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Nanotech Safety 101 or How to Avoid the Next Little Accident

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Somewhere out there, in some obscure laboratory or firm, in the near future, maybe in your neighborhood, is an accident waiting to happen. This accident will involve a new type of technology, nanotechnology, which focuses on the creation of new and novel properties in the world of the very small (a nanometer is approximately one eighty thousandth the diameter of the human hair). This mishap will chill investment, galvanize public opposition, and generally lead to a lot of hand wringing on the part of governments who are betting large sums of money on the nanotech revolution.

Will it be just bad luck or bad practices? Probably the later. Whether we are talking about airplanes, nuclear power plants, electric grids, chemical production facilities, or operating rooms, bad practices, which often go unnoticed or unreported, kill, maim, or otherwise turn a perfectly good day in corporate America into a nightmare. There are a number of reasons to believe that bad practices will appear before good practices in the nanotechnology realm and it will only take one or two significant incidents, played out under the glaring lights of the global media, to kill public confidence in a range of potentially important emerging technologies. Why might something go wrong?

The first involves what Princeton historian Ed Tenner once called the "tendency of advanced technologies to promote self-deception."[i] At the front end of every new technological revolution is an ever-expanding bubble of enthusiasm and optimism. Remember nuclear power (energy too cheap to meter), the PC revolution (the paperless office), or biotech (we will feed the world). Nanotech is riding the hype wave like a happy surfer at Waikiki. Optimism is important for technological success – it drives investment and innovation – but we need to be acutely aware of its likely effects on collective and individual judgment. Research by psychologists like Nobel prize winner Daniel Kahneman at Princeton have shown that optimists often believe that they have much more control over the world than they actual have.[ii] A tendency to err on the side of desired outcomes can have disastrous results. The Columbia Accident Investigation Board found that NASA's top management was provided with over-optimistic assessments of the damaged Columbia spacecraft as it orbited the Earth. In addition, optimists will underestimate (often by orders of magnitude) the costs and levels of effort needed to accomplish longer-term objectives (the low estimates of the costs to adequately reconstruct Iraq are a recent example). In short, when new technologies emerge, hubris often trumps humility and suddenly scientists, engineers, and entrepreneurs actually believe they can predict and control outcomes in complex physical and biological

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systems, and do it cheaply. As Sydney Finkelstein at Dartmouth has noted, honest pride "starts going towards self-confidence, overconfidence, complacency, and arrogance. It's just a natural progression."[iii] If things start to unravel and nature takes revenge it is easy for the scientists and engineers to retreat behind the policy folks, who are left facing an irate public, Congressional hearings, and a hoard of finger-pointing NGOs.

The chance of such self-deception is higher in the case of so-called "national prestige technologies" such as nanotechnology that are turned into surrogate indicators of U.S. technological leadership in the global economy. Despite an annual federal investment in nanotech of over one billion dollars, the Congress was recently told by representatives of the President's Council of Advisors on Science and Technology (PCAST) that "Other countries are aggressively chasing U.S. leadership." If we do not speed up, we will loose the nano-race to the Chinese, or heaven forbid, the South Koreans, who could end up cloning a whole army of nano scientists. These fears around competitive position were expressed by one source who noted that "government officials worry that perhaps for the first time in recent memory, the United States does not have a clear advantage."[iv]

When we wrap the national flag around any technology in a global race to the top, we can quickly kill the kind of dissent that is crucial to the early warning of impending disasters and system failures. Organizations, both public and private sector, create a situation where important information about the risks and threats are lost, distorted, or ignored because "managing the message" and maintaining face often becomes more important than managing risks.[v] This is a dangerous strategy to follow with science, as physicist Richard Feynman noted when he observed that, "For a technology to succeed, reality must take precedence over public relations, for nature cannot be fooled."

But dissent in large organizations is difficult. Think about what happened to the lower-level engineers who tried to speak up about the possible problems with the space shuttle; or David Graham, the doctor at the FDA, who went public with his concerns about the safety of Vioxx; or FBI agent Coleen Rowley, who tried to provide a heads-up on the 9/11 attack plans. Even if some government official believed that our existing set of safeguards and statutes would likely fail if applied to nanotechnologies, the probability that they would publicly state such a proposition is infinitesimally small. This tendency forecloses the possibility of a much needed and balanced debate that should occur early in the introduction of any new technology. Unfortunately, no rules or regulations will save you from this type of "failure to disclose," which is a function of the institutions we create, how we manage them, and their leadership.

Another key challenge involves the structure of the nanotechnology industry itself. Naotechnology will not play out in a handful of large and well-staffed facilities where oversight and proper workforce training are relatively easy. The scientific investment strategies of the U.S. government, and dozens of other countries, have been designed to distribute nanotechnology R&D efforts across hundreds, and eventually thousands, of laboratories globally. These labs will in turn incubate thousands of small firms involved in a Darwinian struggle to push product to market.

Already there are 1200 nanotech start-ups worldwide, with more than 60 percent in the U.S. If one adds university laboratories, we have thousands of people working at the messy and often unpredictable interface between novel technologies and human judgment. Assume that much of the workforce is young -- graduate students, post-docs, and other Gen-Y types with newly minted science or engineering degrees -- a cohort of people convinced of their immortality and more interested in pushing the envelope of physical endurance than adhering to safety protocols in the workplace. Many of these labs and firms will be in places like China, which generally lack the regulatory oversight and ethical controls necessary to pull the brakes on a runaway technological disaster.

Finally, even if we could readily access the thousands of workers and consumers that need information, what would we tell them? No government, including the U.S., has a clear, concise message regarding the risks of nanotechnology and their management, either for workers, the populace in general, or the environment. People do stupid things because they often lack the basic information to know what is right. Even if the knowledge is available, it is difficult to ensure that those who need it have ready access to it. As J.F. Kennedy said during the Cuban Missile Crisis, "There is always some son of a bitch that doesn't get the word." In the case of nanotechnologies, there will be many people distributed throughout the global who may not get the information that they need, when they need it the most, to deal proactively with emerging risks.

So what can be done?

Paradoxically, one of the most important things to do at this stage of the game is to focus on the bad practices. Every single day vigilant and intelligent people recognize errors around them and can often come up with ingenious ways to correct problems. Taken one at a time, these bad practices seldom lead to a disaster, if recognized early and addressed. The challenge is to develop ways for "error correcting knowledge" to be collected, managed effectively, and channeled into solutions. One model for this is the Aviation Safety Reporting System, which collects and analyzes voluntarily submitted reports from pilots, air traffic controllers, and others involving safety risks and incidents. The reports are used to remedy problems, better understand emerging safety issues, and generally educate people in the aviation industry about safety. A similar system in the U.K., called CHIRP, is designed to promote greater safety in both the aviation and maritime industries and is run by a charitable trust.

One option is to create a Nano Safety Reporting System where concerned people working with nanotechnologies, in laboratories, companies, or elsewhere can anonymously share safety issues and concerns. The purpose is not "finger pointing" but encouraging proactive learning before something goes really wrong. Information could be used to design educational materials, better structure technical assistance programs, and provide a heads-up on a host of emerging safety issues.

Second, we need to begin to design better early warning systems to allow due diligence on nanotechnologies to be gathered further "upstream" in the research and development processes. That means that the implications of nanotechnologies must be considered in parallel to the development of applications, not after the fact.   Impact assessment cannot be seen as an "add-on" or simply "outsourced" to other disciplines and institutions. One approach is the development of fast-turnaround screening technologies that can be embedded in the product development cycles of companies. Cost will have to be low (thousands or dollars, not hundreds of thousands), screens fast (producing results in less that 3-4 months), and testing global, designed to screen widely, looking for novel and non-traditional effects that one might expect with nanotechnologies.

Beyond this, the government needs "push strategies" directed at small businesses, start-ups and labs. If someone is running an 8-10 person nanofirm, how much time and how many resources do you think they have to devote to environmental, health. and safety issues? The government (at federal, state, and local levels) needs to knock on their door with useful technical assistance. One of the best ways of delivering this information is to use existing outreach and education systems such as technical assistance programs at universities or the federal government's large network of extension services.   Other options include the development of peer-to-peer mentoring programs between small businesses and the transfer of expertise by large firms to small nanotech businesses in their supply chains.

Finally, scientists and engineers need to be addressing the basic question: Can nanotech be made *inherently safe*? And, if so, how? This is more than a technological question. One common strategy of mitigating accidents is "defense in depth" which employs multiple backup systems. These technical systems are built regularly into nuclear power plants and electric grids but they have limitations, often in the form of human overrides, error, or negligence. Beyond engineering safe production systems for nanotechnologies (Green Nano), we need strategies to build resilience into the institutional systems involved with nanotechnologies, whether corporate, government, or academic.[vi]   Karl Weick at the University of Michigan has studied highly reliable organizations and his recommendations could easily be applied to organizations involved with nanotechnology: focus on all failures and learn from them; don't simplify the complex; be hyperaware of your operations; build in resilience to keep errors from cascading out of control; and distribute decisionmaking down and around, making sure you listen to your experts, not just your boss.[vii]

Dealing with safety issues around nanotechnology at this point in time is a piece of cake compared to what it coming. As nanotech and biotech converge and as scientists begin to put together systems of nanoparticles with multiple functions, and then systems of systems, the behaviors will become more complex and difficult to predict.

We can do something now, or we can wait. Maybe we will be lucky, but don't count on it.   An explosion at a polyethylene plastics factory in Texas killed 23 people and cost Philip Petroleum $1.4 billion in damages and government penalties.[viii] Three years ago the power grids in the Northeast collapsed. A mature piece of technology, the space shuttle, failed twice. Just when we begin to take technologies for granted, some surprise occurs, some unintended consequence, some bad decision made all too quickly by humans caught off guard by a supposedly infallible system that fails. Nanotechnology is planned disruption and it will surprise us. Given the size of our investment and the promises the technology holds, do we want to take a chance?

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[i] Tenner, Edward (2001). "When Systems Fracture," *Harvard Magazine*, November-December.

[ii] Lovallo, D.& Kahneman, D. (2003). "Delusions of Success: How Optimism Undermines Executives' Decisions," *Harvard Business Review*, July.

[iii] Finkelstein, S. (2003). *Why Smart Executives Fail*: *And What You Can Learn from Their Mistakes*, NY: Penguin Books.

[iv] Hine, Christine (2003)."Nanotechnology: Small Miracles Foreseen; Some Lawyers Say Trend will Rival Semiconductors and the Internet," *New York Law Journal*, 13 November, 5.

[v] Sonnenfeld, Jeffrey (2005). "Why It's So Hard to Blow the Whistle, *Yale Alumni Magazine*, March-April.

[vi] For information on the GreenNano Initiative of the Project on Emerging Nanotechnologies, see: http://www.nanotechproject.org/index.php?id=41

[vii] Weick, K.E. & Sutcliffe, K.M. (2001). *Managing the Unexpected*, San Francisco, CA: JosseyBass.

[viii] Chiles, James (2001). *Inviting Disaster: Lessons From the Edge of Technology*, New York: Harper Business.