% of Americans answered "Yes" and 35% said "Do not know."[16-18] Like Americans, Tokyo residents and Australians exhibit nanotechnological optimism, with 88% of those in Tokyo agreeing that nanotechnology would benefit society, 86% of Australians excited or hopeful about nanotechnology[9] and 53% stating that the benefits of nanotechnology outweigh the risks. However, over half of those in Tokyo also had concerns about nano development,[10] and 49% of Australians want food labeling to inform about any nanotechnology used.[9]

Notably, in the United States and Europe the less-informed lay public appear more likely than their better-informed lay peers to see potential risks as outweighing potential benefits, the more-informed more likely to see benefits as outweighing risk.[7,8,13,14,19,20] As one might guess from this, scientists are also more likely than lay people to be optimistic about the benefits of nanotechnology and see less risk than does the lay public,[21.22] as has been found for other technologies,[23-25] though more likely as well to perceive some specific potential environmental and health risks.[25]

Tests of what happens when people read information about nanotechnology suggest, however, that merely increasing familiarity will not necessarily increase favorable views. Rather, there may be common causes that predispose some people to learn about nanotechnology and to form a positive view.[15,26] In the United States at least, risk attitudes appear to polarize along the lines of prior attitudes toward technology and the environment.[27] However, public exposure to nano risk information remains low. One study showed that coverage of nano health, safety, and environmental risks is extremely low, rising from a mere 13 articles in nationally visible U.S. or U.K. publications in the year 2000, to 60 in 2004.[28]

2.1.1.1. Media trends: To assess media trends more comprehensively, we conducted content and trend analyses in the global media over the last decade, and of two national newspapers each from the Europe (both U.K.) and the United States: the *New York Times* and *Washington Post* in the United States and the *Financial Times* and the *Guardian* in the United Kingdom. These four newspapers are in the top 10 globally for coverage of nanotechnology. We searched for nanotechnolog* or nanoscience*, following the general approach used by Lowndes in his 2005 study[29] and using the Newsbank Access World News database. In addition, to estimate how much of this coverage addresses risk we selected the subset of these results that included risk* or safe* anywhere in the text.

The results show that media coverage has risen in the last decade, both for nanotechnology in general (Fig. 2) as well as for nanotechnology health, safety, and environmental risks (Figs. 2 and 3). But it remains low, with a decrease through 2007 and the first few months of 2008 and recent renewal of the upward trend. While coverage of nano risk and safety has also increased globally (Figs. 2 and 3; note the positive linear slopes in the trend lines), it has risen at a third the rate of the coverage of nano generally (Fig. 2), and remains very low.

In our analyses of nano coverage in the global press since 1986 North America comprised 30% and Europe (the United Kingdom) 40%, respectively, of the news (a total of 8,738 news items), while the relative proportions were reversed for nano risk and safety coverage (North America 36%, Europe/U.K. 44%, of a total of 1,871 news items for 1986–2009 inclusive) (Figs. 2 and 3). Further, almost no positive trend for nano risk coverage is apparent in the top U.S. newspapers reporting on nano, in contrast to the U.K. newspapers (Fig. 3).

Consistent with our finding that U.S. newspapers appear (increasingly) less likely to report on nano risk than U.K. newspapers, Gaskell *et al*.'s content analysis of the *New York Times* (*NYT*) and the *Independent* (a London-based newspaper) showed that from 1990 to 2003, the *NYT* carried more articles on nanotechnologies than the *Independent* (110 compared with 66) and highlighted the benefits of nanotechnologies more frequently.[18] In 2003, for example, there were 18 articles in the *NYT* mentioning the benefits of the technology, but only five in the *Independent*.[18]

2.1.1.2. Other risk communication texts: Not surprisingly, given the paucity of research on beliefs and perceptions about specific nanotechnologies and the lack of evidence about specific risks, many written risk communications to date to deal with risk generically, and by analogy. To wit, the Australian government nanotechnology primer published in April 2008 emphasizes that nanoparticles "already occur in food (as colloid such as milk) and in the air (as aerosols)," and describes a long list of promising problem-solving applications. It also states that nanomaterials may "penetrate the body" and cause harm, and "have unwanted environmental effects (as some pesticides do)."[30] One exception that discusses specific evidence regarding potential risks from nanotechnology is the commercial and scientific Nanowerk.com's introductory material on the web, including *Ten things you* *should know about nanotechnology*. However, it also frames nanotechnology comparatively —"Fact is, that every new technology is inherently risky—plenty of people are being injured or killed every year by electricity, cars, chemicals, or nuclear energy, just to name a few"— and by reference to nature—"The mere presence of nanomaterials is not in itself a threat; as a matter of fact, nanoparticles exist in nature."[3] Other governmental publications such as the U.S. National Nanotechnology Initiative (NNI) 2007 brochure "BigThings from a Tiny World," featured on the NNI homepage and intended for general audiences, employ a similar approach: "Nanoscale materials and effects are found in nature all around us" (p. 3).[4] Although seemingly simple, risk comparisons can evoke unanticipated responses from readers.[(31,32)]

Several advocacy organizations around the world have also published primers or fact sheets on nanotechnologies. For example, ETC Group (Action Group on Erosion, Technology and Concentration) issued "A Tiny Primer on Nano-Scale Technologies and the Little BANG Theory" in 2005.[5] A Tiny Primer emphasizes the same frames used by the International Risk Governance Council (discussed below), but dwells extensively on issues of social and economic control: "*with only a reduction in size and no change in substance, materials can exhibit new properties such as electrical conductivity, elasticity, greater strength, different colour and greater reactivity*" and later, "*While 'Grey Goo' has grabbed the headlines in the media (where self replicating nano-scale mechanical robots escape control until they wreak havoc on the global ecosystem), the more likely future threat is that the merger of living and non-living matter will result in hybrid organisms and products that are not easy to control and behave in unpredictable ways*."

As with previous new technologies, would-be nanotechnology risk communicators face the seemingly inevitable lag of public policy and decisions about risk and safety behind technological development, and an absence of evidence, as well as exuberant engineers. The dominant frame of reference is technological promise, as reflected in risk perception and media research, as well as in consultations at the National Academies, public funding decisions, and communications about consumer products, addressed below in the case studies of sunscreen and socks. Other emerging frames are also evident in debates about new regulatory approaches and categorizations of nanotechnologies for regulatory purposes. In the following we also examine current nanotechnology risk regulation and proposals for conceptualizing new regulatory frameworks.

2.1.2. Exuberant Engineers (The Nanotechnological Imperative)—The Nobel prizes for physics in 2007 went to two scientists, German and French, for their independent discoveries in 1988 of "giant magnetoresistance," called "one of the first real applications of the promising field of nanotechnology," by the Royal Swedish Academy of Sciences, and now in wide use in hard-disk drives for computers.[(33)] Two decades later, technological imperatives are explicit in U.S. National Academy reports on nanotechnology, as illustrated by the concerns voiced by scientists participating in one National Academy workshop on nanoscience and nanotechnology:

> *After a total of eight hours of group discussion, three groups thought they had developed potentially patentable ideas, and the conference organizers were challenged to develop mechanisms by which groups could publicly announce their solutions without losing their intellectual property protection.… At focus group report-outs on the last day of the conference, each group presented its problem and*

[3] http://www.nanowerk.com/nanotechnology/ten_things_you_should_know_9.html, Accessed January 9, 2010.
[4] www.nano.gov accessed January 9, 2010.
[5] BANG stands for bits, atoms, neurons, and genes. Published June 1, 2005. Available at www.etcgroup.org/en/issues/bangconvergence, Accessed January 10, 2010.

> *findings. As the appointed group members spoke, the prevailing feeling was a sense that anything is possible. (NAKFI, p. 4)*[(34)]

It is little wonder that National Academy committee members can barely stop long enough to elaborate on research challenges for the field.[(34)],[6] when nanotechnology has captured not only the spotlight, but light itself. A Dutch scientist now at Harvard, Lene Vestergaard Hau, and her colleagues have slowed and stopped light, and can capture it in a Boze-Einstein condensate with nanocarbon tubes and release it elsewhere.[(35,36)]

Interdisciplinary scientists are now harnessing the properties of nanoscale materials to address global challenges. Nanotechnologies promise clean water for the developing world,[(37)] solutions to cancer and HIV/AIDS, and low-cost, sustainable energy production.[(38)] The nanosolar powersheet, made with "solar absorbing power-ink," was named the top innovation of the year in 2007 by *Popular Science* magazine. A research project[7] on nanoantennas that won two 2007 Nano50 awards promises to make solar cells that collect light in the infrared range, are 80% efficient, and are cheap. In sum, Richard Feynman's 1959 claim that "there is *Plenty* of Room at the Bottom"[8] rings true yet. But exuberance seems to crowd out caution.[(39)]

As research and technology focus at smaller and smaller scales, what were previously black boxes are becoming engineer-able mechanisms of life. The new properties of materials at nanoscales have the potential to create both new benefits and new risks: biologists who can penetrate cell membranes with striped gold nanoparticles[(40)] are part of the nanoscience boom.

Rapid growth of nanotechnology applications is well documented by the Woodrow Wilson Center Project on Emerging Nanotechnologies (PEN) and other organizations.[9] Nevertheless, these are likely but a faint reflection of the growth in applications now under research, supported and spurred by public nanotechnology initiatives globally.

2.2. PUBLIC NANOTECHNOLOGY DECISIONS: LEADING INNOVATION, LAGGING ATTENTION TO RISK AND SAFETY

Public nanotechnology decisions to date include both investments to push development and calls for precaution. Public investments in national and international research and initiatives span the globe, including the NNI in the United States and national initiatives in over 60 other countries.[(41)] The effects of such investments are documented by rapid increases in applications, as well as by increases in research dollars, publication rates in nanotechnology, and patents. Annual nanotechnology-related publications increased more than five-fold between 1995 and 2005.[(42)] Annual patents increased more than ten-fold from 1976 to 2002, and 100-fold by 2006, from a handful in 1976 to over 1,800 in 2006 alone.(41,43)[10]

---

[6]Their assigned task was to brainstorm "major challenges at the crossroads between nanotechnology and biomedical and physical systems." They were not expected to come up with solutions. http://books.nap.edu/openbook.php?isbn=0309096685&page=4.

[7]Research conducted by researchers Dale Kotter, Steven Novack, and Judy Partin at the Idaho National Laboratory U.S. Department of Energy, with partners at Microcontinuum Inc. (Cambridge, MA) and Patrick Pinhero of the University of Missouri, https://inlportal.inl.gov/portal/server.pt?open=514&objID=1269&mode=2&featurestory=DA_101047, Accessed August 18, 2008. For info on Nano50 awards, see http://www.nanotechbriefs.com/nano50/.

[8]Richard P. Feynman's speech December 29, 1959 at the annual meeting of the American Physical Society at the California Institute of Technology (Caltech), first published in the February 1960 issue of Caltech's Engineering and Science. Available at http://www.zyvex.com/nanotech/feynman.html.

[9]http://www.nanotechproject.org/inventories/, see Project on Emerging Nanotechnologies (2008, April 25). New Nanotechnology Products Hitting the Market at the rate of 3–4 per Week. ScienceDaily. Retrieved August 15, 2008, from http://www.sciencedaily.com/releases/2008/04/080424102505.htm.

[10]Nanoscale science and engineering patents rose from 615 in 1976 to 8,219 in 2002, according to analysis of U.S. Patent and Trademark Office data by Huang and colleagues.

Although "chemistry: molecular biology and microbiology" was the dominant nanotechnology field in this time period,[43] as mentioned above, only a small proportion of research investments to date include attending to possible risks. This is despite widespread calls for more attention to nanotechnology environmental, health, and safety.[6,44,45] Of the $1 billion that the U.S. federal government spent on nanotechnology in 2004, only an estimated $8.5 million was spent on researching the environmental and health implications associated with them.[46] For fiscal year 2006, GAO estimated that $30.5 million of the $1.3 billion invested in research by U.S. federal agencies under the National Nanotechnology Initiative was devoted to environmental, health, or safety research, lower than the NNI estimates of about $37 million the GAO reviewed.[47] Although investments in nanotechnology risk research are increasing, as illustrated by the January 2009 U.S. National Science Foundation investment of over $30 million in two centers to study environmental and health aspects of nanotechnologies, a 2009 National Academies study estimated that less than half of a Nanotechnology Environmental Health Implications Working Group estimate of $67.8 million in NNI EHS spending for 2006 was truly EHS related (p. 90).[48] The Royal Society concludes in multiple reports, as does the U.K. Council for Science and Technology, that little has occurred with regard to addressing uncertainties about the health and environmental impacts of nanomaterials since their 2004 joint study was published, a worrying trend.[11](49)

Nevertheless, data suggest that the EU invests far more than the United States in nano risk research.[12] Although the U.S. EPA announced a new strategy for environmental and health risk research in the fall of 2009, whether the strategy will receive sufficient funding remains unclear. In sum, although an increase in interest in regulating risks from nanotechnologies is evident over the last half dozen years,[6,44,49,50] research and regulation of risks lag behind the driving forces of intellectual curiosity and commercial potential.

Nano-policy and nano-risk management, to the extent that it exists at all, remains somewhat incoherent. A few communities have begun to regulate nanotechnologies, but the regulatory framework for nanotechnologies is patchy at best, at all levels of government.[44,51] Launched in December 2009, the Nanotech Regulatory Document Archive[13] is populated primarily by materials from the United States, the E.U., and Australia, as other countries have promulgated little regulation. On March 24, 2009 the European Parliament and Council revised its 1976 cosmetics regulation, and in so doing regulated nano in cosmetics, requiring safety assessments and listing of nanomaterials in the ingredients on the label as "[nano]."[52] The regulation mentions future updates, and notes that there is no uniformly interpreted definition of nanotechnology internationally, currently. A day later the European Parliament adopted a report calling for risk assessment and labeling for nanotechnology in foods.[53] The U.S. EPA intends to regulate nanomaterials under the Toxic Substance Control Act (for example, to require premanufacture notices), and has proposed specific significant new use rules (SNURs) for carbon nanotubes.[14] The California Department of Toxic Substances Control requires carbon nanotube manufacturers to report tests, fate, and transport, and is considering similar requirements for several other nanomaterials.[15] In 2006, Berkeley became the first government in the United States to regulate nanotechnology by amending its municipal code on disclosure of hazardous materials to require "all businesses that manufacture or use nanoparticles to submit a written report of the current

[11]Summarized in the Council for Science and Technology Nanotechnologies Review at http://www2.cst.gov.uk/cst/business/nanoreview.shtml, accessed January 10, 2009.
[12]Project on Emerging Nanotechnology Risk Research Inventory Update April 19, 2008, Woodrow Wilson Center. Available at http://www.nanotechproject.org/news/archive/ehs-update/, accessed January 5, 2010.
[13]http://nanotech.law.asu.edu, accessed January 9, 2010.
[14]Federal Register/Vol. 74, No. 214/ Friday, November 6, 2009 / Proposed Rules.
[15]http://www.dtsc.ca.gov/TechnologyDevelopment/Nanotechnology/index.cfm, accessed January 9, 2010.

toxicology of the nanomaterials reported, and methods for safe handling, monitoring, containing, disposing, and tracking the inventory, thus assisting with prevention and mitigation of releases."[16] Implementing the ordinance may pose a challenge, but could also provide useful insights for those interested in assessing nanotechnology risks and controlling them.[17] Cambridge considered adopting a similar code in 2008, but desisted. Finally, as illustrated in Fig. 4, while some companies are assessing risk, most aren't.[(54,55)]

2.3 Conceptualizing New Regulatory Frames for Nanotechnology

A key endeavor in current social and policy research on nanosciences is to categorize nanotechnology sensibly, in particular with regard to risk. This is hard to do for a technology that we cannot sense unaided, and that nearly every scientific and engineering discipline is now researching:

> *Because there is an infinite variety of nanomaterials, determining the specific risks of each one can be challenging. Researchers are studying them by grouping them not only by size—an obvious choice—but also by chemical composition, shape, structure, and their state of aggregation. Chemically, materials can consist of a single element like carbon or metals like silver and gold or be found as compounds like cadmium selenide or indium phosphide. Examples of structures and shapes include crystals, spheres, tubes, and wires. The aggregation state refers to how the material clumps—or doesn't clump.*[(56)]

Yet this categorization task provides essential scaffolding on which to build public decision making and policy. Multiple categorization schemes for nanomaterials have been proposed.[(57)] For example, Shatkin proposes a classification based on exposure throughout the life cycle of a nanomaterial.[(58)] As pointed out by Hansen *et al*.,[(59)] research as early as 1992 suggested adverse effects of nanomaterials. Nanomaterials have demonstrable biogeophysical effects, including biological effects on human cells and microenvironmental physical effects. These have the potential to affect human morbidity and mortality, the environment, and a social or status change of nanotechnologies themselves.

Some authors focus on characterizing nanomaterials by shape and by analogy with better known risks, such as those from asbestos. For example, carbon nanotubes may induce mesothelioma in mice,[(60)] and have been characterized as exhibiting asbestos-like pathogenic behavior.[(61)] Over 10% of newspaper reports 2000–2004 on nanotechnology risks included comparisons with asbestos (13% in the United States and 16% in the United Kingdom).[(28)]

Nowack and Bucheli[(62)] classify nanoparticles first by whether they are natural (such as soot) or anthropogenic (e.g., carbon nanotubes), organic or inorganic, then by how they are formed (shown in Table I, which is based on their Table 1).

Others categorize according to molecular constituents (metals such as gold or silver), or use and exposure contexts, such as drugs and cosmetics, or computing. The Woodrow Wilson PEN does this, as do several other organizations[(63-64)] (see pp. 13–17 in Ref. 63). Ludlow *et al*.[(64)] review several of these schemas and propose an adaptation, crosscut with lifecycle analysis, from research and development through product manufacture, industrial/

---

[16]Berkeley Title 15 sections 15.12.040 and 15.12.050, are the local version of federal community right-to-know laws. For notice regarding the amendment, see: http://www.ci.berkeley.ca.us/citycouncil/2006citycouncil/packet/120506/2006-12-05%20Item%2013%20Manufactured%20Nanoparticle%20Health%20and%20Safety%20Disclosure.pdf, accessed September 3, 2010.

[17]For a discussion of this, see Sharyl Rabinovici, Javiera Barandiaran, and Margaret Taylor (Oct 2007). Local Disclosure Ordinance as Regulatory Catalyst: Early Insights from the Berkeley, California Manufactured Nanoscale Materials Health and Safety Disclosure Ordinance. Working paper available at socrates. berkeley.edu/sim;raphael/IGERT/Workshop/Rabinovicietal_BerkeleyNano_24Sep07.pdf, accessed August 15, 2008.

commercial use, and disposal, and including transportation throughout. Their schema includes nanoscience and nanotechnologies at the core, nanomaterials at the next level, and imposes on these product categories—such as coating and pigments, cosmetics, electrical equipment, food processing and production, medical applications, textiles, and weapons and explosives—noting that production processes go from the core through these categories.

Hanson *et al*.[(59)] attempt to match product categories up with their chemical identity, and find that it is not possible to do this for almost 60% of the products currently available with the available product characterization. This is a striking lack of information.

A popular distinction is that between passive and active nanotechnologies, between nanotechnologies that as Feynman described them are simply writing information, and those that are doing something about it—walking, wriggling, doing all kinds of marvelous things.[18] Using these two basic frames, the International Risk Governance Council refers to four generations of nanotechnology products: passive nano comprises the first generation, active the second, active integrated nanosystems the third, and active heterogeneous molecular nanosystems the fourth.[(65)] Most other classification systems to date appear only to address what the IRGC calls first-generation nano.

Another type of possible classification scheme is by social context, for example, by the type or size of nanotechnology producer. People provided with the information that large multinational enterprises benefit from nanotechnologies judge the probability of risk scenarios higher than those who are told small or medium-sized enterprises will benefit, with the largest differences for environmental or unknown risks.[(66)]

In general, nano risk-benefit attitudes absent much knowledge are driven by heuristic, affective responses to nanotechnology[(15)] and to science and technology generally.[(11)] Cultural attitudes, for example, predict familiarity with nanotechnology[(27)] and the extent to which people feel nanotechnology "has or has not been developed with their values, interests and beliefs in mind."[(8)] Also, as mentioned above, Kahan *et al*.[(26)] find risk attitude polarization (e.g., positive attitudes get more positive) in their risk communication experiments. But when people receive new information on nanotechnology along with information about the cultural attributes of the communicator, cultural credibility—that is, value similarity—appears to be the stronger effect. In other words, if a (culturally) credible policy expert provides information that differs from one's predispositions, one might have a change of attitude. Trust, driven by salient value similarity, appears to be key in nanotechnology risk communication contexts,[(11)] as it is in other risk contexts (see writings by Cvetkovich, Earle, Löfstedt, Pidgeon, Siegrist, and others[(67-71)]).

Inducing a frame of reference using any of the above approaches, for example, by using a dominating comparison, is a potent way of focusing attention.[(72)] Further, classifying nanomaterials by analogy with risks like asbestos may not only focus attention on risks rather than benefits, but seems likely also to obscure ecological effects by drawing attention to human health effects, and obscure that a nanomaterial may have multiple effects, including different effects in different exposure contexts.

As is evident from regulatory sluggishness to date, the strongest frames of reference for nanotechnologies are likely to be the familiar properties of constituent materials at macroscales, which are generally not relevant to their behavior at nanoscales, and even misleading. Aluminum can, for example, spontaneously combust at the nanoscale. Gold at the nanoscale is red. The "possibility of regulators failing to distinguish between nano forms

[18]Ibid (3) (http://www.zyvex.com/nanotech/feynman.html)

NIH-PA Author Manuscript

NIH-PA Author Manuscript

of products that differ in properties from their equivalent conventional forms" has been identified as a significant gap in regulation of nanotechnology in Australia, for example.(64)

3. AN ABSENCE OF EVIDENCE: THE CASES OF SUNSCREEN AND SOCKS

> Atoms on a small scale behave like *nothing* on a large scale, for they satisfy the laws of quantum mechanics.
>
> – Richard Feynman[19]

Two already prevalent applications of nanotechnology are the use of nanoparticles of silver (n-Ag) as an antimicrobial, for example, in socks, and the use of nanoparticles of titanium dioxide to shield against UV, for example, in sunscreen. A brief review of these cases illustrates the importance of frames for communicating and managing both risks and benefits of nanotechnology, and the complexity and potentially limited usefulness of extrapolating from prior macromaterial-based knowledge (see also Ref. 73).

3.1. Sunscreen

The ozone hole together with high and increasing skin cancer rates[20] have likely contributed to higher awareness of the need for protection from UV. Sunscreen use is widely promoted as a way of preventing skin cancer. In one recent review of almost a thousand sunscreens many were found to incorporate nanoparticles.(74) In another recent study evidence of nanoparticles was found in sunscreens that were not so labeled.(75,76)[21] There is also suggestive evidence that cosmetics are less likely now to be labeled as containing nanoparticles than they were a few years ago in the United States.(77) In Australia, which has the highest skin cancer rates in the world, over 250 registered sunscreens contain nanoparticles of titanium dioxide.(78) Advantages of incorporating titanium dioxide using nanotechnology are that it effectively blocks UV, has the potential to absorb UV at some wavelengths more effectively than conventional titanium dioxide, and is transparent rather than white.

In August 2006 the U.S. Environmental Protection Agency (EPA) found that the titanium nanoparticles used in sunscreens caused neurological changes in mice. However, other research findings suggest lack of skin penetration means that exposure to nanoparticles of titanium dioxide in sunscreen will not harm human health.(49,78-80) It remains unclear whether nanoparticles may be able to penetrate lesions, for example, lesions created by sunburn.(81) Further, while not directly pertinent to skin applications, recent examination of newly installed steel roofing in Australia suggests that photocatalytic activity of some forms of nanoscale titanium dioxide also found in sunscreens can cause severe premature weathering, and may be indicative of dangerous forms of such nanoparticles,(76,78,82)[22] although there is a risk that such comparisons of potentially unrelated, diverse forms of nanoscale titanium dioxide may constitute a rhetorical device for shifting its risk profile.(83)

Weighing in on the risk-benefit balance, Friends of the Earth (FOE) states:

---

[19]Ibid (3) (http://www.zyvex.com/nanotech/feynman.html)

[20]U.S. Cancer Statistics, http://apps.nccd.cdc.gov/uscs/. Melanoma of the skin was the 8th most prevalent cancer site in the United States in 2004. According to the American Cancer Society, Cancer Facts & Figures 2008, www.cancer.org, skin cancers are the most common of all cancers, but can usually be treated successfully if found early.

[21]The PEN nanotechnology inventory included 27 sunscreen products as of mid August 2008 (self-reported nanotechnology products). Nanotechnologists suggested at the September 2008 SRA nano risk workshop that increased demand for nanoparticles may have shifted market shares to such an extent that non-nanoparticles of, for example, titanium dioxide, are increasingly difficult to obtain for products like sunscreen.

[22]http://community.safenano.org/blogs/andrew_maynard/archive/2008/06/21/nano-sunscreens-leave-their-mark.aspx, blog posted by Andrew Maynard, June 21, 2008.

> *While perhaps aesthetically preferable, the mostly cosmetic benefits of nanoparticle sunscreen do not outweigh the potential health risks involved in their use*. (FOE, p.3)[84]

Despite the scientific concerns that have been raised about the potential toxicity of titanium dioxide nanoparticles in sunscreens, the Environmental Working Group (EWG) judged consumer exposures to nanoparticles in sunscreens of less concern than those stemming from toxicological properties of other sunscreen ingredients.[85] They conclude based on existing peer-reviewed studies that nanoscale titanium sunscreen is unlikely to be absorbed through human skin, though ingestion and inhalation may be of concern. The EWG review also notes that the United States lags behind Europe in screening and approving sunscreen technologies.[23]

While some public dialogues and focus group studies have addressed the use of nanomaterials in cosmetics, to the best of our knowledge no published study assesses consumers' perceptions of the risks and benefits of nanotechnology in sunscreens per se, or communications about these. In one risk perception study that did address nano applications in cosmetics, the vast majority of (Norwegian) consumers in the study were unaware of specific nano applications.[77] Nonetheless, nonprofits and advocacy groups have petitioned the FDA to regulate sunscreens more stringently, with some demanding the recall of nanotechnology products, and others demanding that FDA require full safety assessments of the use of engineered nanomaterials.

3.2. "No-Stink" Socks

> *X-System™ has the only real answer to foot odor while hunting. These socks are by far the most technologically advanced in the hunting industry, considering its ability to eliminate the source of odor by preventing bacteria growth with E47™ nano silver technology for days*. Re X-SystemTM Scent Eliminating Boot Socks, by Arc Technologies, from the Woodrow Wilson Center for International Scholars PEN inventory[24]

Among the many applications of nanoparticles, use of nanoparticles of silver (n-Ag) as an antimicrobial agent has flourished and is among the most widespread. One such consumer product application readily available for purchase is the use of nanosilver in socks to eliminate foot odor. Nanosilver in some socks on the market now washes out in as few as four 24-hour washes in ultrapure water.[86] The amount of n-Ag per sock can vary by three orders of magnitude (of those where silver was detectable, from 0.9 μg Ag per gram of sock material to over 1,000 μg Ag/gram), while the silver released over four 24-hour washes can range from undetectable amounts to 1,845 μg. One-hour washes have produced leaching of silver from some socks;[86] rates of leaching vary, depending on agitation, pH, and use of bleach.[87]

The release of nanoscale silver into wastewater may pose risks to ecosystems should it stay in the water or remain in sludge from wastewater treatment. Those risks could differ depending on the state of the silver (e.g., ionic or colloidal[25]). Silver, like other nanomaterials, behaves differently at the nanoscale, and exhibits different toxicological behaviors depending on its specific form.[58,86,88] Experimental evidence shows that coated

---

[23] Singer, N. Bill Seeks Action on Stricter Sunscreen Rules, New York Times, August 2, 2008. In August, subsequent to the release of the EWG review, Senators Dodd of Connecticut and Reed of Rhode Island introduced the Sunscreen Labeling Protection Act of 2008 to address the lack of sunscreen safety standards in the United States. While this was an attempt to force the FDA to make final rules that the agency had proposed and did not directly pertain to nanoparticle ingredients, it highlights the demand for risk-related information on sunscreens.

[24] http://www.nanotechproject.org/inventories/consumer/browse/products/x-systemtm_scent_eliminating_boot_socks/.

[25] Colloidal silver—finely dispersed, suspended particles—is negatively charged, silver ions positive.

nanoscale silver particles can penetrate intact as well as damaged human skin.[89] Modeling the lifecycle of a nanotechnology is necessary in order to understand where and what exposures and risks may arise.[58,88]

In November 2007 the U.S. EPA announced that it would regulate n-Ag used as an antimicrobial as a pesticide under FIFRA, though it did not address the nano issue head on. Other regulations of chemicals may, or should, pertain to nanotechnologies or be amended to do so, as argued by Davies[44] for the Toxic Substances Control Act, and as discussed with regard to the Registration, Evaluation and Authorization of Chemicals (REACH) regime in Europe. At present few nanomaterials are classified as “new” materials in either the Europe or North America,[90,91] with more exceptions in Europe than in North America, as noted above. Hence the production of an existing substance in nanoparticulate form (which includes virtually all nanomaterials) in many cases does not require additional regulatory testing. Regulators have thus far decided for the most part not to differentiate between matter at different scales—silver is silver no matter what minute form it comes in, though the California Department of Toxic Substances Control is considering requesting testing, fate, and transport information from manufacturers on nanosilver, as well as nano titanium dioxide.[11] Nanomaterials, be they new or old, do not per se currently trigger any distinctive E.U. regulatory requirements under the new Registration, Evaluation and Authorisation of Chemicals (REACH) regime, with the exception of carbon and graphite (for a discussion, see Ref. 49), to the chagrin of certain campaign groups.[26] General REACH obligations apply, with “no provisions referring explicitly to nanomaterials.”[27] Neither did they trigger regulatory requirements under TSCA in the United States[44] until October 2008, when the Environmental Protection Agency identified carbon nanotubes as potentially new chemicals under TSCA Section 5, following the example of changes in REACH.[28]

Here too we know of no specific studies of how people perceive the benefits and risks of silver nanoparticles in socks, though such socks are sold widely.

In one of the few studies that have been carried out of perceptions of specific nanotechnologies, perceptions of negative affect (i.e., dread) and control predict most of the variance in perceived risks and benefits of nanotechnology food applications, such as “antibacterial milk bottle for babies” and “*salmonella* detector.”[92] These findings are in line with results from psychometric studies of many other risks.[93,94] They also suggest that a regulatory framing of nanosilver applications as a pesticide might reframe public perceptions of risks and benefits from such applications in ways perhaps not fully anticipated by those who are proponents of this framing.

4. ESSENTIAL UPSTREAM ENGAGEMENT, TARGETED TRANSPARENCY?

As John F. Kennedy proclaimed in 1962, consumers have a right to safety, to be informed, to choose, and to be heard.[77,95] Transparency, access to information, and meaningfulness to non-scientists are emphasized in the European Commission Code of conduct for responsible nanoscience and nanotechnologies research. The Code launched in February 2008 with seven principles: that research should be (1) meaningful to the lay public; conducted in accordance with the principles of (2) sustainability and (3) precaution; open and inclusive, with (4) access to information for all stakeholders; and meet standards of (5) excellence, (6) innovation, and (7) accountability.[29]

---

[26] FOE April 2008 personal communication, Brussels.
[27] http://ec.europa.eu/enterprise/sectors/chemicals/reach/nanomaterials/index_en.htm.
[28] Federal Register/Vol. 73, No. 212/Friday, October 31, 2008, 64946, Toxic Substances Control Act Inventory Status of Carbon Nanotubes. [EPA–HQ–OPPT–2004–0122; FRL–8386–6].

The U.S. National Nanotechnology Initiative also includes among its four goals "Support responsible development of nanotechnology," which has a public engagement component.[30] But in the research strategy for environmental health and safety research published by the United States,(96) risk communication appears only as a subcategory of Risk Management Methods (one of five priority areas), described as "develop specific two-way risk communication approaches and materials" (p. 8). In the report's analysis of spending for FY2006, only one project is listed in this category, funded by the National Institutes of Occupational Health and Safety to address work-place safety.[31] S.1482 The National Nanotechnology Initiative Amendments Act of 2009 (S. 1482) as introduced in the U.S. Senate in 2009 requires deliberative public input (Section 11), and stipulates that the Director of the National Nanotechnology Coordination Office convene a "series of national discussions to engage the people of the United States, increase their awareness of nanotechnology, and give them a continuing voice in the evolution of nanotechnology." The Australian government also lists "foster informed community debate" as one of its three high-level nanotechnology management objectives, and public awareness and engagement as a key initiative in its national nanotechnology strategy.[32] Thus public engagement has been at the forefront of risk communication goals for nanotechnology, in line with calls for engagement "upstream," in the early stages of scientific development.(97) Actual efforts have, however, varied substantially from country to country.

In 2005 and 2006 citizen juries, consensus conferences, and public focus groups on nanotechnology were convened in numerous places around the world, including New Zealand,(98) the United Kingdom,(99,100) Switzerland,(101,102) and the United States,(100,103) as well as Australia and Germany.(104) A closer look at some of these(98,102) shows that personal experiences and analogies with other technologies—such as genetic modification and vaccines—and with other risks such as bovine spongiform encephalopathy (BSE) and asbestos, played a focal role in some of these nanotechnology discussions, and framed the consideration of social and ethical issues (see also Ref. 58). Recurring themes include right-to-know, right-to-choose (*individual* choice), and social identity, as well as a dominant benefit framing, with some applications (e.g., energy) as more obviously beneficial than others (e.g., medical).(100,105) Although these results appear consistent with the survey and experimental research to date,(20) self-selection can be an issue with public engagement strategies, depending on the recruitment and sampling approaches used.(106) Regardless, public deliberations have the potential to create valuable opportunities for interested citizens and consumers to make their voices heard.

Rogers-Hayden and Pidgeon(107) describe four kinds of deficit models as prevalent in risk communication over the last two decades, in chronological order: (1) deficits in public knowledge, (2) a rhetorical switch by science communicators to two-way communication, accompanied by a persistent belief that there are deficits in public understanding of science processes, (3) deficits in public trust, and (4) deficits in engaging publics (first three based on Rayner's work(108)). They suggest that discussions regarding nanotechnology risk communication are tending toward the fourth, the idea that engaging publics upstream is the problem risk managers and communicators need to solve. In their analysis, replacing the first three deficit models with the fourth will fail as a platform for successful societal dialogue about the risks of nanotechnologies. They also argue that the societal dialogue about nanotechnology has yet to be framed.

---

[29]IP/08/193 Brussels, 8 February 2008 Code of Conduct for Responsible Nanosciences and Nanotechnologies, Research.

[30]Public outreach and discussions are also required by 21st Century Nanotech R&D Act of 2003 Public Law 108–153 Section 2B(10)D, which specifically names "citizens' panels, consensus conferences, and educational events, as appropriate."

[31]The National Science Foundation in the United States funds several large social science projects on nanotechnology, including risk perception and risk communication research. These appear to date to be quite disconnected from mission agency activities.

[32]www.innovation.gov.au/Section/Innovation/Pages/AustraliaOfficeofNanotechnology.aspx, accessed August 20, 2008.

Despite engagement efforts to date, advocacy groups claim there has been little to no public influence on nanotechnology policy, and are calling for precaution and policy changes. In July 2007 an international coalition of consumer, public health, environmental, labor, and civil society organizations released fundamental principles for nanotechnology management, including the risk communication principles of transparency through labeling and public participation, as well as environmental and human health protection, lifecycle risk analysis including broader social impacts, mandatory regulatory review of nanomaterials as new substances, and manufacturer liability.[33] In March 2008 one of the signatories, Friends of the Earth, called for "[a] moratorium on the further commercial release of food products, food packaging, food contact materials and agrochemicals that contain manufactured nanomaterials until nanotechnology-specific safety laws are established and the public is involved in decision making."(109) Greenpeace and the Canadian pressure group ETC continue to argue for a moratorium on the development and release of nanoparticles. While some researchers rightly point out the potential pitfalls of "just the facts" approaches, calls for better information, in particular labeling, and public involvement in decision making are widespread.

5. CONCLUSIONS AND RECOMMENDATIONS

In our view, calls for better reporting and information are warranted. Web publication enables even small organizations to reach global audiences with both text and video. As technologies continue to evolve at an increasing rate, regulators and risk communicators need to better understand and employ new media and modes of communicating, including peer-to-peer communications, in order to listen better, engage public imagination, and communicate risk more effectively with diverse stakeholders. To contribute to effective risk message design, risk perception research also needs to continue to move beyond generic public opinion polling, for example, to mental models research.(110,111)

Socks and sunscreen illustrate how engineering exuberance has taken the initiative to date, throwing caution to the wind. The level of exuberance, infancy of risk analysis, lack of coherent risk management, and real potential of nanotechnology heighten the challenge for risk communicators. Upstream engagement and targeted transparency in the form of labeling may not be a panacea, but democratic approaches to decision making—which rely on informed discretion—are still better than the alternatives.(58) New approaches to institutionalizing and expanding public engagement in dialogues about nanotechnology through new media and schools may help.

It appears that the communication strategies surrounding nanotechnologies will not be easy, especially in the food area. In a recent discussion at DG SANCO Brussels regarding nanotechnologies, there was an almost laughable debate regarding whether food contained nanoparticles or not. For example, the chair of the European Food Safety Authority's scientific working group on nanotechnology, Staffan Skerfving, argued: "It is possible that some bulk materials have nano fractions. This should be investigated" (p. 1).(112) Yet he also acknowledged that scientists have no methods to detect whether nano is present in food and that they lack methods to analyze safety. And at the same time the food industry itself denies that it uses nanoparticles in its food. This has caused severe problems. As Rye Senjen at the same conference noted: "We don't know anything. We can't measure it but we can say it is ok? This is an astonishing conclusion from EFSA" (p. 4).(112) Ortwin Renn noted: "Some say that they are not using nano in food, others that they are. Is one of them is lying? No they have different definitions. We need to find the defining properties of nano… Otherwise

[33] Principles for the Oversight of Nanotechnologies and Nanomaterials, July 2007 (signed by over 40 organizations). http://www.icta.org/press/release.cfm?news_id=26, accessed August 20, 2008.

we will run from one misunderstanding to the next" (p. 8).[112] That engineered nanoparticles are often present in sunscreen even when unlabeled or labeled as "micronized" may in some cases be a question of definition as well.

We agree with Ortwin Renn that unless we uncover the defining properties of nano misunderstandings, public and stakeholder distrust toward industry will remain. One way around this is to adopt the European Medicines Agency position that a nanoparticle per se does not relate to size but to a substantive change in the property. For example, nanosilver would remain a nanotechnology even above 100 nm as its properties still fundamentally differ from those of conventional silver.

Going forward, regulators and industry need to more actively engage in proactive risk communication strategies.[58] To date they have in many regards ceded the risk communication reins to NGOs and other third parties, among whose interests the science may sometimes be secondary. If regulators in particular become marginalized from a communications perspective, it will, in our view, be increasingly difficult for them to develop risk science-based policies. Should that occur, nanotechnology appears likely to follow a similar track to that of genetically modified organisms in the past, at least in Europe, with a concomitant loss of related research investments and endeavors. In such a scenario, the lack of a proactive communication strategy for nanotechnology could have an impact on the future development of synthetic biology.[113] That lawyers are already envisioning nanotechnology as ripe for mass torts suggests urgency.[114]

Acknowledgments

We gratefully acknowledge JoAnne Shatkin, Garrick Louis, and the Emerging Nanoscale Materials Specialty Group of the Society for Risk Analysis for their support and encouragement, and thank the participants at the September 2008 workshop Risk Analysis: Informing the Management of Emerging Nanoscale Materials along with the editors and reviewers for their insightful suggestions and helpful comments. All errors are ours alone.

References

1. Bainbridge WS. Public attitudes toward nanotechnology. Journal of Nanoparticle Research. 2002; 4:561–570.
2. Fischhoff, B. Risk perception and communication. In: Detels, R.; Beaglehole, R.; Lansang, MA.; Gulliford, R., editors. Oxford Textbook of Public Health. Fifth Edition. Oxford: Oxford University Press; 2009. p. 940-952.
3. National Research Council. Understanding Risk: Informing Decisions in a Democratic Society. Washington, DC: National Academy Press; 1996.
4. National Research Council. Improving Risk Communication. Washington, DC: National Academy Press; 1989.
5. BMRB International Limited, BMRB Social Research. Nanotechnology: Views of the General Public. Quantitative and qualitative research carried out as part of the Nanotechnology study. Jan. 2004 Prepared for the Royal Society and Royal Academy of Engineering Nanotechnology Working Group BMRB/45/101-666.
6. Royal Society, Science Policy Section and Royal Academy of Engineering (RS-RAE). Nanoscience and Nanotechnologies: Opportunities and Uncertainties. London: Royal Society and the Royal Academy of Engineering; 2004.
7. Peter, D. Hart Research Associates, Inc. Awareness of and Attitudes Toward Nanotechnology and Federal Regulatory Agencies: A report of findings based on a national survey among adults conducted on behalf of the Project on Emerging Nanotechnologies. Washington, DC: Woodrow Wilson International Center for Scholars; Sep 25. 2007 (Survey conducted August 27–28, 2007.) http://www.pewtrusts.org/our_work_report_detail.aspx?id=30539 [August 15, 2008]
8. Priest S. The North American opinion climate for nanotechnology and its products: Opportunities and challenges. Journal of Nanoparticle Research. 2006; 8:563–568.

9. Market Attitude Research Services PTY LTD (MARS). [August 20, 2008] Australian community attitudes held about nanotechnology—Trends 2005 to 2008. Available at: www.innovation.gov.au/Section/Innovation/Documents/MARSStudy2008forwebsite.pdf
10. Fujita, Y.; Abe, S. AIST-NRI, Questionnaire Survey Report on Nanotechnology and Society 2005. Nanotechnology Research Institute, National Institute of Advanced Science and Technology; Jan 31. 2006 (N = 1011, in Japanese). Asia Pacific Nanotech Weekly, 4(6), (summary in English), Available at: http://unit.aist.go.jp/nanotech/ [August 20, 2008]
11. Satterfield T, Kandlikar M, Beaudrie CEH, Conti J, Harthorn BH. Anticipating the perceived risk of nanotechnologies. Nature Nanotechnology. 2009; 4(11):752–758.
12. Curall SC, King EB, Lane N, Madera J, Turner S. What drives public acceptance of nanotechnology? Nature Nanotechnology. 2006; 1:153–155.
13. Barnett, J.; Carr, A.; Clift, R. Going public: Risk, trust and public understandings of nanotechnology. In: Hunt, G.; Mehta, M., editors. Nanotechnology & Society: Ethics, Law & Policy. London: Earthscan; 2006.
14. Cobb MD, Macoubrie J. Public perceptions about nanotechnology: Risks, benefits, and trust. Journal of Nanoparticle Research. 2004; 6:295–405.
15. Kahan, D.; Slovic, P.; Braman, D.; Gastil, J.; Cohen, G. [July 30, 2008] Affect, values, and nanotechnology risk perceptions: An experimental investigation. Cultural Cognition Project. Working Paper No. 22, 2007. Available at: http://research.yale.edu/culturalcognition/content/blogsection/14/90/
16. Gaskell G, Allum N, Stares S. Europeans and biotechnology in 2002. Published 2003. Available at: ec.europa.edu/public_opinion/archives/ebs/ebs_177_en.pdf.
17. Gaskell G, Ten Eyck T, Jackson J, Veltr G. Public attitudes to nanotechnology in Europe and the United States. Nature Materials. 2004; 3(8):496.
18. Gaskell G, Ten Eyck T, Jackson J, Veltri G. Imagining nanotechnology: Cultural support for technological innovation in Europe and the United States. Public Understanding of Science. 2005; 14:81–90.
19. Scheufele DA, Lewenstein BV. The public and nanotechnology: How citizens make sense of emerging technologies. Journal of Nanoparticle Research. 2005; 7:659–667.
20. Macoubrie J. Nanotechnology: Public concerns, reasoning, and trust in government. Public Understanding of Science. 2006; 15:221–241.
21. Siegrist M, Wiek A, Helland A, Kastenholz H. Correspondence. Risks and nanotechnology: The public is more concerned than experts and industry. Nature Nanotechnology. 2007; 2(2):67–67.
22. Besley JC, Kramer VL, Priest SH. Expert opinion on nanotechnology: Risks, benefits, and regulation. Journal of Nanoparticle Research. 2008; 10:549–558.
23. Löfstedt RE. Fairness across borders: The Barsebäack nuclear power plant. Risk Health, Safety and Environment. 1996; 7:135–144.
24. Slovic P, Flynn JH, Layman M. Perceived risk, trust, and the politics of nuclear waste. Science. Dec 13.1991 254:1603–1607. [PubMed: 17782210]
25. Scheufele DA, Corley EA, Dunwoody S, Shih T, Hillback E, Guston D. Scientists worry about some risks more than the public. Nature Nanotechnology. 2007; 2(12):732–734.
26. Kahan, D.; Slovic, P.; Braman, D.; Gastil, J.; Cohen, G.; Kyser, D. [August 14, 2008] Biased Assimilation, Polarization, and Cultural Credibility: An Experimental Study of Nanotechnology Risk Perceptions, 2008. Available at: http://ssrn.com/abstract=1090044
27. Kahan, D.; Slovic, P.; Braman, D.; Gastil, J.; Cohen, G. [July 30, 2008] The Future of Nanotechnology Risk Perceptions: An Experimental Investigation, 2008. Available at: http://research.yale.edu/culturalcognition/content/blogsection/14/90/
28. Friedman SM, Egolf BP. Nanotechnology: Risks and the media. IEEE Tech Soc Magazine. 2005; 24(4):5–11.
29. Lowndes SF. News narratives about nano S&T in major U.S. and non-U.S. newspapers. Science Communication. 2005; 27:175–199.
30. [September 2008] Australian Government, Department of Innovation, Science, Industry and Research, Australia Office of Nanotechnology, April 2008. Nanotechnology—Working with the

smallest things. Apr. Available at: www.innovation.gov.au/Section/Innovation/Documents/Nanotechnology-workingwiththesmallestthings.pdf

31. Roth E, Morgan MG, Fischhoff B, Lave L, Bostrom A. What do we know about making risk comparisons? Risk Analysis. 1990; 10(3):375–387.
32. Bostrom A. Lead is like mercury: Risk comparisons, analogies and mental models. Journal of Risk Research. 2008; 11(1–2):99–117.
33. Howard J, Monatersky R, Trivedi B. European scientists dominate Nobel Prizes: Doris lessing wins for literature. Chronicle of Higher Education. 2007; 54(8):A14.
34. National Academies Keck Futures Initiative (NAKFI). Designing Nanostructures at the Interface Between Biomedical and Physical Systems: Conference Focus Group Summaries; Washington, DC: National Academies Press; 2005. Available at (quote): http://books.nap.edu/openbook.php?isbn=0309096685&page=4
35. Liu C, Dutton Z, Behroozi CH, Vestergaard Hau L. Observation of coherent optical information storage in an atomic medium using halted light pulses. Nature. Jan 25.2001 409:490–493. [PubMed: 11206540]
36. Dutton Z, Ginsberg N, Slowe C, Vestergaard Hau L. The art of taming light: Ultra-slow and stopped light. Europhysics News. Mar-Apr;2004 35(2):33–39.
37. Majewski PJ, Ping Chan C. Water purification by self-assembled monolayers on silica particles. International Journal of Nanotechnology. 2008; 5:291–298.
38. Nano. [September 3, 2010] Jun. 2008 Available at: nanomagazine.co.uk
39. Kohler AR, Som C. Environmental and health implications of nanotechnology—Have innovators learned the lessons from past experiences? Human and Ecological Risk Assessment. 2008; 14(3): 512–531.
40. Verma A, Uzun O, Hu Y, Hu Y, Han H, Watson N, Chen S, Irvine DJ, Stellacci F. Surface-structure-regulated cell-membrane penetration by monolayer-protected nanoparticles. Nature Materials. 2008; 7(7):588–595.
41. Chen HC, Roco MC, Li X, Lin YL. Trends in nanotechnology patents. Nature Nanotechnology. 2008; 3(3):123–125.
42. Youtie J, Shapira P, Porter A. National nanotechnology publications and citations. Journal of Nanoparticle Research. 2008; 10(6):981–986.
43. Huang Z, Chen H, Yip A, Ng G, Guo F, Chen ZK, Roco MC. Longitudinal patent analysis for nanoscale science and engineering: Country, institution and technology field. Journal of Nanoparticle Research. 2003; 5:333–363.
44. Davies, JC. Nanotechnology Oversight: An Agenda for the New Administration. Woodrow Wilson International Center for Scholars, Project on Emerging Nanotechnologies (PEN); Jul. 2008 PEN-13, Available at: www.nanotechproject.org/process/assets/files/6709/pen13.pdf [September 3, 2010]
45. Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR). The Appropriateness of Existing Methodologies to Assess the Potential Risks Associated with Engineered and Adventitious Products of Nanotechnologies. Brussels: European Commission, Health and Consumer Protection Directorate-General; 2006.
46. Balbus J, Denison R, Florini K, Walsh S. Getting nanotechnology right the first time. Issues in Science and Technology, Summer. 2005:65–71.
47. U.S. Government Accountability Office (GAO). [August 20, 2008] Nanotechnology: Better Guidance Is Needed to Ensure Accurate Reporting of Federal Research Focused on Environmental, Health, and Safety Risks. Mar. GAO08–402, Available at: http://www.gao.gov/new.items/d08402.pdf
48. National Research Council. Review of Federal Strategy for Nanotechnology-Related Environmental, Health, and Safety Research. Washington, DC: National Academies Press; 2009. Committee for Review of the Federal Strategy to Address Environmental, Health, and Safety Research Needs for Engineered Nanoscale Materials, Committee on Toxicology, Board on Environmental Studies and Toxicology (BEST), National Materials Advisory Board (NMAB).

49. Maynard AD, Aitken RJ, butz T, Colvin V, Donaldson K, Oberdörster G, Philbert MA, Ryan J, Seaton A, Stone V, Tinkle SS, Tran L, Walker NJ, Warheit DB. Safe handling of nanotechnology. Nature. 2006; 444:267–269. [PubMed: 17108940]

50. Renn O, Roco MC. Nanotechnology and the need for risk governance. Journal of Nanoparticle Research. 2006; 8:153–191.

51. Mantovani, E.; Porcari, A. FramingNano Project: A multistakeholder dialogue platform framing the responsible development of Nanosciences & Nanotechnologies: Mapping Study on Regulation and Governance of Nanotechnologies. AIRI/Nanotec IT; Jan. 2009 Available at: www.framingnano.eu

52. [September 3, 2010] European Parliament Legislative Resolution of 24 March 2009 on the Proposal for a Regulation of the European Parliament and of the Council on Cosmetic Products (recast) (com(2008)0049 C6–0053/2008 2008/0035(cod)). Available at: http://www.europarl.europa.eu/sides/getDoc.do?type=TA&reference=P6-TA-2009-0158&language=EN#BKMD-13

53. [September 3, 2010] European Parliament legislative resolution of 25 March 2009 on the proposal for a regulation of the European Parliament and of the Council on novel foods and amending Regulation (EC) No XXX/XXXX [common procedure] (COM(2007)0872 – C6–0027/2008 – 2008/0002(COD)). P6 TA(2009) 0171, Available at: http://www.europarl.europa.eu/sides/getDoc.do?type=TA&reference=P6-TA-2009-0171&language=EN&ring=A6-2008-0512

54. Helland A, Scheringer M, Siegrist M, Kastenholz HG, Wiek A, Scholz RW. Risk assessment of engineered nanomaterials: A survey of industrial approaches. Environmental Science & Technology. 2008; 42(2):640–646. [PubMed: 18284176]

55. Conti JA, Killpack K, Gerritzen G, Huang L, Mircheva M, Delmas M, Harthorn BH, Appelbaum RP, Holden PA. Health and safety practices in the nanomaterials workplace: Results from an international survey. Environmental Science & Technology. 2008; 42(9):3155–3162. [PubMed: 18522088]

56. Karn, B.; Matthews, SH. [August 14, 2008] Nano particles without macroproblems. IEEE Spectrum. Sep. 2007 online, Available at: http://www.spectrum.ieee.org/sep07/5487

57. International Risk Governance Council. Risk Governance of Nanotechnology Applications in Food and Cosmetics. In: Grobe, A.; Renn, O.; Jaeger, A., editors. Dialogik GmbH for IRGC. Geneva: International Risk Governance Council; Sep. 2008 Report prepared by

58. Shatkin, JA. Nanotechnology: Health and Environmental Risks. Boca Raton, FL: CRC Press, Taylor and Francis Group; 2008.

59. Hansen SF, Michelson ES, Kamper A, Borling P, Stuer-Lauridsen F, Baun A. Categorization framework to aid exposure assessment of nanomaterials in consumer products. Ecotoxicology. 2008; 17:438–447. [PubMed: 18454314]

60. Takagi A, Hirose A, Nishimura T, Fukumori N, Ogata A, Ohashi N, Kitajima S, Kanno J. Induction of mesothelioma in p53+/- mouse by intraperitoneal application of multi-wall carbon nanotube. Journal of Toxicological Sciences. 2008; 33:105–116. [PubMed: 18303189]

61. Poland CA, Duffin R, Kinloch I, Maynard A, Wallace WAH, Seaton A, Stone V, Brown S, MacNee W, Donaldson K. Carbon nanotubes introduced into the abdominal cavity display asbestos-like pathogenic behaviour in a pilot study. Nature Nanotechnology. 2008; 3:423–428.

62. Nowack B, Bucheli TD. Occurrence, behavior and effects of nanoparticles in the environment. Environmental Pollution. 2007; 150(1):5–22. [PubMed: 17658673]

63. Chaudhry, Q.; Blackburn, J.; Floyd, P.; George, C.; Nwaogu, T.; Boxall, A.; Aitken, R. Final Report: A Scoping Study to Identify Gaps in Environmental Regulation for the Products and Applications of Nanotechnologies. London: Defra; 2006.

64. Ludlow, K.; Bowman, D.; Hodge, G. A Review of Possible Impacts of Nanotechnology on Australia's Regulatory Framework. Monash Centre for Regulatory Studies, Faculty of Law, Monash University; Australia: Sep. 2007 Final Report

65. International Risk Governance Council (IRGC). Nanotechnology Risk Governance: Recommendations for a Global, Coordinated Approach to the Governance of Potential Risks. Geneva: International Risk Governance Council; 2007.

66. Schutz H, Wiedemann P. Framing effects on risk perception of nanotechnology. Public Understanding of Science. 2008; 17:369–379.
67. Cvetkovich, G.; Löfstedt, RE., editors. Social Trust and the Management of Risk. London: Earthscan; 1999.
68. Earle, TC.; Cvetkovich, GT. Social trust: Towards a Cosmopolitan Society. London: Praeger; 1995.
69. Löfstedt, RE. Risk Management in Post Trust Societies. Basingstoke: Palgrave/Macmillan; 2005.
70. Siegrist M, Cvetkovich GT, Roth C. Salient value similarity, social trust, and risk/benefit perception. Risk Analysis. 2000; 20:353–362. [PubMed: 10949414]
71. Poortinga W, Pidgeon NF. Prior attitudes, salient value similarity, and dimensionality: Toward an integrative model of trust in risk regulation. Journal of Applied Social Psychology. 2006; 36(7): 1674–1700.
72. Nisbet MC, Scheufele DA. The future of public engagement. Scientist. 2007; 21(10):38–44.
73. Morgan K. Development of a preliminary framework for informing the risk analysis and risk management of nanoparticles. Risk Analysis. 2005; 25(6):1621–1635. [PubMed: 16506988]
74. Gray, S.; Lunder, S.; Markey, K.; Sutton, R.; Leiba, N.; Houlihan, N. Environmental Working Group. [August 14, 2008] Nanotechnology. Available at: http://cosmeticsdatabase.com/special/sunscreens2008/report_nanotechnology.php
75. [September 3, 2010] Dec. 2008 Consumer Reports, No Nano Sunscreens? Available at: http://www.consumerreports.org/health/healthy-living/beauty-personal-care/skincare/no-nano-sunscreens-12-08/overview/no-nano-sunscreens-ov.htm
76. U.S. EPA. Nanomaterial Case Studies: Nanoscale Titanium Dioxide (External Review Draft). Washington, DC: U.S. Environmental Protection Agency; 2009. EPA/600/R-09/057
77. Throne-Holst H, Strandbakken P. Nobody told me I was a nano-consumer: How nanotechnologies might challenge the notion of consumer rights. J Consumer Policy. 2009; 32:393–402.
78. Australian Government, Department of Health and Ageing, Therapeutic Goods Administration. [August 16, 2008] A review of the scientific literature on the safety of nanoparticulate titanium dioxide or zinc oxide in sunscreens. 2006. Available at: www.tga.gov.au/npmeds/sunscreen-zotd.htm
79. Bennat C, Muller-Goymann CC. Skin penetration and stabilisation of formulations containing microfine titanium dioxide as physical UV filter. International Journal of Cosmetic Science. 2000; 22:271–284. [PubMed: 18503414]
80. Schulz J, Hohenberg H, Pflucker F, Gartner E, Will T, Pfeiffer S, Wepf R, Wendel V, Gers-Barlag H, Wittern KP. Distribution of sunscreens on skin. Advanced Drug Delivery Reviews. 2002; 54(1):S157–S163. [PubMed: 12460721]
81. Clift, R. Nanotechnology: An example of risk management and regulation in an emerging technology. In: Hunt, G.; Mehta, M., editors. Nanotechnology Risk, Ethics and Law. Earthscan; Available at: sei.nnin.org/doc/resource/clift%20report.pdf [November 15, 2008]
82. Barker P, Branch A. The interaction of modern sunscreen formulations with surface coatings. Progress in Organic Coatings. 2008; 62:313–320.
83. Berube D. Rhetorical gamesmanship in the nano debates over sunscreens and nanoparticles. Journal of Nanoparticle Research. 2008; 10:23–37.
84. George, Kimbrell; Georgia, Miller; Jennifer, Sass; Erich, Pica; Rye, Senjen, editors. Friends of the Earth (FOE). [August 20, 2008] Nanotechnology & Sunscreen: A Consumer Guide for Avoiding Nano-Sunscreens. 2007. Written by Ian Illuminato with contributions from, Available at: http://www.foe.org
85. Environmental Working Group (EWG). [January 10, 2010] EWG's 2009 Sunscreen Investigation, Section 4: Nanotechnology & Sunscreens. Available at: http://www.ewg.org/cosmetics/report/sunscreen09/investigation/Nanotechnology-Suns creens
86. Benn TM, Westerhoff P. Nanosilver nanoparticle silver released into water from commercially available sock fabrics. Environmental Science & Technology. 2008; 42:4133–4139. [PubMed: 18589977]
87. Geranio L, Heuberger M, Nowack B. The behavior of silver nanotextiles during washing. Environmental Science & Technology. 2009; 43(21):8113–8118. [PubMed: 19924931]

88. Luoma, SM. Project on Emerging Nanotechnologies. Woodrow Wilson International Center for Scholars; Washington, DC: 2008. Silver Nanotechnologies and the Environment: Old Problems or New Challenges?.
89. Larese FF, D'Agostin F, Crosera M, Adami G, Renzi N, Bovenzi M, Maina G. Human skin penetration of silver nanoparticles through intact and damaged skin. Toxicology. 2009; 255(1–2): 33–37. [PubMed: 18973786]
90. Council of Canadien Academies (CCA). [September 4, 2008] Small is Different: A Science Perspective on the Regulatory Challenges of the Nanoscale. Report of the Expert Panel on Nanotechnology. Jul 10. 2008 Available at: http://www.scienceadvice.ca/publications.php
91. Antje, GroB; Ortwen, Renn; Alexander, Jaeger; Dialogik, GmbH, editors. International Risk Governance Council. Risk Governance of Nanotechnology Applications in Food and Cosmetics. Geneva: International Risk Governance Council; 2008. Prepared by
92. Siegrist M, Stampfli N, Kastenholz H, Keller C. Perceived risks and perceived benefits of different nanotechnology foods and nanotechnology food packaging. Appetite. 2008; 51(2):283–290. [PubMed: 18406006]
93. Fischhoff B, Slovic P, Lichtenstein S, Read S, Combs B. How safe is safe enough? A psychometric study of attitudes towards technological risks and benefits. Policy Sciences. 1978; 9:127–152.
94. Slovic, P. The Perception of Risk. Earthscan; 2000.
95. Kennedy, JF. XXXV President of the United States: 1961–1963. In: Woolley, John T.; Peters, Gerhard, editors. 93—Special Message to the Congress on Protecting the Consumer Interest. The American Presidency Project; Santa Barbara, CA: Mar 15. 1962 [online] Available at: http://www.presidency.ucsb.edu/ws/?pid=9108 [January 9, 2010]
96. National Nanotechnology Initiative (NNI), National Science and Technology Council, Committee on Technology, Subcommittee on Nanoscale Science, Engineering, and Technology (NSET), Nanotechnology Environmental and Heath Implications (NEHI) working group. Executive Office of the President of the United States. Strategy for Nanotechnology-Related Environmental, Health and Safety Research; Feb. 2008 Available at: www.nano.gov/html/society/home_society.html [August 15, 2008]
97. Wilsdon, J.; Willis, R. See-Through Science: Why Public Engagement Needs to Move Upstream. London: Demos; 2004. Available at: http://www.changethis.com/12.SeeThroughScience [September 22, 2010]
98. Cook, AJ.; Fairweather, JR. Results from New Zealand focus groups, Research Report No 281. Canterbury, New Zealand: Agribusiness and Economics Research Unit, Lincoln University; Dec. 2005 Available at: http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.135.482 [September 3, 2010]
99. Pidgeon N, Rogers-Hayden T. Opening up nanotechnology dialogue with the publics: Risk communication or "upstream engagement"? Health Risk & Society. 2007; 9(2):191–210.
100. Pidgeon N, Herr Harthorn B, Bryant K, Rogers-Hayden T. Deliberating the risks of nanotechnologies for energy and health applications in the United States and United Kingdom. Nature Nanotechnology. 2009; 4:95–98.
101. Bellucci S, Burri R. Public perception of nanotechnology. Journal of Nanoparticle Research. 2008; 10(3):387–391.
102. TA-Swiss. Nanotechnology, Health and the Environment. Bern: Centre for Technology Assessment at the Swiss Science and Technology Council; 2006. Public Reactions to Nanotechnology in Switzerland. Report on Publifocus Discussion Forum. TA-P 8/2006
103. Kleinman, D.; Powell, M. Report of the Madison Area Citizen Consensus Conference on Nanotechnology; April 24, 2005; Available at: http://www.nsec.wisc.edu/NS-Nugget.php?ID=3
104. Bowman DM, Hodge GA. Nanotechnology and public interest dialogue: Some international observations. Bulletin of Science, Technology & Society. 2007; 27(2):118–132.
105. Bhattachary, D.; Stockley, R.; Hunter, A. [September 3, 2010] Nanotechnology for Health Care, British Market Research Bureau. 2008. Available at: http://www.epsrc.ac.uk/pubs/reports/Documents/ReportPublicDialogueNanotechHealthcare.doc
106. Löfstedt, RE. King's Centre for Risk Management. King's College London; Jan. 2008 Should big pharma be worried about nanotechnology?. Working paper

107. Rogers-Hayden T, Pidgeon N. Moving engagement "upstream"? Nanotechnologies and the Royal Society and Royal Academy of Engineering's inquiry. Public Understanding of Science. 2007; 16:345–364.
108. Rayner S. The novelty trap: Why does institutional learning about new technologies seem so difficult? Industry and Higher Education. 2004; 18(5):340–55.
109. Friends of the Earth (FOE). Out of the Laboratory and Onto Our Plates: Nanotechnology in Food & Agriculture. In: Georgia, Miller; Rye, Senjen, editors. A report prepared for Friends of the Earth Australia, Friends of the Earth Europe, and Friends of the Earth United States and supported by Friends of the Earth Germany. 2. Friends of the Earth Australia Nanotechnology Project; Apr. 2008 Written by Available at: http://action.foe.org/t/3878/content.jsp?content_KEY=4068 [August 20, 2008]
110. Bostrom A, Fischhoff B, Morgan MG. Characterizing mental models of hazardous processes. Journal of Social Issues. 1992; 48:85–100.
111. Morgan, MG.; Fischhoff, B.; Bostrom, A.; Atman, CJ. Risk Communication: A Mental Models Approach. Cambridge: Cambridge University Press; 2002.
112. European Food Law Weekly. Food could already contain nano, says EFSA. Oct 10.2008
113. International Risk Governance Council (IRGC). Risk and Opportunities of an Emerging Field. Geneva: International Risk Governance Council; 2008. Concept note: Synthetic biology.
114. Devries, SP.; Jehl, S. Toxics Law Report. Vol. 24. BNA, Inc.; Dec 3. 2009 Nanotechnology: The next battleground for mass torts?; p. 11362-11364.

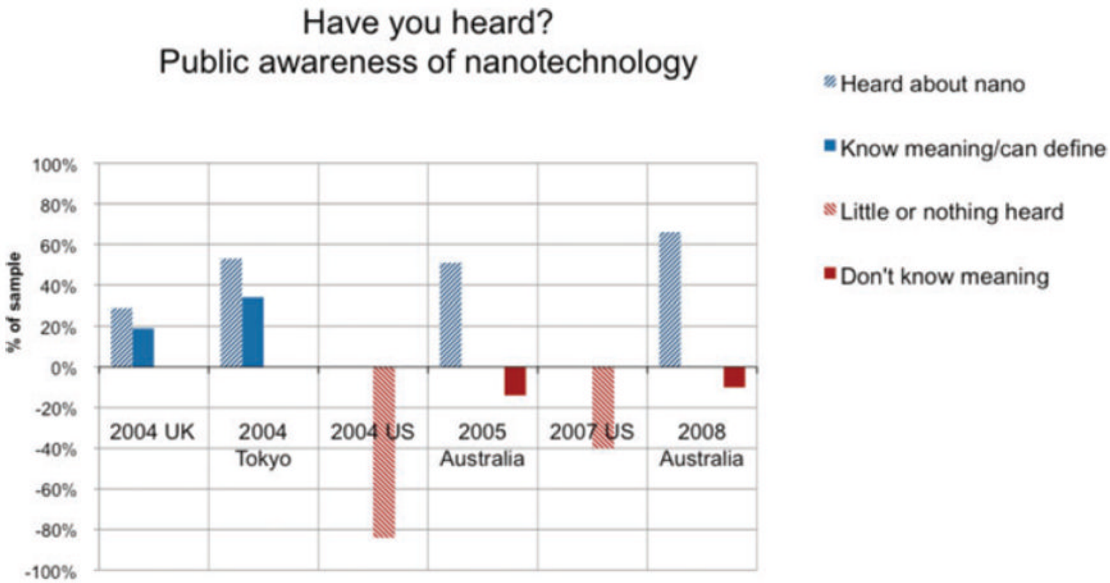

Fig. 1.

Public awareness of nanotechnology, based on data from BMRB, Royal Society, MARS, Peter D. Hart.[5-7,9]

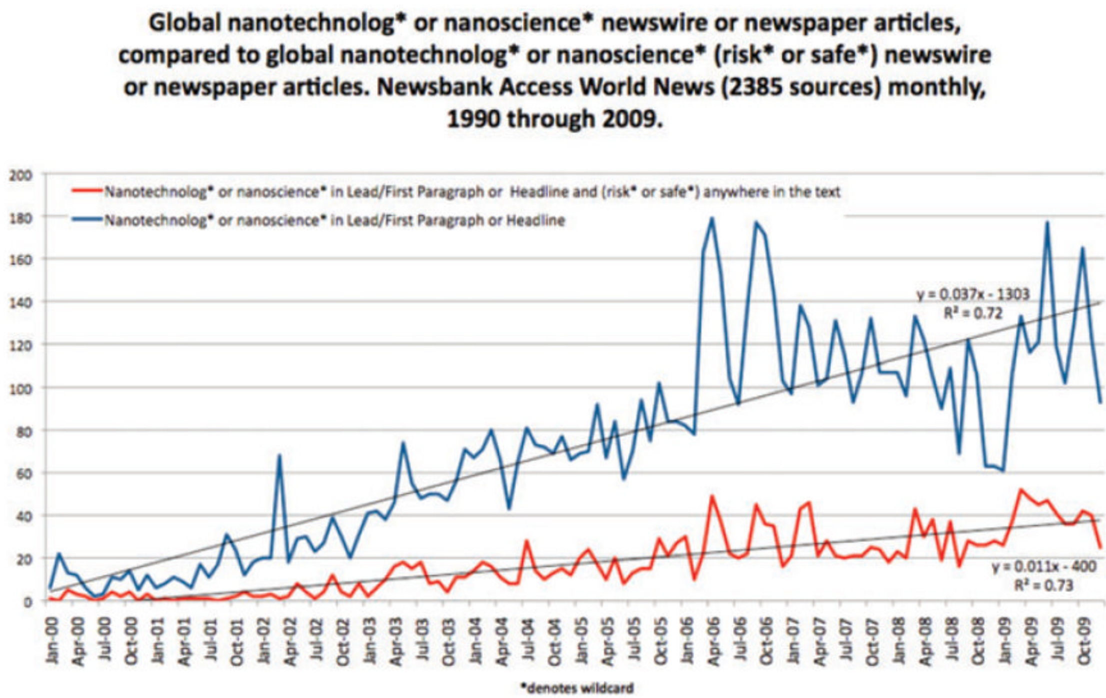

Fig. 2.

Nanotechnolog* or nanoscience* coverage in newspaper or newswire articles globally and monthly from January 2000 to December 2009, compared with the subset of those articles that include risk* or safe* in the text, linear trend lines overlaid. * a wildcard.

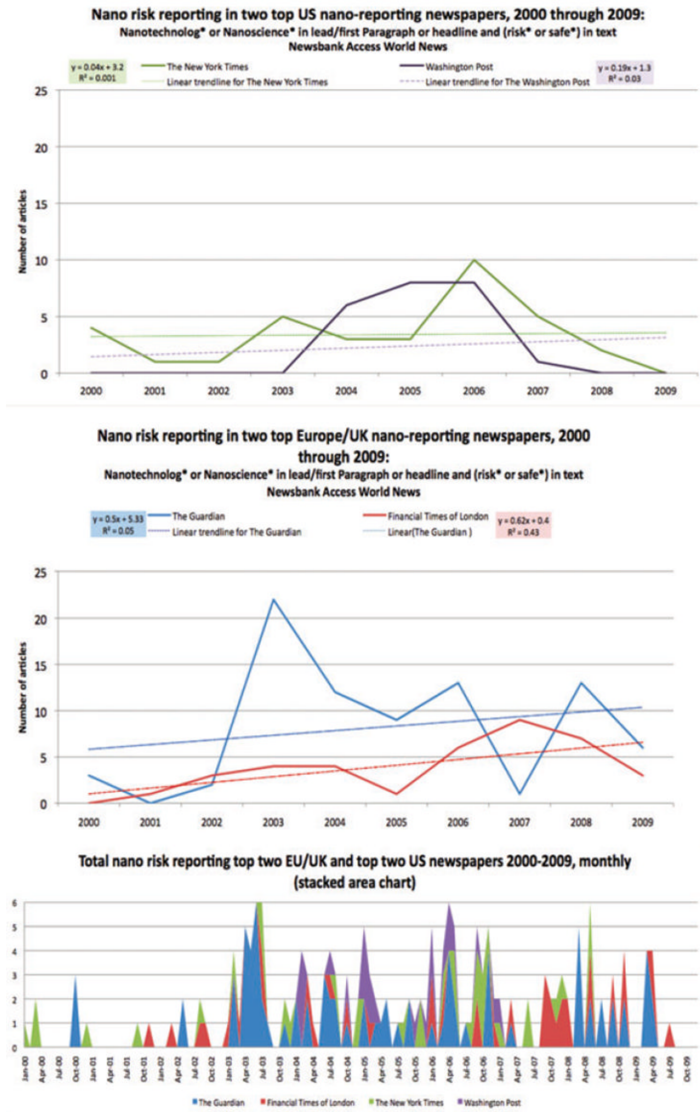

Fig. 3.

Nanotechnology risk coverage in leading U.S. and U.K. newspapers 2000–2009. Search on *nanotechnolog** or *nanoscience** (* wildcard) in the headline or lead paragraph, and *risk** *or safe** in the text, Newsbank Access Worldnews database.

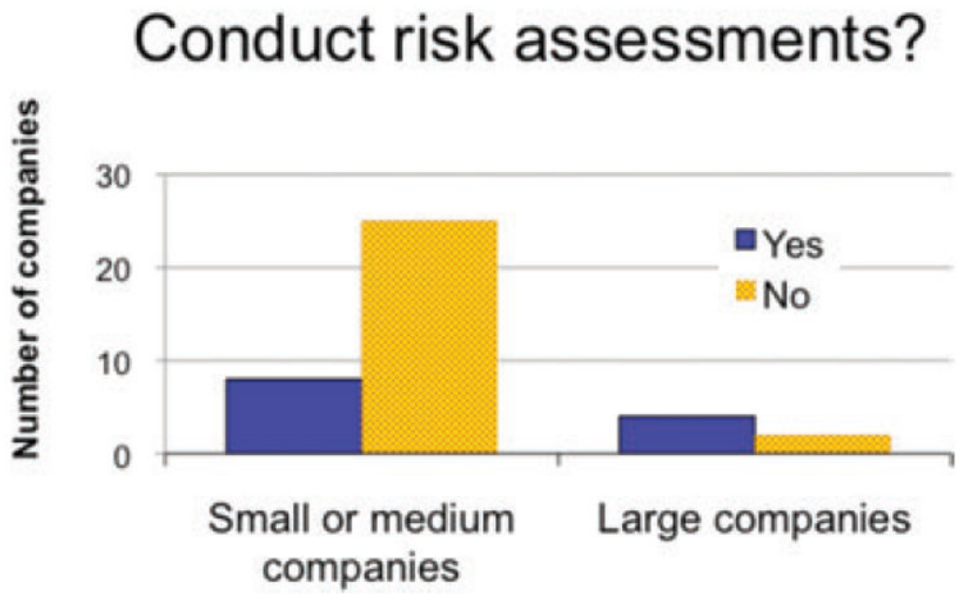

Fig. 4.
Survey data on whether Swiss nanotechnology companies conduct risk assessments, by size of company, from the study by Helland *et al*.[55]

Table I

Classification of Nanoparticles, from Nowack and Bucheli (2007)

		Formation		**Examples**
Natural	C-containing	Biogenic	Organic colloids	Humic, fulvic acids
			Organisms	Viruses
		Geogenic	Soot	Fullerenes
		Atmospheric	Aerosols	Organic acids
		Pyrogenic	Soot	CNT
				Nanoglobules, onion-shaped nanospheres
	Inorganic	Biogenic	Oxides	Magnetite
			Metals	Ag, Au
		Geogenic	Oxides	Fe-oides
			Clays	Allpohane
		Atmospheric	Aerosols	Sea salt
Anthropogenic (manufactured, engineered)	C-containing	By-product	Combustion by-products	CNT
				Nanoglobules, onion-shaped nanospheres
		Engineered	Soot	Carbon Black
				Fullerenes
				Functionalized CNT, fullerenes
			Polymeric NP	Polyethyleneglycol (PEG), NP
	Inorganic	By-product	Combustion by-products	Platinum group metals
		Engineered	Oxides	TiO_2, SiO_2
			Metals	Ag, Iron
			Salts	Metal-phosphates
			Aluminosillicates	Zeolites, days, ceremics