Workshop on Societal Implications of Nanoscience and Nanotechnology
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Good afternoon. My instructions are to provide a "visionary presentation focusing on the future of the field" of nanotechnology from the perspective of the federal government. Let me say at the outset that "nanotechnology" is not so much a "field" as a word -- a neologism -- that has been pressed into service to symbolize the status of a very large and important sector of contemporary science. It is possible to find narrower uses of the word, some of which I will mention later, but participants in this workshop are surely aware that nanotechnology refers implicitly to a set of capabilities at the atomic scale that grew steadily throughout the last half of the past century into the basis for a true technology revolution in our society.

I speak of a revolution in *technology* rather than in *science*, because the underlying science is not itself revolutionary. Not that the scientific work is complete or unexciting -- to the contrary -- but we have known for more than a century that all the matter of everyday life is made of atoms. And we have known in principle for nearly fifty years how to calculate, with exquisite precision, many of the properties of matter, given certain input information and enough computing power. But not until recently have we actually had the instruments to make atomic level measurements, and the computing power to exploit that knowledge. Now we have it, or are getting it, and the implications are enormous. Everything being made of atoms, the capability to measure, manipulate, simulate, and visualize at the atomic scale potentially touches every material aspect of our interaction with the world around us. That is why we speak of a revolution -- like the industrial revolution -- rather than just another step in technological progress.

It is no wonder that developed nations are eager to produce and acquire the technologies that are being spawned by these new atomic scale capabilities. As far as I can tell, the science plans for every developed nation and the European Union have a strong "nano" focus. The United States has been a world leader in the development of the underlying science infrastructure for the revolution, and the development of nanotechnology is today a national priority. Let me take a few moments to put the National Nanotechnology Initiative into perspective.

The revolution implicit in nanotechnology extends to all functional behavior of material that is influenced by nanoscale structure. That includes much of biology, chemistry, and materials science. These subjects have long histories, and therefore many of the issues we are gathered to discuss today are already familiar to us in other guises. This has implications that I will describe shortly. For now, I want to point out that federal funds have supported investigations into nanoscale phenomena in biology, chemistry and materials science for a long time. Much, but not all, of biotechnology is what I like to call "wet nanotechnology." A growing fraction of federally funded biomedical research extending over four decades deals with the nanoscale molecular basis of life processes in humans and other organisms. This Administration's substantial increase in federal funds for medical research -- now consuming nearly half the total federal science and technology budget -- is justified in large part by the enormous promise of biotechnology as applied to medicine.

The instrumental and computational infrastructure that provides the new nano-scale capabilities have also been built up with federal funding over decades, particularly in the Department of Energy multi-program laboratories, but with significant facilities also at NIST and NSF-funded university centers. They include electron microscopes, bright x-ray sources, nuclear magnetic resonance devices, mass spectrometers, scanning probe microscopes, and a variety of optical and infrared spectroscopic devices. They also include the inexorably improving power of computation, communication, and data storage capabilities that we lump together under "Information Technology." The development of information technology and its application to nanoscale technologies are today national priorities.

In the current fiscal year, the President requested, and Congress is likely to fund, the National Nanotechnology Initiative (NNI) at approximately $850 million among 10 federal agencies, of which the National Science Foundation manages the largest share. This interagency program is coordinated through a Subcommittee under the National Science and Technology Council (NSTC) which is the mechanism established for such purposes and managed by OSTP. Congress very recently passed a nanotechnology bill (S189) that establishes important new principles for the pursuit of this broad area of science and technology. On this very day, President Bush will sign this bill into law in a special ceremony at the White House.

This audience should be aware that the nanotechnology bill includes a number of provisions related to societal concerns. It requires, for example, that the program ensure "that ethical, legal, environmental, and other appropriate societal concerns, including the potential use of nanotechnology in enhancing human intelligence and in developing artificial intelligence which exceeds human capacity, are considered during the development of nanotechnology ..." The bill also requires 1) the establishment of a research program on these issues, 2) that societal and ethical issues be integrated into all centers established by the program, and 3) that public input and outreach be integrated into the program. A provision to set aside 5% of overall program funding to study societal and ethical issues was defeated during markup of the bill in the House Science Committee, but the proposal indicates how seriously Congress takes these issues. The bill charges a Presidential Advisory Committee with determining and reporting bi-annually to the President whether social and ethical concerns are being "adequately addressed by the program." The bill further requires two studies by the National Research Council, one on the technical feasibility of "molecular self-assembly for the manufacture of materials and devices at the molecular scale," and another on the responsible development of nanotechnology. Finally, the bill requires a center focused on societal and ethical issues of nanotechnology.

This is heavy machinery, and indicates an extraordinary level of interest in these issues within Congress. The bill language also suggests specific areas of societal and ethical concern that will receive the most attention, at least in the immediate future. My own view of these concerns is first, that they have to be taken seriously, and second, that the scientific community owes the public and Congress a clear and rational vision of nanotechnology that can lead to a productive engagement.

We should begin to construct that clear vision by distinguishing science from science fiction, and emphasizing the strong links of nanotechnology to things we already know a great deal about. While the technologies enabled by atomic scale capabilities are revolutionary, they are not about to spring, like Athena, fully armed from the brow of god-like scientists. Nature has experimented with nanostructures since the earth began to cool four and a half billion years ago, and has blessed us with a rich legacy of examples to stimulate our imaginations. These range from the microstructures of minerals to the intricate molecular mechanisms of life. While it is now possible for us to manufacture structures that do not occur in nature, we are strongly guided by the immense variety of those that do occur. Some of the most important applications of biotechnology are likely to be the tuning up of useful cellular machinery that Nature has not yet had time to evolve to its most efficient form. We have been doing something similar for a century and a half with organic molecules -- dyes, for example, or synthetic fibers -- and Japanese metallurgists were inventing new microstructures over a much longer history to create edged tools and weapons of legendary quality. They were not aware of the nanoscale origins of their products, but they were producing them just the same.

And throughout this long history, society has built up systematic ways of protecting itself against the undesirable consequences of these evolving technologies. During the past half century, in particular -- and as a direct result of growing scientific knowledge -- society has acted through its governmental machinery to establish procedures to protect public and environmental health from new materials technology, whether biological, chemical, or radiological. The 25 year old RAC process for example -- (RAC stands for "Recombinant DNA Advisory Committee") -- or a modified version of it recently proposed by an NRC committee chaired by MIT's Stanley Fink, are designed basically to address concerns about new nano-scale phenomena. The Toxic Substances Control Act governing the review and registration of potentially toxic chemicals originated at about the same time as the famous Asilomar Conference that recommended the RAC.

Congress clearly wants to know whether these mechanisms, or reasonable extensions of them, are adequate to respond to concerns about the products of nanotechnology. It is clear that some such products are already covered by existing mechanisms. Can we identify the manner in which new nanotechnology products differ from these older threats? It is important that we do so. I believe the differences are likely to occur in very well-defined areas, and that even in those cases the existing means for addressing threats they may pose to the environment or public health are likely to suffice with relatively little modification or extension.

This emphasis on the continuity of nano-products with natural or older man-made substances may help us refocus public attention on the most likely short term issues. The media, Hollywood, and some imaginative commentators have focused on self-replicating "nanobots" as the archetypal hydra-headed nano-thing. In my opinion, that is utterly wrong-headed. The most common nano-substances will be passive structures, suspended or dispersed within a matrix. The most common objective of a nano-project is likely to be the preparation of a bulk functional material or extended structure with nanoscale intrinsic architecture. The production of stand-alone, nano-entities will be far down the line, and these will be closely similar to, but simpler than, the intricate naturally occurring proteins, nucleic acids, and the cellular machinery comprised of them. For many years, biotechnology will remain far ahead of nanotechnology in producing new entities of this sort, and I think it likely that the protective protocols developed for biotechnology will suffice for hazard control. The ethical issues associated with human biological applications of nano-products are the same as with similar applications of "genetically engineered" bio-products. I am not saying we have answered all ethical questions that are raised by such possibilities as sensory enhancement and protracted longevity promoted by these applications, but the idea that there are procedures already in place to deal with these new applications ought to be reassuring.

Nanoparticles of chemical substances have properties that differ from the bulk. Probing and understanding those differences are part of the exciting unfinished work of nanoscience. Perhaps our system of cataloguing chemicals needs to be extended to account for the spectrum of new characteristics, analogous to nuclear isotopes, that appear at the nanoscale. It seems unlikely to me, however, that the current system for identifying, registering, and controlling hazardous chemicals will need to be changed very much to accommodate this new category of substances.

Let me close by pointing out that ethical decisions about the introduction of new things or new processes can be arranged in two broad categories that ought to be kept separate. In one category fall decisions based on the sacredness of objects, entities, or conditions. In the other are decisions based on potential harm to individuals or societies, including the environment that sustains all life. The former are easier for science, but much more difficult for society to deal with. The latter category depends heavily on science to assess potential harm. But I believe that neither category is new, nor requires essentially novel kinds of thinking; only a particularizing of principles to the case at hand.

This workshop is important, as was the one that preceded it in 2000. The organizers have brought together experts from diverse fields, and I encourage you to take advantage of this opportunity to share ideas with others who are thinking about the uses and implications of nanotechnology. I am grateful to all of the participants for devoting their time and their ideas to the elucidation of these thorny topics, and look forward to the proceedings.