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#816 - Nanotechnology and the Precautionary Principle

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Nanotechnology -- or nanotech, for short -- is a new approach to industrial production, based on the manipulation of things so small that they are invisible to the naked eye and even to most microscopes.

Nanotech is named for the nanometer, a unit of measure, a billionth of a meter, one one-thousandth of a micrometer. The Oxford English Dictionary defines nanotechnology as "the branch of technology that deals with dimensions and tolerances of less than 100 nanometers, especially the manipulation of individual atoms and molecules." Nanotech deals in the realm where a typical grain of sand is huge (a million nanometers in diameter). A human hair is 200,000 nanometers thick. A red blood cell spans 10,000 nanometers. A virus measures 100 nanometers across, and the smallest atom (hydrogen) spans 0.1 nanometers.

In the realm below 50 nanometers, the normal laws of physics no longer apply, quantum physics kicks in and materials take on surprising new properties. Something that was red may now be green; metals may become translucent and thus invisible; something that could not conduct electricity may now pass a current; nonmagnetic materials may become magnetized; insoluble substances may dissolve. Knowing the properties of a substance in bulk tells you nothing about its properties at the nano scale, so all nano materials' characteristics -- including hazardous traits -- must be learned anew by direct experiment.

Nanotechnologists foresee a second industrial revolution sweeping the world during our lifetimes as individual atoms are assembled together into thousands of useful new products. Few deny that new products may entail new hazards, but most nanotechnologists say existing regulations are adequate for controlling any hazards that may arise. In the United States, nanotech is not now subject to any special regulations and nano products need not even be labeled. Furthermore, no one has developed a consistent nomenclature for nano materials, so rigorous discussion of nanotech among regulators and policymakers is not yet possible. Without consistent nomenclature, standardized safety testing lies in the future.

No one denies that nanotech will produce real benefits, but, based on the history of nuclear power, biotechnology and the chemical industry, skeptics are calling for a precautionary approach. The resulting clash of philosophies -- "Better safe than sorry" versus "Nothing ventured, nothing gained" or even in some cases "Damn the torpedoes, full speed ahead!" -- may offer a major test of the Precautionary Principle as a new way of managing innovation.

"WORLD PEACE, UNIVERSAL PROSPERITY"

The pressure for rapid development of nanotech is enormous. The surprising properties of materials at the nano scale have opened up a new universe of industrial applications and entrepreneurial dreams. Largely unnoticed, hundreds of products containing nano-sized particles have already reached the market -- metal surfaces and paints so slick they clean themselves when it rains; organic light-emitting diodes for computer screens, digital cameras and cell phones; sub-miniature data storage devices (aiming to hold the Library of Congress in a computer the size of a sugar cube); specialty lubricants; long- mileage vehicle tires; nano-reinforced plastics for stronger automobile fenders; light-weight military armor; anti-reflective and scratch-resistant sun glasses; super-slippery ski wax; powerful tennis rackets and long-lasting tennis balls; inkjet photographic paper intended to hold an image for 100 years; high-contrast MRI scanners for medical diagnosis; efficient drug and vaccine delivery systems; vitamins in a spray; invisible sunscreen ointments containing nano particles of titanium or zinc; anti-wrinkle cosmetic creams; and so on.

And this is just the beginning. Nanotech wasn't possible until the invention in the 1980s and early 1990s of ways to arrange individual atoms under software control. Nano particles, nanotubes and carbon nano crystals called Bucky Balls (after Buckminster Fuller) are now being manufactured in ton quantities for industrial use. Currently technologists are working feverishly to coax nature's most successful nano factory, the living cell, to grow useful new nano assemblies. It is no exaggeration to say that the field of nanotech is gripped by something approaching a gold rush mentality. Worldwide, governments are spending an estimated $3 billion per year on nanotech research, and the private sector is thought to be spending at least that much. The U.S. government alone will spend at least $3.7 billion on nano R&D during the next four years. The global market for nano products is expected to reach $1 trillion in 10 years or less. Any day of the week you can check in at http://nanotech-now.com and catch a glimpse of the gold rush in action.

But for some prominent proponents of nanotech, this is about more than money -- it is about reinventing the entire world, including humans, as they now exist. According to the U.S. National Science Foundation, nanotechnology is the foundation stone of NBIC -- a revolutionary convergence of nanotech, biotech (manipulation of genes), info tech (computers), and cogno tech (brain function). In a report sponsored by the National Science Foundation and the Department of Commerce, the technologists and politicians who are promoting this revolution say it is "essential to the future of humanity" because it holds the promise of "world peace, universal prosperity, and evolution to a higher level of compassion and accomplishment." They say it may be "a watershed in history to rank with the invention of agriculture and the Industrial Revolution." The ultimate aim of this revolution has been an explicit human goal for at least 400 years -- the "conquest of nature" and the enhancement of human capabilities.

Whatever else it may offer, the nanotech revolution entails a radical new approach to industrial production with the potential to change every existing industry, plus create new ones. Typical manufacturing today -- even construction of the tiniest computer circuit -- relies on "top-down" techniques, machining or etching products out of blocks of raw material. For example, a common technique for making a transistor begins with a chunk of silicon, which is etched to remove unwanted material, leaving behind a sculpted circuit. This "top-down" method of construction creates the desired product plus waste residues.

In contrast, nanotech makes possible "bottom-up" construction in which atoms are arranged under software control -- or in ideal cases they will self-assemble, just as living cells self-assemble -- into the desired configuration with nothing left over, no waste. Instead of cutting trees into lumber to make a table, why not just "grow" a table? Thus nanotech seems to offer the possibility of waste-free manufacturing and therefore a cleaner environment. Furthermore, nanotech may help remediate past pollution. U.S. Environmental Protection Agency (EPA) is funding research on releasing nano particles into the environment to detoxify mountains of toxic waste remaining from the 20th century's experiment with petroleum-based chemistry.

INSURING A NANOTECH FUTURE

Nevertheless, without denying plausible benefits, critics want nanotech's potential problems brought into the open:

** Unless nanotechnology is shared generously, it may create a "nano divide" similar to the "digital divide" that exists now between those with ready access to computers and those without.

** Humans given enhanced mental or physical capabilities may gain great advantage over normal people. On the other hand, some people may be coerced to accept dubious or unwanted enhancements.

** Inequalities within and between nations may be exacerbated if individuals and corporations gain monopoly control of nanotech by patenting the building blocks of the universe -- a precedent set in 1964 when Glenn T. Seaborg was issued a patent on an element he discovered and named Americium.

In the longer term, some leading technologists like Ray Kurzweil, inventor of the first reading machine for the blind, and Bill Joy, one of the founders of Sun Microsystems, fear that nanotech will give individuals -- inadvertently or intentionally -- destructive potential greater than the power of atomic weapons. As Joy wrote in 2000, "I think it is no exaggeration to say we are on the cusp of the further perfection of extreme evil, an evil whose possibility spreads well beyond that which weapons of mass destruction bequeathed to the nation-states, on to a surprising and terrible empowerment of extreme individuals."

Others, such as the insurance industry, have more mundane concerns about nanotech -- chiefly, the potential health and environmental hazards of tiny particles. In May of 2004, Swiss Re, the world's second-largest reinsurance firm, issued a report calling for the Precautionary Principle to guide nanotech development. Swiss Re itemized a host of potential problems that it says need to be resolved before nanotech products are fully deployed, including these:

** One of the new properties of nano-sized particles is their extreme mobility. They have "almost unrestricted access to the human body," Swiss Re points out, because they can enter the blood stream through the lungs and possibly through the skin, and seem to enter the brain directly via olfactory nerves. Once in the blood stream, nano particles can "move practically unhindered through the entire body," unlike larger particles that are trapped and removed by various protective mechanisms.

** If they become airborne, nano particles can float for very long periods because -- unlike larger particles -- they do not readily settle onto surfaces. In water, nano particles spread unhindered and pass through most available filters. So, for example, current drinking water filters will not effectively remove nano particles. Even in soil, nano particles may move in unexpected ways, perhaps penetrating the roots of plants and thus entering the food chains of humans and animals.

** One of the most useful features of nano particles is their huge surface area. The smaller the particle, the larger its surface in relation to its mass. A gram of nano particles has a surface area of a thousand square meters. Their large surfaces give nano particles some of their most desirable characteristics. For example, drug-coated nano particles may one day transport pharmaceuticals directly to specific sites within the human body. Unfortunately, their large surface also means that nano particles may collect and transport pollutants.

Furthermore, their large surface means nano particles are highly reactive in a chemical sense. As Swiss Re noted, "As size decreases and reactivity increases, harmful effects may be intensified, and normally harmless substances may assume hazardous characteristics." Nano particles may harm living tissue, such as lungs, in at least two ways -- through normal effects of chemical reactivity, or by damaging phagocytes, which are scavenger cells that normally remove foreign substances. Phagocytes can become "overloaded" by nano particles and cease functioning. Worse, overloaded phagocytes retreat into deeper layers and so become unavailable to protect against foreign invaders. Successive particles are then able to do their full reactive damage, and other invaders, such as bacteria, may penetrate unhindered. The surface reactivity of nano particles gives rise to "free radicals," which are atoms containing an "unsatisfactory" number of electrons (either too few or too many for stability). Free radicals swap electrons with nearby atoms, creating further instabilities and setting off a cascade of effects. Free radicals give rise to inflammation and tissue damage, and may initiate serious harm, such as growth of tumors. On the other hand, some free radicals are beneficial, destroying invaders. So the role of nano particles in producing free radicals remains to be clarified.

** Nano particles would normally tend to clump together, forming larger, less dangerous particles -- but nanotechnologists take pains to prevent clumping by adding special coatings. As a result, nano particles in many commercial products, sprays and powders remain reactive and highly mobile.

** Whether nano particles can pass through the skin into the blood stream is the subject of intense debate. Different experiments have yielded conflicting results, presumably because test protocols have not been standardized. Some believe that nano particles may slip between the layers of outer skin and penetrate through to the blood below. Others believe that hair follicles offer a direct route for nano particles to penetrate from skin to blood. No one knows for sure. Despite this knowledge gap, sun screens, skin lotions and baby products containing nano particles are already on the market. Clearly this is a problem for insurance firms providing liability coverage. Swiss Re says, "Considering the wide variety of products already on the market, the need for a solution is urgent."

** Ingested nano particles can be absorbed through "Peyer's plaques," part of the immune system lining the intestines. From there, nano particles can enter the blood stream, be transported throughout the body, "and behave in ways that may be detrimental to the organism," Swiss Re notes. While in the blood stream, nano particles have been observed entering the blood cells themselves.

** Once in the body, nano particles can enter the heart, bone marrow, ovaries, muscles, brain, liver, spleen and lymph nodes. During pregnancy, nano particles would likely cross the placenta and enter the fetus. The specific effects in any given organ would depend upon the surface chemistry of particular particles, which in turn would be determined by their size and surface coating. "It is likely that in the course of its entire evolution, humankind has never been exposed to such a wide variety of substances that can penetrate the human body apparently unhindered," Swiss Re says.

** The brain is one of the best-protected of all human organs. A guardian "blood-brain barrier" prevents most substances in the blood from entering the brain (alcohol and caffeine being two well-known exceptions). However, nano particles have repeatedly been shown to pass into the brain, where their effects are unknown. Will they accumulate and, if so, to what effect?

** Nano particles may disrupt the immune system, cause allergic reactions, interfere with essential signals sent between neighboring cells, or disrupt exchanges between enzymes, Swiss Re says. Some of these characteristics may be harnessed for benefit -- for example, in experiments a carbon nano crystal has been able to disrupt one of the processes that allows the AIDS virus to multiply.

** Nano particles in disposable products will eventually enter the environment. In the environment, nano particles represent an entirely new class of pollutants with which scientists (and nature) have no experience. Swiss Re speculates that, "Via the water cycle, nano particles could spread rapidly all over the globe, possibly also promoting the transport of pollutants." Swiss Re asks, "What would happen if certain nanoparticles did exert a harmful influence on the environment? Would it be possible to withdraw them from circulation? Would there be any way of removing nanoparticles from the water, earth, or air?"

** Turning to workplace hazards, Swiss Re asks whether nano particles will become the next asbestos. To protect workers, effective face masks are "not a very realistic prospect at present, since the requisite design would render normal breathing impossible." New designs may be possible but remain unproven.

PRECAUTION ON A SUPER-SMALL SCALE

Swiss Re notes that, in the past, the drive toward rapid technological innovation has "prevented the introduction of the Precautionary Principle in relation to new technologies for more than 20 years." But now, "in view of the dangers to society that could arise out of the establishment of nanotechnology, and given the uncertainty currently prevailing in scientific circles, the Precautionary Principle should be applied whatever the difficulties," Swiss Re asserts. "The Precautionary Principle demands the proactive introduction of protective measures in the face of possible risks, which science at present -- in the absence of knowledge -- can neither confirm nor reject."

What would precaution look like in a rapidly developing field like nanotech? The British Royal Society and the Royal Academy of Engineering issued a nanotech report in July 2004 recommending a series of precautionary actions, with the following chain of reasoning:

** "The evidence we have reviewed suggests that some manufactured nanoparticles and nanotubes are likely to be more toxic per unit mass than particles of the same chemicals at larger size and will therefore present a greater hazard."

** "There is virtually no evidence available to allow the potential environmental impacts of nanoparticles and nanotubes to be evaluated."

** Therefore, "the release of nanoparticles to the environment [should be] minimized until these uncertainties are reduced."

** And, "until there is evidence to the contrary, factories and research laboratories should treat manufactured nanoparticles and nanotubes as if they were hazardous and seek to reduce them as far as possible from waste streams."

These recommendations reverse the traditional approach to industrial materials, which have historically been assumed benign until shown otherwise.

The Royal Society puts the burden of producing information about safety on industry, not on the public: "A wide range of uses for nanotubes and nanoparticles is envisaged that will fix them within products.... We believe that the onus should be on industry to assess ... releases [of nano particles from products] throughout a product's lifetime (including at the end-of-life) and to make that information available to the regulator." From such a recommendation, it is a very short step to the European Union's precautionary proposal for industrial chemicals, called REACH (Registration, Evaluation and Authorization of Chemicals), which is often summarized as, "No data, no market."

The Royal Society recommended that the use of zinc oxide nano particles and iron oxide nano particles in cosmetics should "await a safety assessment" -- in other words a moratorium on these products is recommended. Likewise, "the release of free manufactured nanoparticles into the environment for [pollution] remediation (which has been piloted in the USA) should be prohibited until there is sufficient information to allow the potential risks to be evaluated as well as the benefits."

The Precautionary Principle is sometimes called the foresight principle. Importantly, the Royal Society's report fully embraces foresight for nanotechnology (and all other new technologies): "Our study has identified important issues that need to be addressed with some urgency" and so it is "essential" for government to "establish a group that brings together representatives of a wide range of stakeholders to look at new and emerging technologies and identify at the earliest possible stage areas where potential health, safety, environmental, social, ethical and regulatory issues may arise and advise about how these might be addressed." The group must provide "an early warning of areas where regulation may be inadequate for specific applications of these technologies." And, finally, "The work of this group should be made public so that all stakeholders can be encouraged to engage with the emerging issues."

Thus nanotech is sparking not only a new industrial revolution but demands for a reversal of traditional approaches to managing innovation and a turn toward precautionary action. Whether the momentum gathering behind the precautionary approach can redirect the charge behind nanotech -- a confluence of government and technophile advocates in alliance with an emerging industrial lobby -- remains uncertain.

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