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Small Security: Nanotechnology and Future Defense

by John L. Petersen and Dennis M. Egan

Overview

Scientists believe that nanotechnology will soon give humans the ability to move and combine individual atoms and molecules into microscopically tiny mechanical, electrical, and biological "machines" that will replace many of today's production processes and tools. Although current work is focused on materials, optics, and electronics, nanotechnology eventually will find applications throughout society. Advances in nanotechnology will feed back into conventional industry, which in turn will demand and promote further advances in nanotechnology in a cycle that is familiar from the silicon revolution of recent decades. This time, however, the cycle will operate more rapidly and produce even more far-reaching change. Computers based on nanotechnology will be smaller and more powerful and will accelerate advances in nanotechnology itself. Even without computers, nanotechnology will allow incorporation of a kind of intelligence into materials that will react to and influence their environment in complex and predictable ways, much as biological organisms do. Taken a step further, nanoscale robots, or nanobots, will be able to operate autonomously to inspect, mend, or destroy targeted substances. Biological nanobots will do the same operating on DNA instructions. Both types of nanobots will be able to replicate themselves.

Such revolutionary capabilities will produce change that can be predicted only in its magnitude, not its details. The Internet already assures the nearly instantaneous and universal dispersion of information; nanotechnology will extend and ramify the Web until it becomes an encompassing fog of interconnection that will take globalization to its extreme. Today, information and pollution have no national boundaries. Before many years, the same will be true of another of humanity's constructs, nanotechnology.

The Beginning of a Technological Revolution

Advances in integrated electronic circuit design have yielded production processes at the microscopic level. That is, many electronic components are measured in micrometers, or millionths of a meter. Though such products may be minuscule, a visitor to a typical factory today easily can understand what is being manufactured by watching the fabricating process. Soon, however, that may not be the case. Science and technology rapidly are moving beyond microtechnology to nanotechnology, or nanotech, which deals with production in the range from 5 microns to 50 nanometers, or 50 *billionths* of a meter.[1] Scientists believe that the ability to move and combine individual atoms and molecules will revolutionize the production of virtually every manufactured object and usher in a new industrial revolution at least as significant as the silicon revolution of the last century.[2] Mihail Roco, nanotech advisor to the White House, predicts, "Because of nanotechnology, we'll see more changes in the next 30 years than we saw in all of the last century."

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Though there is some uncertainty about when the technology will mature,[3] nanotechnology is likely to be the manufacturing wave of the future. In recognition of its importance, the National Nanotechnology Initiative pumped almost half a billion dollars into research in the year 2000 alone.[4] Industry leaders believe that in 10 to 15 years, the global market for nanotech products will exceed $1 trillion annually.

Nanotech has potential implications for every area of human activity, but initial work is being concentrated in medicine, materials (and nanostructured chemical catalysts), electronics, and optics, all of which intersect with the interests of the national security community.

In the nanomedicine area, nanoscale objects made of inorganic materials can serve in biomedical research, disease diagnosis, and therapy.[5] Drugs will be delivered with nanoparticles that will carry the active ingredient to just the right location in the body. Minuscule building blocks may someday repair human tissues. Pioneers in nanotechnology envision the day when small, molecular-sized robots may autonomously cruise the body and seek out and repair cells that are not quite up to par because of disease or aging. Carlo Montemango at Cornell University has already constructed a working biomolecular motor less than one-fifth the size of a red blood cell. Adam Heller, a biochemical engineer at the University of Texas, Austin, is looking at harnessing biology to produce electricity within the body. Quicker, more sensitive tests of selected substances (including biological agents) are likely, which should prove particularly useful for sensing bioterrorist agents.

Similarly, computing will not be the same after nanodevices become a reality. Nanoelectronics advances have recently resulted in nanotransistors, diodes, relays, and logic gates, all of which are computer components.[6] Nanotech researcher Ralph Merkle writes that in the coming decades nanotechnology could yield a supercomputer so small that it could barely be seen in a light microscope.[7]

Nanotechnology is developing very quickly. In 2001, the RAND National Defense Research Institute published a report, *The Global Technology Revolution,* that identified technology wildcards and stated that "Another approach known as *molecular electronics* would use chemically assembled logic switches organized in large numbers to form a computer. These concepts are attractive because of the huge number of parallel, low-power devices that could be developed, but they are not anticipated to have significant effects by 2015."[8] But on October 18, 2001, *The Washington Post* reported the success of Lucent Technology Bell Laboratories in creating the first such device through "chemical self-assembly."[9] If this new device is viable, at the rate of present technological change, it is unlikely that it will take 13 years to convert this breakthrough into practical use.

Nanoelectronics researchers also are working on DNA computing, which could produce very large-scale parallel processing and ultrasensitive detectors for gas molecules and biological compounds. Nanodetectors of this kind could theoretically sense single atoms or molecules of selected substances. Also, the Defense Advanced Research Projects Agency has a nanoelectronics program that is exploring and developing material processing technologies, quantum and conventional devices, and device architectures for a next generation of information processing systems and subsystems.[10]

Nanomaterials development focuses mostly on a single device: the carbon nanotube, a superthin pipe made of a rolled sheet of carbon atoms. Nanotubes have the greatest tensile strength of any fiber—60 times greater than that of steel of the same weight—and they also have extraordinary electrical properties. In certain configurations, they are semiconductors or insulators, while in others they are electrical conductors, and they might even be configured as superconductors.

the manipulation of atoms and molecules will lead to construction of devices that are inconceivable today

With nanofabrication techniques that allow individual atom manipulation, carbon atoms (from crude oil, for example) could easily be arranged in the lattice structure of a diamond, allowing a great number of things to be constructed of that material. Consider the implications of things essentially built out of diamond: such systems would be smaller, lighter, and stronger than present ones. The manipulation of atoms and molecules will lead to new, custom-designed materials that will allow construction of devices that are inconceivable today.

New nanoptical switches are likely to form the beginnings of an all-optical telecom network backbone. These devices would convert data packets from one wavelength to another in nanoseconds with minuscule lasers that are only 8 nanometers wide.[11] They enable engineers to reconfigure network traffic in a matter of nanoseconds and redirect huge volumes of traffic across thousands of miles of networks.

Nanotech also could yield clean factories and clean, cheap, and abundant power from low-cost solar cells and batteries. "Intelligent" materials with integral sensors and microprocessors, much like the skin on the hand, would not only perform structural tasks but also be highly sensitive to heat, pressure, electromagnetics, and chemical compounds.

To the extent that bionanodevices successfully bridge the sensory gap among humans, new devices will emerge that amplify haptics to the degree that hearing and sight are extended around the world today. Nanotechnology literally has the potential to produce a real-time global nervous system. Billions of nanobotic devices employing massive parallel computing in an asynchronous mode could establish a collective consciousness in an "intelligent fog." The fog's "knowledge" may be downloaded to other remote devices through laser probing, radar probing, thermal emission, microwave emission, or electromagnetic discharge (like a lightning bolt). Such means of establishing new personal connections to a collective consciousness may have some interesting connections to mob psychology.

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Defense Applications

Nanotech opens a broad spectrum of possible military uses that both expand and extend existing systems and define radical new applications. A three-dimensional assembly of nanostructures can yield much better versions of most conventional weapons (for example, guns can be lighter, carry more ammunition, fire self-guided bullets, incorporate multispectral gunsights, or even fire themselves when an enemy is detected).[12] In unconventional terms, bionanobots might be designed that, when ingested from the air by humans, would assay DNA codes and self-destruct in an appropriate place (probably the brain) in those persons whose codes had been programmed. Nanobots could attack certain kinds of metals, lubricants, or rubber, destroying conventional weaponry by literally consuming it.

Other potential defense applications include:[13]

- information dominance through advanced nanoelectronics
- virtual reality systems based on nanostructure electronics that enable more affordable, effective training
- enhanced automation and robotics to offset reductions in military manpower, reduce risks to troops, and improve vehicle performance
- higher performance (lighter weight, higher strength) military platforms that provide diminished failure rates and lower life-cycle costs
- improvements in chemical/biological/nuclear sensing and in casualty care
- nuclear nonproliferation monitoring and management systems
- combined nanomechanical and micromechanical devices for control of nuclear defense systems.

From a defense perspective, new realms of clothing are possible, such as smooth, strong fabrics; sensory enhanced garments of fibers mixed with nanochips; chameleon-like camouflage that interacts with the environment; clothing that changes reflectivity and insulation; and protective clothing that can absorb or reject chemical agents or toxins. Even new synthetic skin could be developed, as well as internal repair robots to enhance healing on the battlefield.

All current work at the nanoscale uses variations of conventional manufacturing methods. Some breakthroughs have been made in small-scale manipulation, but the real revolution will come when small, intelligent nanobots can replicate themselves to produce billions of parallel manufacturing devices, which, in turn, can build things by piling single atoms on top of each other, many billions of times per second.

We are just at the beginning of this revolution. As a writer for *Scientific American* has said, "It is becoming increasingly clear that we are only *beginning* to acquire the detailed knowledge that will be at the heart of future nanotechnology. This new science concerns properties and behavior of aggregates of atoms and molecules, at a scale not yet large enough to be considered macroscopic but far beyond what can be called microscopic."[14] Eric Drexler, who coined the term *nanotechnology*, has said, "Whatever the progress to date, we're still far from our goal. Research today focuses on demonstrations of phenomena and isolated devices, but truly revolutionary advances won't appear until nanodevices are integrated into nanosystems."[15]

Microelectromechanical Systems

Microelectromechanical systems (MEMS) sometimes are mistakenly referred to as nanotechnology. They are very small components and systems, but they are designed and operate around the same principles that govern most other technologies. In the past few years, significant MEMS advances have been made in highly accurate navigation components (for example, accelerometers, magnetic detectors, and inertial systems) that have no moving parts and are produced in packages the size of two matchboxes. MEMS-based designs, for example, can produce systems on a chip in which a transceiver, batteries, sensors, and microprocessor are all on a single component not much larger than a postage stamp. Researchers are working to produce a full system the size of a grain of sand. They anticipate that within several years, such devices will be able to communicate with satellites and fly as insects do, have microrockets that could propel them over tall buildings, and cost less than 1 cent to manufacture.

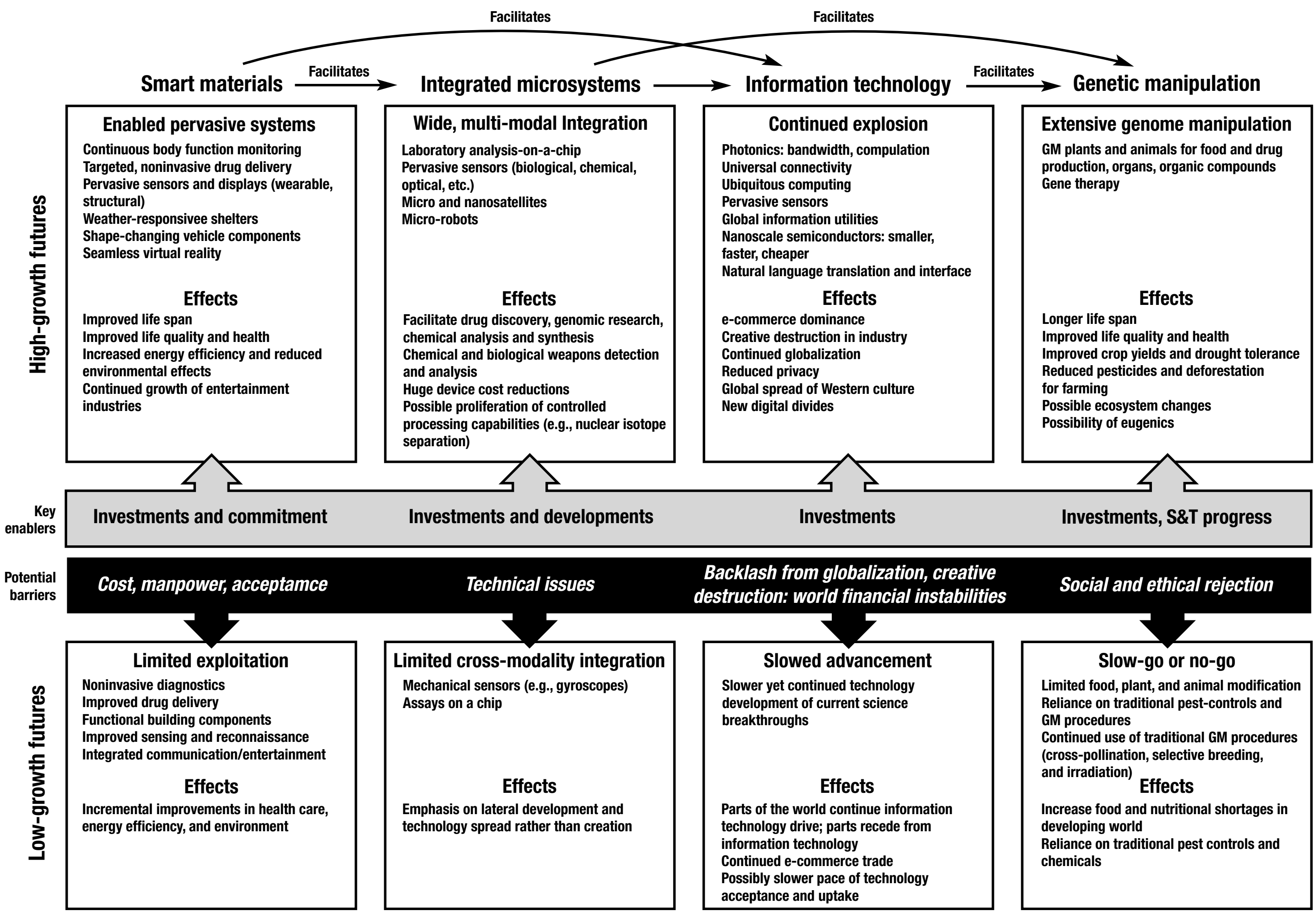
Nanotech is not happening in a vacuum. This technology is developing within a rapidly evolving, dynamic context. Even with established approaches, computer processing power is growing at extraordinary rates. Most analysts believe that Moore's Law (the doubling of capability every 18 months) will apply until about 2020. Current state-of-the-art microprocessors have more than 40 million transistors; by 2015, they could have nearly 5 billion. These new machines would be used to accelerate the development of the nanoenvironment. The new wildcard of quantum computing could increase the power of computers billions of times over what they are now, allowing the development rate of nanoreplicators and assemblers to explode.

The future will increasingly be shaped by autonomous, intelligent systems that can access and analyze great amounts of information. Inventor and futurist Ray Kurzweil believes the increased capabilities of computers alone will precipitate a "singularity" about 2029, where computers become more intelligent than humans and we as a species become subservient to them. Add to this rapid advancements in biotechnology, with humans gaining significantly more control over the form and capabilities of humans, animals, and plants, and you have a world that is really quite different than that which we now understand and experience.

The interplay and evolution of these extraordinary trends can be seen in the table on the next page.

A potential consequence of this revolution could be a growing inequality in the distribution of wealth that might be called the *nano divide*. Those who participate in the nano revolution stand to become not only wealthy but also powerful. Those who do not may find increasing difficulty in affording the technological wonders that it engenders. One near-term example will be medical care: nanotech-based treatments may be initially expensive, hence accessible only to the wealthy.[16] The confluence of these and other significant driving forces are certain to produce a general environment of great change and uncertainty.

The Range of Some Potential Interacting Areas and Effects of the Technology Revolution by 2015



Source: Philip S. Anton et al., MR–1307–NIC, *The Global Technology Revolution: Bio/Nano/Materials Trends and Their Synergies with Information Technology by 2015* (Santa Monica, CA: RAND, 2001). © Copyright 2001 RAND. Used by permission.

National Security in the World of the Small

All of these trends are painting the picture of a new world in which security is defined in different terms. As the National Science Foundation has pointed out, research in nanotechnology has no national borders. It is an exciting research frontier that has been pursued by many nations for more than a decade. Europe and Asia are strong competitors with America for advances in nanotechnology.[17] The Internet facilitates and enhances this trend. Researchers can now use the Web to contact colleagues all over the world for help in finding almost instantaneous answers to problems that previously would have taken months to resolve.

Furthermore, the future security environment is going to be colored by terrorist threats as much as by conventional state-to-state conflicts. This diffused, decentralized problem lends itself to solution neither by conventional military means nor by the advent of nanoagents. Anticipating, finding, and mitigating bioterrorists is hard, frustrating, and potentially destabilizing; nanoterrorists will be able to wreak even more havoc with invisible devices that are hard if not impossible to sense. The emergence of nanotechnology, coupled with decentralizing trends in the larger environment, suggest that the role of the U.S. military may need to change with the shifting context.

Seven years ago, Admiral David Jeremiah, former vice chairman of the Joint Chiefs of Staff, voiced a concern that was a harbinger of what is now a growing question about the effectiveness of our military in a world where vastly powerful weapons are invisible:

> Somewhere in the back of my mind I still have this picture of five smart guys from Somalia or some other nondeveloped nation who see the opportunity to change the world. To turn the world upside down. Military applications of molecular manufacturing

> have even greater potential than nuclear weapons to radically change the balance of power. In anticipation of that possibility the uniformed policymaker is likely to impose restrictions on the development of technology in such a way as to inhibit commercial development (ultimately beneficial to mankind) while permitting those operating outside of the restrictive bounds to gain an irrevocable advantage.[18]

General John Sheehan (Ret.), former Commander in Chief, Atlantic/Supreme Allied Commander, Atlantic, has gone further and suggested that in this era, the principal role of the U.S. military is not to fight and win wars but rather to *prevent* armed conflict. He has argued that decisive solutions seldom, if ever, come from the use of force anymore. In fact, new problems that continue for many years can be unintended consequences of military action. The power of modern weapon systems often produces destruction that is expensive in diplomatic and economic terms.

Sheehan believes that the principal function of the U.S. military is to help assure global stability for economic development. For this reason, the military should be structured and positioned so that it is unmatched at anticipating and defusing emerging instability before it evolves into chaos requiring armed intervention. A requirement for the use of arms in traditional ways will continue, but the military should become more proactive to emerging problems rather than primarily reactive to those that have gotten out of hand.

Americans regularly ask whether technology is moving too fast for society to keep up. They wonder what the significant implications of change might be that we do not yet understand. They essentially are asking whether we, in our thinking, policies, and institutions, are moving as quickly as the context is changing, and if not, whether we could find ourselves facing serious problems that we cannot effectively respond to because our thinking did not change with the times.

nanotechnology offers some extraordinary opportunities for a new, proactive approach to national security

Advances in nanotechnology (as well as biotechnology) represent a sea change—a transition—into a new era for humanity that is as different as the Industrial Age was from the Middle Ages, but in this case, the change is much greater and coming much faster. Nanotechnology represents a *fundamental* shift in the capabilities that are available not only to nations but also to individuals and small groups. We must anticipate and respond to this change in turn.

Mark Avrum Gubrud has said:

> The bombed-out cities of the Second World War, and the nuclear holocausts of our imagination, have persuaded rational minds that there can be no expectation of a meaningful victory in a total war between states armed with hundreds of deliverable nuclear weapons. From that point of view, war is obsolete, at least direct and open war between great powers.
>
> Nanotechnology will carry this evolution to the next step: deterrence will become obsolete, as it will not be possible to maintain a stable armed peace between nanotechnically armed rivals. The implications of this statement stand in sharp contradiction to the traditions of a warrior culture and to the assumptions that currently guide policy in the United States and in its potential rivals.[19]

He further identifies a significant dilemma for the military:

> It was technology, not policy, that forced the doctrine of deterrence on us, just as it was technology that determined the outlines of the nuclear arms race, once the decision to pursue nuclear confrontation had been made. The logic of military technology produced a confrontation so complex and unmanageable, and with such short time lines for decision and action, that it threatened to explode in spite of "assured destruction." Again, people were intelligent enough to recognize realities, and to place restraints on the offensive arms race while shelving futile dreams of defense.
>
> If technological realities now demand that we go further, and give up the warrior tradition, the illusion of independence and the vanity of sovereign self-defense, will we heed these demands, or will we try to preserve the institutions and attitudes of an earlier epoch, until we are surprised by a disaster beyond even our worst nuclear nightmares? If it is impossible to maintain an armed confrontation between nanotechnology-armed and hostile nations, then this is exactly our dilemma.[20]

Gubrud suggests that "Ultimately, the only way to avoid nanotechnic confrontation and the next world war is by evolving an integrated international security system, in effect a single global regime." He is arguing not for a world government but for an integrated international security system. (How interesting that as the United States attempts to put in place an initiative against global terrorism in the aftermath of September 11, it is attempting to build a set of relationships that are a de facto international security system.)

The parallels in the character and fundamentals of the terrorism problem and a nanotechnology world are apparent: nonstate actors, decentralized organizations, very low cost, broadly accessible threat agents. Reasonable security analysts question the utility of most of our weapon systems in responding to terrorism. The same could be said in responding to threats from nanotechnology.

Another aspect of nanosecurity should be considered. Like money, nanotechnology is a value-neutral tool; it can be used for both good and bad. If General Sheehan is correct and there is a new role for the military in helping to prevent conflict—not just delivering force—then nanotechnology offers some extraordinary opportunities for a new, proactive approach to national security.

If stability is the objective, where in the world is instability brewing? Those places where poverty, lack of education, and lack of human rights are concentrated. In fact, one could argue that the dichotomy between the haves and the have-nots (both in terms of economic disparity and the "digital divide" that was the subject of the World Economic Forum meetings) is by far the greatest looming global security issue. Exacerbated by extraordinary increases in population that will continue for at least a couple of decades, it is a problem just waiting to explode in any of a number of manifestations.

For the first time in history, a new technology holds forth the promise of providing inexpensive energy, food, clean water, and probably education for everyone on the planet. Nanotechnology could also be used in innovative ways to encourage national political stability and responsibility. We should begin to think about the future in these terms, for we have a choice: Either we will be defensive and respond to the problems as they arrive, or we will shift to the offense and use our military and these new tools in creative new ways to deal with problems while we still can.

Notes

[1] One hundred nanometers is about one-thousandth the width of a human hair—large on the scale of atoms and molecules; a 100-nanometer-wide wire would be about 500 silicon atoms across. At the lowest level, nanotechnology involves building things with individual atoms.

[2] "Sandia Joins National Charge into 21st Century Nanotechnology Revolution," Sandia National Laboratories, accessed online at <http://www.sandia.gov/media/newsrel/nr2000/nanotech.htm>.

[3] George Whitesides of Harvard University suggests that this area "is fuzzy around the edges. . . . It is still science, not technology. There isn't going to be any quick return on investment for a while." Jerry Pournelle, "AAAS 2001: Nanotechnology Update," *BYTE.com*, March 12, 2001.

[4] <http://nano.gov>.

[5] A. Paul Alivisatos, "Less Is More in Medicine," *Scientific American*, September 2001.

[6] Charles M. Leiber, "The Incredible Shrinking Circuit," *Scientific American*, September 2001.

[7] Ralph C. Merkle, "Nanotechnology is Coming," accessed online at <http://www.merkle.com/papers/FAZ000911.html>.

[8] Philip S. Anton, Richard Silberglitt, James Schneider, *The Global Technology Revolution: Bio/Nano/Materials Trends and Their Synergies with Information Technology by 2015* (Santa Monica, CA: RAND), accessed online at <http://www.rand.org/publications/MR/MR1307/>.

[9] Accessed online at <http://www.washingtonpost.com/wp0dyn/articles/A12448-2001Oct18.html>.

[10] Accessed online at <http://darpa.mil/mto/ultra/index.html>.

[11] Lee Bruno, "Bright Lights," *Red Herring* (June 15–July 1, 2001), 55.

[12] Mark Avrum Gubrud, "Nanotechnology and International Security," paper presented at Fifth Foresight Conference on Molecular Nanotechnology (Palo Alto, CA: November 5–9, 1997), accessed online at <http://squid.umd.edu/~gubrud/>.

[13] National Science Foundation, *Societal Implication of Nanoscience and Nanotechnology* (March 2001).

[14] Michael Roukes, "Plenty of Room Indeed," *Scientific American*, September 2001.

[15] K. Eric Drexler, "I Started It," *New Scientist* (October 6, 2001), 37.

[16] *Societal Implications of Nanoscience and Nanotechnology*.

[17] Ibid.

[18] David E. Jeremiah, "Nanotechnology and Global Security," paper presented at Fourth Foresight Conference on Molecular Nanotechnology (Palo Alto, CA: November 9–11, 1995).

[19] Gubrud, "Nanotechnology and International Security."

[20] Ibid.

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