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Communicating the risks, and the benefits, of nanotechnology

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Abstract

Issues surrounding the wide spectrum of (perceived) risks and possible benefits associated with the rapid advance of modern nanotechnology are deliberated. These include the current realities of nanotechnological hazards, their impact vis-à-vis perceived nanotech-risks and perceived nanotech-benefits, and the consequent repercussions on the public and society. It is argued that both the risks and the benefits of nanoscientific advances must be properly communicated if the public is to support this emerging technology.

Keywords

Nanoscience; nanotoxicology; risk-benefit analysis; risk communication; risk management; risk perception

1 Introduction

Nanoscale science and technology occupy an intriguing place in early 21st century scientific inquiry. (We define nanotechnology broadly as study, development, and application of technologies at the atomic, molecular, or macromolecular levels, with at least one dimension on a scale below 100 nanometers.) Developments in nanoscale processes and manufacturing have been startling; recent technical and scientific discoveries may lead to new biomedical cancer therapies, drug delivery systems, information technology advances, consumer conveniences, and perhaps other societal improvements yet to be envisioned. Some of these successes have already been realized, although in many cases they are relatively modest innovations such as nanofiber-enhanced clothing that protects the wearer or resists stains (Robertson, 2002), nanoparticle-based cosmetics and sunscreens that improve product efficacy (Wissing and Müller, 2003), or nanocomposites that improve automobile impact strength, body lightness, durability, etc. (Presting and König, 2003; Hong *et al.*, 2005). Nonetheless, ongoing nanotechnological breakthroughs have led some nanoscientists to predict visionary advances in how our society and civilization will treat disease, manufacture products, image small-scale phenomena, build and employ new computer technologies, and clean up environmental pollution (Drexler, 1992;, 2001; Sahoo and Labhasetwar, 2003; Tolles and Rath, 2003; West and Halas, 2003). The recent joint report by the U.K. Royal Society/Royal Academy of Engineering (Royal Society/Royal Academy of Engineering, 2004) gives an informative overview of these many applications.

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Some ‘nano-visionaries’ have gone so far as to suggest utopian scenarios, expanding on the modest advances noted above. Offsetting this, a community of critics (‘nano-skeptics’) has also arisen; some simply oppose the visionary claims, but others express legitimate apprehension about the technology itself (beyond the utopian claims). Among the concerns: profit-driven nanomanufacturing can lead to environmental exploitation; unexpected toxicity of selected nanoparticles (NPs) may endanger public health; automated, runaway, self-assembling nanobots may transform the planet into a molecular ‘grey goo’ (a term coined by Drexler (Drexler, 1986) to describe a mass of small molecular assemblers that self-replicate and run wild, covering the planet with uncountable copies of themselves — depending on the source, it is also called ‘green goo’, ‘khaki goo’, and other colorful outgrowths of the original, alliterative concept; see http://www.nanotech-now.com/goo.htm); etc.

Informed, counterbalanced skepticism to any utopian claims is of course healthy (Smalley, 2001; Whitesides, 2001; Baum, 2003; Twist, 2004). But, when two contradicting viewpoints develop over an advanced, emerging technology, they can feed off each other and define the debate to the exclusion of more pertinent, central arguments. The positions quickly become exaggerated and turn to hype (Nature Editorial, 2003), distorting unbiased communication — and even perception — of the true risks associated with the technology. In this short commentary we question the validity of the hype surrounding nanotechnological risks, and of the reality that underlies it, along with some suggestions for where and how proper risk communication efforts can improve the situation. Section 2 reviews some of the nano-hazards that have been forecast, what is understood at present, and their connection with the perceived risks that have appeared in the literature and in the media. Section 3 expands on the risk perception issue, and highlights some previous examples where proper communication of risk also required communication of the *benefits* associated with a perceived hazard. Section 4 concludes with a brief discussion, building on the examples in §3 to emphasize that successful communication of nanotechnological risk must also convey the benefits of this emerging technology if the general public is to accept further development of nanoscale science.

2 Where is the Reality?

Negative arguments that emphasize risks to public health or to the environment often tend toward a polarized perspective, and in doing so they can sway public opinion against further technological development. The effect is to *stigmatize* the risks associated with the new technology (Garrick, 1998). Gregory *et al*. (1995; Gregory *et al*., 1996) formalize this, noting that stigmatized products or technologies exhibit five common features: (i) the stigma’s source is a potential hazard, (ii) accepted standards of “what is right and natural” are violated or in question, (iii) detrimental impacts are perceived to be inequitably distributed, (iv) the detrimental outcomes have an unbounded potential, and (v) questions exist about how the hazard is managed. For the hazards associated with nanotechnology the issue has for the most part been based on perceived rather than actualized risk, but these perceptions are nonetheless driving toward all five of Gregory *et al*.’s stigmatization conditions: (i) nanomaterials — the stigma’s source in the case of nanotechnology — are potential toxins (see below) that can adversely effect human health and the environment and (iv) an unbounded negative potential. Also, to non-experts, the designed and controlled synthesis of novel nanomaterials can be perceived as (ii) an ‘unnatural’ effort (challenging, perhaps, the notion of what is natural and what is not), controlled by product manufacturers and not yet under extensive public or regulatory scrutiny, so that (iii) any eventual risks and benefits may be unequally distributed; there are even plans for military applications (Phoenix and Drexler, 2004). This leads naturally to (v) questions about how the hazards associated with these nanoproducts are to be managed and regulated (Feder, 2002;, 2003; Henderson, 2004; Oberdörster *et al.*, 2005).

As Gregory *et al.* point out (p. 219), "the occurrence of [a] stigma is a signal that normal risk-management responses have failed" and that societal opinions of the potential hazard are polarizing. In such a climate, it is difficult to re-center the debate away from risks perceived as extreme (Gregory *et al.*, 1996). Previous risk perception research has demonstrated that in the absence of actual evidence on hazardous outcomes (and sometimes despite it; see §3), the public tends to be hesitant of emerging and unknown technologies over which they have little control (Slovic, 1987; Renn, 2004) and that are seen as "tampering" with nature (Sjöberg, 2000). Risk perception is of course far more multidimensional than these few factors admit (Bennett and Calman, 1999; Sjöberg, 2000); indeed, among lay observers some will work through the subject rationally and come to an informed opinion about the risk, but many others will form personalize heuristics and likely act only on those. Polarized positions on emerging nanotechnologies typically highlight just these sorts of high-risk characteristics. As a result, modern risks perceived to be associated with nanotechnological development appear in a state of flux.

Even so, genuine scientific data on nanotechnological hazards are limited: reliable information on how the size, shape, and surface functionality of nanomaterials affects their bioavailability, uptake, metabolism, and degradation is only now emerging. Initial studies have appeared on the toxic effects of NPs, but to date the results vary: some findings showed no significant toxicity (Hucszko and Lange, 2001; Hucszko *et al.*, 2001; Merget and Rosner, 2001; Connor *et al.*, 2005) or mixed outcomes (Warheit *et al.*, 2004), while more recent works have identified selected toxic effects (Service, 2003; Shvedova *et al.*, 2003; Lam *et al.*, 2004; Oberdörster, 2004). These studies typically involve human or animal endpoints, and other important issues such as detrimental/toxic potential to larger ecosystems remain open (Moore, 2002); indeed, the current call is for more studies that can identify and define the broader spectrum of toxicity resulting from NP exposures (Hood, 2004); see Oberdörster *et al.* (2005) for an extensive, modern review of the evolving science of nanotoxicology.

With a view towards the future, the uses and applications of manufactured nanomaterials will presumably intensify, and this has led to concerns that products previously viewed as innocuous may exhibit detrimental qualities as they are reduced to the nanoscale (Geske, 2004). If so, the risk to public health and the environment will far exceed that originally anticipated, and efforts must be redoubled to study, understand, and communicate this to society at large (Schuler, 2003; Renn, 2004; Schuler, 2004; Service, 2004). Hett (p. 41) puts it pointedly enough:

> "Most nanoparticles are presumably non-toxic in the strictest sense. In view of their diminutive size, however, they have special properties with resultant risks that are still largely unknown. [N]o one really wants to wait and see what the lessons of long-term experience will be." (Hett, 2004)

That is, since the reality with nanoscience is that its risks are not fully understood (Wilsdon, 2004), a cautionary approach to development of the technology may be the wiser course of action at present. Risk analysts will recognize the embedded appeal to the famous *Precautionary Principle*: "if the consequences of an action, especially concerning the use of technology, are unknown but are judged by some scientists to have a high risk of being negative … then it is better not to carry out the action rather than risk the uncertain, but possibly very negative, consequences" (http://en.wikipedia.org/wiki/). The principle is often invoked when there is a lack of full scientific certainty about the threat of harm from an activity, at least as applied to possible environmental outcomes (Kriebel *et al.*, 2001), and as seen above, the currently understood risks of toxic and otherwise detrimental effects of nanotechnology are indeed uncertain. Applications of precautionary measures, from comprehensive moratoria on continued technological development to targeted management of selected industries/technologies, are generally based on a spectrum of possible strategies (Hrudey and Leiss, 2003). For nanotechnologies the options include: minimization of haphazard release of NPs into the environment, a shift of the burden of proof (of safety) on to the nanotechnology proponents and industrialists, enhanced public communication (mentioned above) and participation in the decision-making process, increased levels of truly interdisciplinary and cross-industry collaborations in modern nanotechnological research, and a greater emphasis on *managing* the risks of this new, innovative technology until their realities can be more fully understood, without, of course stifling any future research into the nature and potential adverse effects of NP exposures (Hett, 2004; Royal Society/Royal Academy of Engineering, 2004; Schummer, 2004; Hett, 2005; Oberdörster *et al.*, 2005). The challenge is real: Montague (2004) remarks that nanotechnology "may offer a major test of the Precautionary Principle as a new way of managing innovation" and, as we argue below, an important component of this effort includes properly balanced communication of both the risks of the technology and the benefits it may achieve.

3 Risk communication vs. Benefit Communication

Communicating the risk(s) of an emerging technology takes careful effort, especially within the context of uncertain, future hazards. Risks of adverse events from technological change are often perceived with heightened concern (Frewer, 1999b; Garvin, 2001; Ropeik and Slovic, 2003), and similar to Gregory *et al*.'s stigmatization schema (§2), perceived risks can be exacerbated by the lay publics' greater lack of background technical knowledge, by large inequities among individuals or groups exposed to the new technology, by limitations in personal control of the actual exposures, by increased pace of diffusion of the technology into the social environment, and in some cases by lack of trust with the sponsoring institution(s) (Renn, 2004). The phenomenon is socially constructed, multidimensional, and psychologically complex. Successful communication of an emerging technology's risks requires a blending of science and judgment with pertinent psychological, social, cultural, and political inputs (Slovic, 1999).

Many examples exist where the communication effort has failed, often when "spin" control was lost after organizations with hyper-targeted agendas and/or the media took interest in the issue. A classic case occurs with the nuclear power industry, where mid-20th century forecasts heralded great societal benefits from the development of unlimited, inexpensive, non-polluting nuclear energy. By the late 20th century, however, these promises gave way to social concerns about radiation exposure and consequent human health risks, unsafe and improper nuclear waste disposal, poor and uneven nuclear risk stewardship/management, and environmental degradation due to power plant accidents. (There is also the issue of investment risks for the nuclear plant owners, which we leave aside in this discussion.) These risks are unassailable (Grimston, 2002), and the power plant disasters at Chernobyl in 1986 and, to a lesser extent, Three Mile Island in 1979 certainly brought them to center stage. A public relations boon to the growing number of anti-nuclear interest groups, the accidents illustrated that extreme events can in fact occur and that consequences to public safety and ecosystem health can be substantial. Into the 21st century, nuclear risk continues to generate public anxiety, due in part to these earlier accidents and to the public relations hype that followed, and also to the above-mentioned issues of public hesitancy with highly technical, potentially untrustworthy industries over which it has little control.

Overlooked, however, were the cases — previous and since — of safe, successful nuclear power plant operation, and the societal benefits that have accrued. Indeed, there is considerable disparity between the perceived risk and actual risk: the combined average loss of life expectancy due to reactor accidents or occupational radiation exposure is one fifth of that due to motor vehicle accidents: 42 days vs. 207 days, respectively (Everitt, 2002). One factor contributing to these disparities is that the benefits initially put forth in support of commercial nuclear power did not settle fully into the public's consciousness, despite ongoing promotional efforts highlighting informed expert opinion on the larger social benefits the industry provides. To date, efforts to educate the public typically fail to overcome the perceived high-risk consequences of nuclear power.

More generally, expert opinion extolling safety is often a difficult sell to a public that has experienced a low-probability/high-consequence event, and whose level of trust in the underlying risk managers or industry leaders has been affected (Garvin, 2001). Those instituting the new technology or championing its cause must view the larger public as true stakeholders in the process, and not merely as uninformed onlookers (Santos and McCallum, 1997; Renn, 2004). Useful in this regard is further emphasis on the specific, day-to-day benefits provided by the industry. For example, if energy consumers can understand how and why nuclear power generation brings them workplace, commercial, or lifestyle enhancements, their view of the risks associated with it can be put into a larger focus. Indeed, a *benefit analysis* such as this may mitigate high-risk public perceptions of nuclear risk (Slovic, 1999).

More recent, and also more pertinent to the nanotechnology debate, is the ongoing public concern with emerging biotechnologies such as genetically modified (GM) foods. Take, e.g., the case of Bt corn. (“Bt” stands for *Bacillus thuringiensis*, a soil bacterium whose genetic material is transfected into the corn, enhancing its protective capabilities against certain crop destroying insects.) Seen as a cost-effective alternative to agricultural pesticide spraying, Bt corn has become a popular GM crop for U.S. agricultural production (Martin and Hyde, 2001). A controversy over it was triggered, however, when in 1999 a preliminary scientific study suggested that Bt corn pollen may endanger the monarch butterfly by harming its developing larvae (Losey *et al.*, 1999). On the day following release of the study, both the U.S. and European media covered the story with sensationalized headlines: Biotech vs. ‘Bambi’ of insects? Gene-altered corn may kill monarch” (*Washington Post*); “Engineered corn kills butterflies, study says” (*USA today*), “Pollen from GM maize shown to kill butterflies” (*The Guardian, London*), etc. Opponents of genetic engineering quickly emphasized that scientists had overlooked the harmful environmental impacts of bioengineered plants such as Bt corn, and the detrimental risk perceived to be associated with GM foods rose. This had substantive consequences for the GM crop industry as many food producers, under public pressure, announced that they would no longer use GM ingredients. European response was particularly severe: already sensitive to public fears over GM biotechnologies, the European Union (EU) set a moratorium on GM foods.

Lost in the din was the fact that the original study was only preliminary (and, to some observers, exhibited debatable scientific standards): even the paper’s authors argued that “it is imperative that we gather [further] data necessary to evaluate the risks associated with this new agrotechnology…” (Losey *et al.*, 1999). A larger study, supported in part by major Bt corn producers (Monsanto, Novartis, and Dupont) but also reviewed by the prestigious U.S. National Academy of Sciences, did just that. The conclusions, published in 2001, suggested that the early hype was an overreaction: Bt corn was shown to present minimal risks to monarch larvae (Sears *et al.*, 2001). Further studies have shown no overt toxicity to animals that consume the corn, including humans (Stewart *et al.*, 2000; Aumaitre, 2002). In fact, to date the only established risks of Bt corn involve possible food allergenicity, horizontal gene transfer into other non-target plants, the economic impacts to organic farmers of the GM plants out-crossing to their organic crops, and the potential investment risk to Bt corn producers affected by international market wariness of GM crops (see below) (Wu, 2004). All are valid risks, to be sure, but none so debilitating as to require broad-based bans of the technology. By contrast, realized benefits of Bt corn production include increased yields to farmers employing the crop, consequent decreases in consumer costs (when passed on by the producers and agribusinesses), positive environmental/ecological consequences from decreased used of chemical pesticides, and, interestingly, an increase in resistance of the corn to contamination by certain fungal mycotoxins — apparently, greater fitness due to lowered insect stress allows the plants to better resist the fungal infection — leading to improved health in the livestock that eventually consume the corn (Wu, 2004).

Despite scientific input on the limited risk of the technology, public perception that Bt corn is an environmental hazard remains largely unaffected. Although production continues in the U.S. and some other nations, the EU and many allied political entities remains opposed to GM foods; indeed, a 2002 donation of GM corn was initially refused by a number of famine-stricken sub-Saharan nations due to concerns over its environmental, economic, and public health risks (The Economist Print Edition Editors, 2002). As with the older debate over nuclear power, expert scientific opinion and even societal needs cannot seem to overcome negative public perception of risks from the new technology.

But why? Arguably, Bt corn has achieved all five of Gregory *et al*.'s stigmatization conditions from §1, and its comparative value has not been successfully communicated to its potential consumers. Indeed, in the EU the public stigma may be irreparable: realized benefits to stakeholders in the debate are uneven, and the corn-consuming public does not appear to view the advantages of Bt corn higher than its perceived risks. A persuasive argument can be made that the initial media hype has in fact been largely dismissed, and that it is not misperceived risks so much as the limited benefits and lack of true innovative character that burdens GM foods (Gaskell *et al.*, 2004). (Put bluntly, how important is it to an urban professional in Paris that a farmer in Nebraska uses less pesticide on his corn fields?) The debate would likely change if the consumer price for corn dropped to pennies on the kilogram, or if the GM technology led to, say, a cure for cancer. At present, however, the perceived (and actual) risks of this emerging technology cannot be overcome by its existing, limited benefits (Wu, 2004).

4 Discussion: Consequences for nanotechnology

The values of proactive benefit communication for an emerging technology complement more traditional forms of risk communication (Frewer, 1999a); indeed, one can be viewed as an arm of the other. For the emerging applications of nanotechnology, perception of risks is still evolving, and while the risk realities are of lesser magnitude than their hype (§2), the technology may be close to achieving a risk stigmatized status. Once in place, risk stigmas are often difficult to overcome (Slovic, 1987); nanotechnology holds a slight edge here in that, so far, many of its operating mechanisms and manufacturing processes remain largely opaque to non-experts (Hett, 2004). While this has encouraged public skepticism, it also suggests a relatively blank slate upon which both the risks and the benefits of the technology may be defined. Thus nanoscientists have an opportunity to take the lead in communicating the real risks and benefits of nanotechnology to the public. Maintaining credibility will be crucial here: societal skepticism is natural when vested interests take the lead in communicating the benefits of an emerging technology (Leiss, 1995; Jungermann *et al.*, 1996), and loss of public confidence in expert testimony can lead to breakdowns in public trust and risk perception. Indeed, perceptive dimensions such as public belief, societal conviction, and ethical consequences have received limited attention in this area; how these views will evolve with advances in nanoscience and nanotechnology must be explored as well (Baird *et al.*, 2004).

Beyond this, however, a coordinated mix of informed expert input and public participation should be brought forth on both the risks *and the benefits* of this emerging technology (Borm, 2005; Oberdörster *et al.*, 2005). As with the example of GM foods (§3), without an understanding of how nanotechnological advances in small-scale biomedicine, product manufacturing, environmental clean-up, and even stain-free pants, etc., will make the world better for herself or himself, the typical public observer is as likely as not to be swayed by simpler, hyped arguments, the majority of which may tend to highlight extreme-but-improbable risks such as the now-infamous grey goo. The communication effort can take many forms, but a set of common features should lie at its core: the depth of technical material should be limited ("keep it simple"); balanced media reporting should be encouraged and supported; the public benefits should represent the leading edge of any communication campaign, highlighting in particular the economic impacts to individuals and to society in terms relevant to them (Taig, 1999); uncertainties in the risks must be acknowledged (Wilsdon, 2004); and, of course, in no cases should any misinformation or factual fabrications be promulgated. To counter possible high-profile/short-on-detail hype from antagonistic sources, we suggest a form of hype 'immunization': operate pro-actively to increase inclusionary processes and participatory models of public engagement in the process (Amendola, 2001). Possible vehicles include consensus conferences (widely employed in communicating biomedical disease risks), citizen juries/citizen's schools, and focus groups, where participants learn about nanotechnological risks and benefits, formulate opinions and ideas relating to the technology, interact with panels of invited experts, etc. These strategies are enjoying growing interest in communicating technological risk to the public, particularly in the Pacific rim and Europe (Fujigaki, 2002; Rowe and Frewer, 2004), although of course further developments are possible. Indeed, the efforts share similarities with the larger push to 'democratize' scientific and technological agendas among the lay public and engage an informed public in a multi-way debate (Charnley *et al.*, 2000); here again, some successes along these lines have already been achieved within the European nano-tech community (Wilsdon, 2004).

Of course, some intangibles still persist. Ongoing toxicity studies with nanomaterials have identified greater toxic potential than previously identified (Hood, 2004), and while sufficient data are still lacking for complete, formal hazard assessments, an outline and approach for analyzing the risks of NP exposure has been well characterized (see, e.g., Fig. 15 in Oberdörster *et al.* (2005)). In any case, the outlook on nanotechnology has become more circumspect; e.g., in their 2004 report on opportunities and uncertainties of nanotechnological development, the U.K. Royal Society/Royal Academy of Engineering noted that despite apparent public enthusiasm for the benefits nanotechnological breakthroughs could bring about, questions lingered on potential impacts to public health and safety, and to the environment. (Indeed, analogies were often reported with both nuclear power and with GM bio-materials.) The joint report's consequent recommendations were decidedly precautionary (cf. §2, above); among them, setting occupational exposure limits to very low levels, redirecting scientific and regulatory resources to gain a better understanding of the vulnerabilities and hazards associated with the new technology, minimizing release of nanomaterials into the environment, and viewing manufactured NPs as if they were hazardous "until there is evidence to the contrary" (Royal Society/Royal Academy of Engineering, 2004). These recommendations represent a reversal of more traditional societal approaches to technological and industrial development, where historically most new, innovative products have been assumed benign until proven otherwise (Montague, 2004). In a sense, the risk perception 'bar' is being raised on the benefits required to counter the heightened risk, and the advances promised by nanotechnology will need to involve more than simple consumer comforts such as stain-resistant pants or more convenient sunscreens. (Once again, how much will our friendly urban professional in Paris care about buying nano-sunscreens?) Indeed, a countervailing argument exists, suggesting that by raising public attention to a controversial technology, especially through broad, popular media coverage, public attention will center on the detrimental outcomes, increasing overall opposition to the technology's development. (That is, even if the supportive and oppositional views are presented in a fair and balanced fashion, the net effect will be to raise doubt in the public mind about the wisdom of disseminating the technology.) Hence from a partisan perspective, opponents of nanotechnology should *encourage* maximum media coverage, as this is likely to increase public fear and opposition. By contrast, proponents of nanotechnology should work to minimize media coverage, allowing the development and evaluation of the technology to proceed "below the radar" of hype-susceptible observers. While plausible, we view this latter perspective as overly cynical; we believe the lay public and the media at large will not be so easily distracted, and that if allowed to participate in the discussion, if given a balanced view of the risks and the benefits, and if those communicated benefits are seen to outweigh the communicated risks, they will come to fair conclusions about emerging nanotechnologies.

On the whole, nanotechnology may bring great benefits to our society: improved medical, dental, and pharmaceutical therapies (and possibly even that notorious cure for cancer) lead the list, but many other extraordinary possibilities follow right behind. It may also bring some substantive risks. All components of this risk-benefit spectrum — from human toxicity of NP exposure to advances in medicine and manufacturing — should be communicated in a participatory manner to the lay public, so as to maximize its capacity to decide between the two and to make an informed judgment about the technology. By engaging open debate on the matter such that public participants are approached as key stakeholders, and by combining this with open information on the benefits of this emerging technology (and not just focusing on the possible risks), we believe a substantive difference can be made in the public's acceptance or rejection of nanotechnology.

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