

**VIEWS OF THE NIST NOBEL
LAUREATES ON SCIENCE POLICY**

HEARING
BEFORE THE
SUBCOMMITTEE ON ENVIRONMENT, TECHNOLOGY,
AND STANDARDS
COMMITTEE ON SCIENCE
HOUSE OF REPRESENTATIVES
ONE HUNDRED NINTH CONGRESS

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VIEWS OF THE NIST NOBEL LAUREATES ON SCIENCE POLICY

WEDNESDAY, MAY 24, 2006

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENVIRONMENT, TECHNOLOGY, AND
STANDARDS,
COMMITTEE ON SCIENCE,
Washington, DC.

The Subcommittee met, pursuant to call, at 9:45 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Vernon J. Ehlers [Chairman of the Subcommittee] presiding.

**SUBCOMMITTEE ON ENVIRONMENT, TECHNOLOGY
AND STANDARDS
COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES**

Views of the NIST Nobel Laureates on Science Policy

Wednesday, May 24, 2006

9:30 AM – 11:00 AM

2318 Rayburn House Office Building (WEBCAST)

Witness List

Dr. William Phillips
Nobel Laureate, Physics, 1997

Dr. Eric Cornell
Nobel Laureate, Physics, 2001

Dr. John Hall
Nobel Laureate, Physics, 2005

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HEARING CHARTER

**SUBCOMMITTEE ON ENVIRONMENT, TECHNOLOGY, AND
STANDARDS****COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES****Views of the NIST Nobel
Laureates on Science Policy**WEDNESDAY, MAY 24, 2006
10:00 A.M.—12:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING**Purpose**

On Wednesday May 24, 2006, at 9:30 a.m., the Subcommittee on Environment, Technology, and Standards of the House Committee on Science will hold a hearing to learn the views of the Nobel Prize winners from the National Institute of Standards and Technology (NIST) on science policy.

Witnesses

Dr. William D. Phillips is a scientist in the physics division at the NIST laboratory in Gaithersburg, Maryland. He won the 1997 Nobel Prize for physics.

Dr. Eric Cornell is a senior scientist at the NIST laboratory in Boulder, Colorado, and a fellow at JILA, the joint institute between NIST and the University of Colorado. He won the 2001 Nobel Prize for physics.

Dr. John (Jan) Hall is a scientist emeritus at the NIST laboratory in Boulder, Colorado and a fellow at JILA, the joint institute between NIST and the University of Colorado. He won the 2005 Nobel Prize for physics.

Overarching Questions

The hearing will address these overarching questions:

1. Why has NIST been so successful at cultivating Nobel Prize winners?
2. What are the implications of the Nobel Prize-winning research at NIST and how can that work get used outside of NIST?
3. What steps are most necessary to improve U.S. performance in math, science and engineering, and U.S. competitiveness?

Overview of NIST

The National Institute of Standards and Technology, created by Congress in 1901, is the Nation's oldest federal laboratory. NIST's mission is to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life. NIST has two laboratory campuses, one in Gaithersburg, MD, and the other in Boulder, CO, and a joint institute for physics research with the University of Colorado at Boulder, known as JILA.

The NIST's research programs are carried out through eight laboratories:

- Building and Fire Research Laboratory
- Chemical Sciences and Technology Laboratory
- Electronics and Electrical Engineering Laboratory
- Information Technology Laboratory
- Manufacturing Engineering Laboratory
- Materials Science and Engineering Laboratory
- Physics Laboratory
- Technology Services Laboratory.

In addition, NIST houses major facilities that play a critical role in measurement and standards research, as well as supporting technology development for future in-

dustries. These facilities include the atomic clock, the National Center for Neutron Research, and the National Nanotechnology and Nanometrology Facility.

NIST's FY 2007 Budget Request

NIST is one of the three agencies included in the President's American Competitiveness Initiative. (The other two are the National Science Foundation and the Department of Energy Office of Science.) The Initiative, announced in the State of the Union message and included in the Fiscal Year (FY) 2007 budget, calls for a doubling of the combined budgets of the three agencies over 10 years. (The Initiative does not include NIST's extramural research programs—the Manufacturing Extension Partnership program and the Advanced Technology Program.)

For details on the NIST budget, see the chart below.

The proposed increase in laboratory programs for FY 2007 would fund major upgrades and enhancements of NIST's two national research facilities in Gaithersburg, MD: the NIST Center for Neutron Research and the Center for Nanoscale Research and Technology. The budget request would also fund expansion of NIST's existing presence at the National Synchrotron Light Source at Brookhaven National Laboratory. The request for NIST will increase the ability of U.S. researchers to develop, characterize, and manufacture new materials. In addition, the proposed budget would increase NIST laboratory and technical programs directed at solving measurement and other technical problems in energy, medical technology, manufacturing, homeland security, and public safety.

NIST Appropriations and Reauthorization

In May 2005, the House passed H.R. 250, the *Manufacturing Technology Competitiveness Act*, which included authorization language and funding levels for NIST, using the President's FY 2006 request of \$426 million as a baseline. The Senate Commerce Committee recently reported out S. 2802, a bill that also includes a NIST authorization.

Account	NIST Appropriations FY 05-FY 07					H.R. 250 Authorization		
	FY 05 Actual	FY 06 Request	FY 06 Actual	FY 07 Request	\$ Change FY07 request vs. FY06 actual	FY 06	FY 07	FY 08
NIST Labs	378,764	426,267	399,869	467,002	67,133	426,267	447,580	456,979
Construction	72,518	58,898	175,898	67,998	(107,900)	58,898	61,843	63,389
ATP	140,399	0	80,000	0	(80)	0	0	0
MEP	107,544	46,800	106,000	46,332	(59,668)	110,000	115,000	120,000
TOTAL	699,225	531,965	761,767	581,332	(180,435)	595,165	624,423	640,368

How NIST Supports Promising Scientists

There are several means available to NIST to reward or encourage scientists who are pursuing promising avenues of research: the Competence program, the Presidential Early Career Award for Scientists and Engineers (PECASE), and increasing support for individual scientists from NIST's base funding. Each of NIST's Nobel laureates benefited from one or all of these programs.

The NIST Competence program was established to provide five years of funding for high-priority research by NIST researchers. The focus is to develop new technical competence required to support national measurement science or standards. If, at the end of the five years, the research has been successful, the Competence funding can be replaced with more permanent program funding to continue the research. For example in 1992, John Hall was awarded \$340,000 per year for five years in Competence funding to pursue research "Beyond Quantum Limits," funding that he used in part to hire Eric Cornell to create a Bose-Einstein Condensate (BEC).

The NIST Director can nominate NIST scientists for PECASE, which was established in 1996 to support the extraordinary achievements of young scientists and engineers in the Federal Government. Dr. Cornell received this award in 1996. NIST and the Department of Commerce also have some internal awards that are made in recognition of outstanding service by their employees.

Finally, the NIST Director can support talented scientists with additional funding from the NIST laboratory budget. For example, in recognition of Dr. Cornell's achievement of BEC in 1995, the NIST Director gave him an additional \$250,000 in base lab funding. Dr. Cornell has stated that this research funding, received

without making a request or proposal, was one of the reasons he decided to stay at NIST, despite personally lucrative offers elsewhere.

Nobel Prize-winning work at NIST

Two of the NIST Nobel laureates won their Prize for work related to low-temperature physics. NIST scientists conduct low-temperature physics research because understanding the properties of atoms and materials at low temperatures can improve the science of measurement, which is critical to improving the competitiveness of U.S. industry.

One application of low-temperature physics is technology to improve the accuracy of atomic clocks. By cooling atoms of cesium, scientists have made atomic clocks that are a billion times more accurate than an ordinary wristwatch. Highly accurate clocks are essential to navigation instruments and other devices that use the Global Positioning System (GPS), because the GPS depends on atomic clocks that circle the earth in satellites. By comparing time information from several satellites, GPS receivers in cars, airplanes, or hand-held instruments can determine their location on earth with an accuracy of just a few meters. The more precise, accurate, and better synchronized the clocks, the more accurate the associated locational data becomes.

Dr. William D. Phillips' Nobel Prize, which he shared with Dr. Steven Chu and Dr. Claude Cohen-Tannoudi in 1997, was awarded for the development of a technique called "laser trapping and cooling." This technique allows researchers to use lasers as pincers to immobilize individual or small groups of atoms.

Dr. Eric Cornell won his Nobel Prize, which he shared with Dr. Carl Wieman, for creating a Bose-Einstein Condensate (BEC), a previously unobserved state of matter, predicted in 1920s by Albert Einstein and an Indian colleague. In the BEC state, a gas, cooled to super-low temperatures, behaves like a superfluid—neither a gas nor a liquid nor a solid. Cornell and Wieman used the laser cooling technique pioneered by Dr. Phillips, together with another technique.

Dr. Jan Hall won his Nobel Prize, which he shared with Theodor Hänsch, for his contributions to laser-based precision spectroscopy, including the development of the "optical frequency comb" technique. The optical frequency comb is a new measuring method for the frequency of light, and is critical for the solution to the problem of measurements, including the standard definition of the meter. Optical frequency combs are now commercially available.

Witness Questions

The witnesses were asked to briefly describe the research that led them to the Nobel prize-winning discoveries, and answer the following questions:

1. Describe the role that NIST plays in your field of science.
2. Describe the steps that you had to take from the development of the initial scientific concepts through to the experiments for which you won the Nobel Prize. What are the applications or potential applications of your discoveries and what steps have been or will be taken to translate this new science into technology and other applications?
3. What do you believe are the most important steps the Federal Government should take to improve the competitiveness of U.S. scientific research?

Chairman EHLERS. Good morning. This hearing will come to order.

It is a real pleasure to conduct this hearing today. As I told our witnesses, this is likely to be a love fest rather than an interrogation, and the brief conversation I had with them before the meeting made me think perhaps I should resign my position and get back into research. You folks have all of the fun.

But at any rate, if I weren't here, you probably wouldn't have as much money to do your research, either. So to each his own. We all contribute in our own way to the enterprise of science.

Welcome to today's hearing entitled "*Views of the NIST Nobel Laureates on Science Policy*." It is my great privilege to chair the Science Subcommittee that oversees the National Institute of Standards and Technology, also known as NIST. This gives me the opportunity to hold hearings such as this one, where we can highlight some of the best science being done in the world today by U.S. researchers at a humble federal science agency. Although if they get more Nobel Prize winners, they may no longer be humble. NIST has become the world leader in standards by employing superb scientists who do excellent work. Nothing more clearly demonstrates the phenomenal quality of the Agency's work than the three Nobel Laureates NIST has produced in less than 10 years, a truly remarkable accomplishment.

Having been a physicist myself, I have some understanding of how difficult your job can be.

I might mention this as an entirely Pavlovian operation in the Congress: the bells ring, we vote. In this case, we do not vote. We are just starting the—a sequence, and the Prime Minister of Israel will be addressing us later. So we can be assured of an uninterrupted hearing today.

Continuing, having been a physicist myself, I have some understanding of how difficult your job can be: science is hard work. I think the public understands in an abstract way that if you win the Nobel Prize, you must be very smart. That is one of the prerequisites. But what people frequently do not think about and do not realize or appreciate is the incredible amount of time, effort, and often frustration that goes into a successful, or even unsuccessful, scientific experiment. Optical and low-temperature physics, in particular, are fields where everything has to work perfectly. The margins for error are very tiny, the precision required is sublime, and experiments that work well in theory take months or years, time that is more often than not fraught with setbacks and frustrations, to produce a result in the laboratory. It takes true dedication and tenacity to push back the frontiers of science the way you have, and I think everyone here stands in awe of your achievements.

We are not here today just to learn about your research. In 1945 Vannevar Bush, Director of the Office of Scientific Research and Development, laid out a bold new vision for science in this country in the book "*Science: the Endless Frontier*." The publication of this historic document resulted in the creation of the National Science Foundation and launched a new era in U.S. scientific research. In 1998, I decided that the book by Vannevar Bush, although excellent, is somewhat outdated, and I worked together with House

Speaker Newt Gingrich and Science Committee Chairman Jim Sensenbrenner and re-released “*Unlocking the Future: Towards a New Science Policy*,” a document that I had worked for two years with the aid of Sharon Hayes, a document that was intended to guide the development of a long-term science and technology policy for the United States. We did not claim that it was a new science policy in itself, but we tried to point the direction to and the need for a good launch from science and technology policy for the United States.

These policy documents are important, because they help us take a long view of the critical role of science in our society, and they force us to organize and update our science priorities. Now we are, once again, due for an update, and you are helping in the beginning of that update.

As leading scientists in your fields, we look forward to hearing your perspectives. You are products of the U.S. education system and have benefited from federal support for scientific research. The Science Committee is interested in learning your opinions about how the United States can improve both its education and its research systems so that we will continue to be at the cutting edge of science and winning Nobel Prizes in the future. Now I might add, the goal is not so much to win prizes, per se, but they symbolize the progress that we, as a nation, make.

I am pleased today to welcome Dr. William Phillips, who has been here several times before since receiving his Nobel Prize, Dr. Eric Cornell from Boulder and the JILA arm of NIST, and my former colleague, Dr. Jan Hall, also from JILA whom I worked with years ago, and I spent a year and later three summers at JILA—a wonderful institution, wonderful people, and good research. It is my pleasure to welcome all three Nobel Laureates in Physics from NIST as our witnesses today.

I now recognize Mr. Wu for an opening statement.

[The prepared statement of Chairman Ehlers follows:]

PREPARED STATEMENT OF CHAIRMAN VERNON J. EHLERS

Good morning, and welcome to today’s hearing, entitled “*Views of the NIST Nobel Laureates on Science Policy*.” It is my great privilege to chair the Science Subcommittee that oversees the National Institute of Standards and Technology, also known as NIST. This gives me the opportunity to hold hearings such as this one, where we can highlight some of the best science being done in the world today by U.S. researchers at a humble federal science agency. NIST has become the world leader in standards by employing superb scientists who do excellent work; nothing more clearly demonstrates the phenomenal quality of the Agency’s work than the three Nobel laureates NIST has produced in less than ten years, a truly remarkable accomplishment.

Having been a physicist myself, I have some understanding of how difficult your job can be: science is hard work. I think the public understands in an abstract way that if you win the Nobel Prize you must be very smart. But what people frequently do not think about and do not appreciate is the incredible amount of time, effort, and often frustration that goes into a successful, or even unsuccessful, scientific experiment. Optical and low-temperature physics in particular are fields where everything has to work perfectly, the margins for error are very tiny, the precision required is sublime, and experiments that work well in theory take months or years—time that is more often than not fraught with setbacks and frustrations—to produce a result in the laboratory. It takes true dedication and tenacity to push back the frontiers of science the way you have, and I think everyone here stands in awe of your achievements.

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vision for science in this country in the book *“Science: the Endless Frontier.”* The publication of this historic document resulted in the creation of the National Science Foundation, and launched a new era in U.S. scientific research. In 1998, I, together with House Speaker Newt Gingrich, released *“Unlocking the Future: Towards a New Science Policy,”* a document that was intended to guide the development of a long-term science and technology policy for the United States. These policy documents are important because they help us take a long view of the critical role of science in our society and they force us to organize and update our science priorities. Now we are once again due for an update.

As leading scientists in your fields, we look forward to hearing your perspectives. You are products of the U.S. education system and have benefited from federal support for scientific research. The Science Committee is interested in learning your opinions about how the U.S. can improve its education and research systems so that we will continue to be at the cutting edge of science and winning Nobel Prizes in the future.

I am pleased to welcome Dr. William Phillips, Dr. Eric Cornell, and my former colleague Dr. Jan Hall, the three Nobel laureates in physics from NIST as our witnesses today.

Mr. WU. Thank you, Mr. Chairman, for holding this hearing. And I would like to take this opportunity to welcome everyone. And I want to congratulate the NIST Nobel Prize winners before us today.

The Chairman was a scientist, and I was just a science wannabe, or a scientist wannabe, but had I known when I bailed out on medical school, or took an extended leave of absence from medical school 25 years ago, that 25 years later the most important thing that I would be doing is making sure that our education and research functions were funded. Well, who knows? I could have been a doctor.

But I want to take just a couple of minutes to make two points.

You all before us today are outstanding in your fields. And it is my impression that we have many, many outstanding researchers at NIST. NIST’s work in metrology and standards has put at the forefront of many fields in scientific research, and I wouldn’t be surprised if Dr. Debbie Jin, the 2002 McArthur Genius Grant winner, is a Nobel Prize recipient in the near future. In reading through these summaries about your work, I was struck by how this work represents a strong commitment to NIST in cutting-edge research. It is a tribute to the vision and the foresight of past NIST directors and managers.

Second, I welcome the opportunity to interact and to question you all about our support for research and for education. I am especially interested in the role of federal support for scientific research and the concerns that we sometimes have about losing our research edge, whether it was two decades ago to the Japanese or whether it is today to, potentially, some other countries.

And also, I am deeply concerned about our application of resources to education in all its forms, whether it is graduate education, undergraduate education, or K–12 education and would be very interested in your perspective and views on those topics, and especially on a comparative basis between us and other countries.

And so I intend to use today’s opportunity to hear about your opinions and recommendations. And again, congratulations and welcome to the Committee.

Thank you, Mr. Chairman.

[The prepared statement of Mr. Wu follows:]

PREPARED STATEMENT OF REPRESENTATIVE DAVID WU

I want to welcome everyone to this morning's hearing and I want to congratulate the NIST Nobel prize winners before us today.

I want to take a few minutes to make two points. While the researchers before us today are outstanding in their fields, it is my experience that all the researchers at NIST are first rate.

NIST's work in metrology and standards has put the agency at the forefront of many fields of scientific research. I wouldn't be surprised if Dr. Debbie Jin, the 2002 MacArthur genius grant winner, is named NIST's fourth Nobel Prize recipient.

In reading through the summaries of these three individual's work, I was struck by how their work represents a forty year commitment by NIST to cutting-edge research in related fields. This is a tribute to the vision and foresight of past NIST directors.

I welcome the opportunity to learn about our panelists' research efforts and their potential impact. However, I am especially interested in their thoughts on federal support for scientific research.

We hear many reports that the U.S. is losing its research edge and that China, India and Mexico are outpacing us in the graduation of scientists and engineers.

There has also been great concern that the quality of our K-12 science education is putting us behind other countries. So I intend to use today's opportunity to ask them about their opinions and recommendations on these topics as well.

Again, my congratulations to all our witnesses on their accomplishments.

Chairman EHLERS. Thank you, Mr. Wu.

I mentioned earlier the little pamphlet we produced some years ago, or booklet, "*Unlocking the Future: Towards a New Science Policy.*" My aid, Amy, was good enough to loan me her copy so I could show you. It was an immense amount of work. Science policy is an immense amount of work and not nearly as rewarding as research. But it is very essential to the future of this nation, and I think we have fallen down in not paying attention to science policy during the 50 years between Vannevar Bush's work and this document, and I would hope we take it more seriously in the future.

Having said that, if there are any other Members who wish to submit additional opening statements, those statements will be added to the record. Without objection, so ordered.

At this time, I would like to introduce our witnesses. First of all, Dr. William Phillips, winner of the 1997 Nobel Prize for Physics, a very fine physicist. I happen to have a personal connection to all three. My connection with Dr. Phillips is that one of his graduate students who worked on his prize-winning research is now teaching at Calvin College in Grand Rapids, Michigan, not only my hometown, but also my home institution where I taught for many years and helped develop the department and the equipment base that your student is using.

I was hoping to recognize Dr.—pardon me, Congressman Udall, who wanted to be here to introduce the next two witnesses, because they are from his district, but unfortunately, he has been tied up in a meeting. But I am pleased to also introduce Dr. Cornell from the Joint Institute for Laboratory Astrophysics, which is now just called NIST—pardon me, JILA, which is partly supported by NIST. And Dr. Cornell is a staff member of the National Institute of Standards and Technology.

Also, Dr. Hall, who was very active when I spent my time in JILA years ago, but I hardly ever saw him, because he has a unique habit of hiding behind a desk, which is covered with six-foot stacks of paper, and so it is very hard to see him, because you really have to make a concerted effort. But that is good planning. I have adopted that technique partially myself to intimidate visitors

to the office. But both have done very, very good work in the case of Dr. Hall for many, many years at JILA. He was outstanding when I was there, and he has continued that since.

Dr. Cornell is a junior member here, but did a very, very important experiment on Bose-Einstein condensates. It is kind of neat to do an experiment that shows that Bose and Einstein were both right, almost a century ago, wasn't it, when they worked for NIST.

So we are pleased to have all of you here.

As I assume the witnesses have been told, your spoken testimony is limited to five minutes each, and after that, we would take turns in rotation asking five minutes worth of questions of you. We are not. In view of the nature of the panel and the time we have and the lack of other Members here, we will let you exceed the five minutes, if you wish.

We will start by hearing the testimony of Dr. Phillips.

STATEMENT OF DR. WILLIAM D. PHILLIPS, SCIENTIST, PHYSICS DIVISION, NIST LABORATORY; NIST FELLOW; 1997 NOBEL PRIZE WINNER FOR PHYSICS

Dr. PHILLIPS. Thank you, Chairman Ehlers and Members of the Subcommittee. It is a great honor to be here, and it is a pleasure to be with Eric Cornell and Jan Hall who are friends and colleagues in government service and distinguished scientists whose work has profoundly influenced my own.

For more than 27 years at NIST, I had been cooling gases of atoms with laser light. I was not hired to do this, but because cold slow atoms could make better atomic clocks, NIST management encouraged me to pursue my crazy idea as a sideline to my main job. Ten years later, laser cooling was my main job.

We made atoms as cold as a gas had ever been, but things didn't behave quite as expected. Driven by our scientific curiosity, we pursued the discrepancies rather than colder temperatures and discovered, much to everyone's surprise, that our gas could be colder than anyone had thought possible. By 1995, we had gotten under a millionth of a degree above absolute zero, the coldest anything had ever been.

This exciting development illustrates an important lesson about mission-driven research. Had we not taken a detour into basic understanding of the underlying physics, we never would have reached our goal.

Today, laser-cooled atoms define time. At the naval observatory, they keep time for our military. They synchronize GPS, which guides everything from military jeeps to commercial aircraft. NIST's standard clock is accurate to less than one second in 60 million years. We like to call this "close enough for government work."

And that is just the start.

Jan Hall's work promises even better clocks. But most of laser cooling's applications were undreamed of at the outset, something that is typical of basic research. One of the most exciting applications is quantum information. Eric Cornell, who cooled atoms 1,000 times colder than our 1995 record, will say more about this. But quantum computation and communication has code-breaking potential and guaranteed privacy with crucial national security implications.

Secure quantum communication is here and now. Quantum computing needs a lot more basic research and technology development, but NIST is leading the way.

What role does NIST play in my work and in my field generally?

To put it succinctly, I would not have done any of this work had I not been at NIST, and NIST is the field's world leader. The mission of NIST is measurement science, and so I pursued laser cooling. The mission was the motivation, but the NIST environment made the research flourish. NIST encourages us to take a long view of our mission and to pursue targets of scientific opportunity. NIST didn't just tolerate my sideline research; they encouraged it and supported it.

But the most important feature of NIST's environment is the quality of the people. People often ask why am I still at NIST when I could make a lot more money some place else, and the answer is my colleagues. NIST has assembled some of the best scientists in the world, and it has maintained them in an atmosphere that nurtures the best possible basic research. The payoff has been obvious: three Nobel Prizes in eight years, world leadership in measurement science, lines of research with applications in commerce, science, industry, and the military.

You have asked what the Federal Government can do to improve the competitiveness of U.S. research.

First, support basic research strongly, especially in the physical sciences and in universities and in government laboratories. Basic research created, for example, the electronics industry where innovation keeps America's position strong in spite of cheaper production overseas. A landmark was the invention of the transistor at Bell Labs. But today, that tradition of far-sighted industrial research has virtually disappeared. Where industry has stepped back, government must step up. And it is vital that—what should I do? Just go on?

Chairman EHLERS. Just—it will take just a second.

Dr. PHILLIPS. Okay. Thank you.

And it is vital that mission-focused government laboratories like NIST do not adopt this same short-term thinking that infects industry. NIST has always recognized the importance of strong investment in basic research for the long haul, and I believe this is the correct path for all mission agencies, civilian and military. The recent legislative and executive initiatives to dramatically increase basic research in physical sciences are right on target. America's economic advantage depends on her research advantage. Unless we invest in basic research in good times and in bad, in war and in peace, we risk being unable to compete in the world market, and we risk being unprepared to respond to threats.

A great strength of U.S. science is the diversity of funding: the NSF, NASA, DOE, DARPA, ONR, AFOSR, ARO all provide opportunities for basic research funding with different cultures, styles, and missions. We should resist attempts to homogenize the approach to funding. We should maintain all of these opportunities, each with their own approaches, and each with a strong basic research component. We need the diversity. I don't want every funding agency to be like DARPA, and I don't want every funding agen-

cy to be like the NSF. That diversity that we have is one of the most important things making our nation's research great.

Finally, the American research environment is crucial. It is a magnet drawing the best scientific minds from around the world. Unfortunately, legitimate concerns about national security may have the unintended consequence of isolating the United States scientifically. Many foreign scientists now see the United States as a less friendly place scientifically. At the same time, foreign-born workers fill close to half of our science and technology jobs. We must improve the educational pipeline supplying Americans for our high-tech needs, and we must welcome the best of the foreign scientists as students, collaborators, and new Americans. If we do not, we risk putting ourselves out of the main marketplace of ideas and out of the game.

I want the United States to be the world leader in making the great discoveries of the 21st century and in claiming the fruits of those discoveries, and I know that you do as well.

Thank you very much for your attention. Thank you especially for your concern about this issue. I will be happy to answer questions.

[The prepared statement of Dr. Phillips follows:]

PREPARED STATEMENT OF WILLIAM D. PHILLIPS

Mr. Chairman and Members of the Committee:

As a Federal Employee and, like each of you, a public servant, it is a great pleasure for me to appear before you. And it is an honor to appear along with Eric Cornell and Jan Hall, friends and colleagues in government service, and distinguished scientists whose work has had such a profound influence on my own research. I have worked for the National Institute of Standards and Technology (formerly the National Bureau of Standards) for more than 27 years. I was hired to make precision electrical measurements—an activity directed toward the NIST missions of providing the high quality measurement services needed for modern industry and science and of exploring the frontiers of knowledge relating to measurement science. At the same time I was encouraged by the management of NIST to pursue, as a side interest, topics in laser physics that could benefit NIST's mission, broadly interpreted.

In my spare time, with scrounged equipment and funds, I investigated a seemingly crazy idea—that you could cool something by shining laser light on it. The “something” I wanted to cool was a gas of atoms, and the motivation was to make the atoms move more slowly, since colder simply means that the atoms are moving more slowly. Why? Because if the atoms were moving more slowly, we could measure them better, and better measurement is one of the key services we at NIST deliver. In particular, I wanted to make better atomic clocks—to make our best time-keepers even better.

How could laser light cool a gas of atoms? The idea was to use the light to push on the atoms in such a way as to make them slow down. Or at least that was the dream that I pursued, in odd moments, as a young physicist in 1978. I was inspired by the fact that earlier that year, Dave Wineland and his colleagues at the NIST laboratories in Boulder, CO, had done just that—laser cooling ions, electrically charged atoms that were easier to hold onto. It was going to be harder to do that with neutral atoms, which, lacking an electric charge, were harder to control and confine. And I was eager to take on the challenge.

With the strong support of NIST and of the ONR, by 1988 laser cooling had become my sole assignment. The international scene had changed considerably. In 1978 a lone group in the Soviet Union was our only competitor in laser cooling of neutral atoms. By 1988 groups across the U.S. and around the world had joined in the fun. At NIST, we had first learned how to slow down beams of atoms from well over the speed of sound to human running speeds. We learned to trap the atoms, suspending them in vacuum using first magnetic fields and then lasers. Things were going well. We were learning to use the tools of laser and magnetic manipulation of atoms to make them do what we wanted. But there were problems. Things were

not behaving exactly as our calculations had predicted. We tried modifying the theory in reasonable ways, but nothing worked.

Physicists are, by nature and by training, driven to make sense out of what we see in the world and in the laboratory. And things were not making sense. Things were working well enough, and we were well on our roadmap to slow our atoms down, but not everything was adding up. And we could not let it rest. We turned our attention to figuring out what was going wrong. Or, more precisely, what was going *on*. And, after something like a year of investigation, we learned, much to our surprise, and to the surprise of colleagues around the world, that the strange behavior was tied to the fact that we were cooling our atoms to temperatures far lower than we or anyone had thought possible. We were astounded! Experiments rarely work better than expected, and, in trying to get temperatures as low as possible, we had gotten to temperatures a lot lower than thought possible.

The results were so unexpected that we confirmed them four different ways before we reported them publicly. After other laboratories had reproduced our results and theorists had deduced a new mechanism for laser cooling, we eventually (in 1995) reached temperatures more than a hundred times lower than had been thought possible. We achieved temperatures lower than millionth of a degree about absolute zero—at that time, the coldest temperature ever achieved. It was one of the most exciting and satisfying experiences a scientist could hope for, and it illustrates an important feature about mission driven science and basic research. We had set out to laser cool a gas of atoms in order to make better clocks. We were sidetracked by basic scientific questions about the nature of the interaction of light and matter, and by studying those questions, we learned new and unexpected things about light and matter. And although we did not know at the outset how important it would be, that knowledge, gained through our digression into basic research, was what made it possible to achieve our mission goal of making a better clock.

Today, clocks using laser cooled atoms provide the official definition of the second, the unit of time. Clocks based on this principle are in use at the US Naval Observatory, and laser cooled clocks provide the accurate timekeeping needed for modern military and commercial needs. The Global Positioning System or GPS, which guides everything from jeeps in the desert to commercial aircraft to private cars, is synchronized using laser cooled clocks. The best of these clocks is NIST's F-1 cesium fountain clock with a fractional inaccuracy of better than 5×10^{-16} , or less than one second in 60 million years. At NIST, this is known as "close enough for government work."

So, laser cooling is already in use for military and commercial purposes. But this has only been the beginning of the story. A still more advanced generation of clocks using both laser cooled ions and laser cooled neutral atoms is under development and these clocks have achieved performance that already promises to be ten times better than the best current clocks. But most of the things that laser cooling is now used for were completely unanticipated when we began our studies. (This is a common feature of the fruits of basic research—the best of those fruits are often evident only well after the inception of the work.) One of the most exciting applications of ultra-cold atoms is in the emerging field of quantum information. Here, single atoms or single ions are used to store information in the form of quantum bits or "qubits." Computation and communication of information with qubits can perform feats impossible with ordinary computers or ordinary secure communications systems. Eric Cornell will say more about this in his remarks. Among the most important applications of quantum information are code breaking and eavesdropping-proof communications. These applications are crucial to issues of national security, and NIST is pursuing them. Quantum communication is now a reality, with a testbed at NIST producing quantum cryptographic code at live-video rates. Quantum computers are still a distant dream, with a great deal of both basic research and technological advancement needed before they are a reality.

The Committee has asked for a discussion of the role that NIST plays in my work and my field generally. To put it succinctly, I do not believe that I would have done any of this work had I not been at NIST. When I was a young postdoctoral fellow at MIT, I had lots of ideas about where to take my future research. One of those ideas was laser cooling. But had I gone to a university or to an industrial research laboratory, I would have pursued other goals. It was because the mission of NIST involves measurement and improving measurement science that I decided to pursue laser cooling. In this case, the application provided the motivation. But it was the environment of NIST that made the research flourish. NIST encourages its scientists to think "outside the box," to take a long and broad view of our mission, and to pursue targets of scientific opportunity at the same time that we are attending to the problems at hand. My dabblings in basic atomic physics were not just tolerated—they were encouraged and supported. And some of the things that my col-

leagues and I accomplished laid the foundations for the things that Eric Cornell and Jan Hall achieved, just as their achievements enabled much of what we did and set us onto new directions.

NIST holds a leading position in Atomic, Molecular and Optical Physics. The three recent Nobel prizes in the area are but one testament to that fact. The strong research environment in this area was crucial to the development of my own research program, and the cross-fertilization was and continues to be extremely important.

This brings me to what is probably the most important aspect of the NIST scientific environment—the quality of the researchers themselves. People often ask me why I am still at NIST; why I have not accepted offers of greater salaries in other institutions. The main answer is my colleagues. I cannot imagine a better and more stimulating environment than the one I enjoy at NIST. The colleagues in my own research group, plus people like Eric Cornell, Jan Hall, and a long list of others from whom I learn and benefit on a daily basis, are what makes working at NIST such a rewarding and stimulating experience. When I hear someone characterize government workers as clock-watching slackers, I know they haven't met my colleagues. When I hear claims that the government should hire people who are just good enough to do the job I am horrified. NIST has assembled some of the best scientists in the world, and has kept them by providing an atmosphere which nurtures the best kinds of research. The pay-off has been obvious: three Nobel prizes in eight years; world leadership in measurement science; and lines of research with present and future applications in commerce, science, industry and the military.

Finally, you have asked for my perspective on what the Federal Government can do to improve the competitiveness of U.S. scientific research. When we speak of the competitiveness of American science, there are two aspects. One is how well science itself competes with the science of the rest of the world. The other is how well American science contributes to the economic competitiveness of the U.S. in the global marketplace. My view is that the one enables the other. We often talk, quite rightly, about technology transfer. But most important is having technology to transfer. I think that resources of the Federal Government devoted to discovery are extremely productive, and that the good results will be taken up commercially as long as the environment for doing that is kept friendly and relatively free of artificial impediments. I must emphasize that these perspectives are my own personal ones and not necessarily those of NIST's management. Also, while I may be an expert in laser cooling, I am not an expert on the sociology and economics of science research. But I have developed some ideas about what makes American science strong and what we need to do to continue to maintain our position in the increasingly competitive international research landscape.

First I believe it is essential to maintain and in fact increase support for basic research, especially in the physical sciences. Post WWII, the physical sciences had strong support, in large part because of the correct understanding that a legacy of basic research had played a key role in the development of such crucial wartime technologies as radar and nuclear weapons. That strong support for physical science research led to the development of a computer and consumer electronics market where American leadership in innovation has allowed us to retain a strong position in the face of cheaper production overseas. Similarly, advances in medical and life sciences were underpinned by strength in the physical sciences. Tools like magnetic resonance imaging and other modern medical diagnostic tools had their roots in the basic physics research conducted earlier in the 20th century. That basic research was being carried out in a wide variety of environments—university labs, supported by both civilian and military agencies, military and non-military government labs, as well as industrial labs.

The invention of the transistor at Bell Telephone Labs set the stage for a booming electronics industry that has sustained much of the U.S. economy. It came from a strong and sustained program in basic research at Bell Labs, one that was mirrored in other industrial labs like RCA, Raytheon, Ford, Xerox, IBM, and so forth. Today, many business analysts seriously contend that AT&T never got a significant return on its research investment and denigrate the value of any long-range, basic research in any industry, focusing instead on very short-term return on investments. Today, Bell Labs is a shadow of its former self in regard to basic research and that sort of far-sighted support of research has virtually disappeared from American industry. I don't know if we can ever expect to return to the golden age of industrial research, but I strongly believe that we must, as a nation, regain and maintain that level of basic research if we are to remain competitive in a world economy. If industry cannot or will not take its traditional share of this responsibility, I believe that government must compensate. Furthermore, in my opinion it is vital that government laboratories like NIST, with a mission focus, do not fall into the same short-term think-

ing about research that infects industry. Imagine where the U.S. economy would be today if we as a nation had not made the long-term investments, done in part by industrial labs, which led to the current semiconductor electronics industry. My reading of our history is that NIST has always recognized the importance of substantial investment in basic research for the long haul, and I commend this attitude to all other mission agencies, both civilian and military.

The recent initiatives by the executive and legislative branches of the Federal Government to dramatically increase the support for basic research in physical sciences certainly have the right spirit in regard to basic and long-term research, and I applaud these efforts.

In a global economy where both manufacturing and service can be provided half a world away, it is through innovative use of new knowledge that America can expect to maintain a competitive edge. And the first ones with the best opportunity to make use of new knowledge are the ones who create it in the first place. That is why basic research is so vital, and why America continues to compete successfully in a world where labor and other costs are so much less elsewhere. But unless we strengthen our position in basic research investment, we run the risk of losing what edge we have. I believe that it particularly important to make these investments in both good times and bad. One never wants to be in a position of eating one's seed-corn, and a reduction of our research portfolio in times of tight budgets would amount to exactly that. An extension of that reasoning says that for Defense purposes we should invest in basic research both in times of war and peace, and in times of global superpower competition and in its absence. Being able to respond to threats with technology depends greatly on having the basic understanding that underpins that technology, and basic research is the way one gets that.

I believe that one of the great strengths of the U.S. research climate compared to that of other nations is the diversity of environments for doing research and of sources of funding for research. Many countries have their research centralized under a "ministry of science" and one periodically hears calls for similar centralization in the U.S. My opinion is that this would be a big mistake. Here in the U.S. we have university labs, military labs, national labs, both civilian and government operated, with both classified and unclassified work. Each has a different environment and culture and therefore a different opportunity to make discoveries. I firmly believe that we need to maintain this diversity of research opportunities and maintain the strength of all of these different parts of our research landscape.

Similarly, researchers can go to a multitude of agencies for support of research in their own institutions. The National Science Foundation, NASA, the Dept. of Energy, the intelligence agencies, and the various military agencies like DARPA, ONR, AFOSR, and ARO all provide opportunities for funding basic research with different missions, styles and cultures. The NSF relies on extensive peer review from multiple outside experts, while the ONR often makes decisions based on the judgment of a single internal program manager. NASA often provides support for projects over decades while DARPA changes its portfolio on a much shorter time scale. I got my start in large part because a single manager at the Office of Naval Research believed in me and was interested in the military applications of better clocks. Different aspects of my work have, at various times also been supported by NASA and the NSA. I am keenly aware of the importance of the ability to seek support from agencies with different agendas and styles. And I believe that it is vital that we maintain each of these various sources, with their individual cultures, with a strong basic research component: I do not believe that any research institution is well served if it lacks a strong basic research program. I urge that we resist attempts to homogenize the approach to funding. I do not believe we would be well served if all agencies acted like DARPA, or if they all acted like the NSF. I do not believe we would be well served if all research were done in universities or if all research were done in mission agencies like NIST. We need that diversity—it is one of the most important things that makes our nation great in the sphere of research.

Finally, just as the research environment that we enjoy at NIST has been crucial to the success of our NIST mission, the research environment in the U.S. is essential to American competitiveness on the global scene. That environment has been the magnet that has drawn the best scientific minds from around the world to the U.S. to study, to collaborate with U.S. scientists, and often to remain in the U.S., become Americans, and add permanently to our scientific strength. Unfortunately, legitimate concerns about national security may have the unintended consequence of isolating the U.S. scientifically. There is a strong perception among many foreign scientists that the U.S. has become a less hospitable place for scientific collaboration. The organizing committees of some international conferences are avoiding venues in the U.S. because of concerns that some participants may be denied visas. U.S. researchers are concerned that students or visitors from certain countries may

be unable to work in their laboratories because of deemed export regulations regarding who is allowed to work with certain classes of equipment. Foreign students, who provide a substantial fraction of the manpower for the discovery engine of American university research, are now choosing other countries in which to pursue advanced degrees in part because of their perceptions about the U.S. attitude toward foreigners. Today, close to one half of the high tech science and engineering positions filled in the U.S. are filled by foreign born workers. We need to improve the educational pipeline supplying American workers for our high-tech needs, and we need to find ways, compatible with our real national security needs, to continue to welcome the best of the foreign scientists as students, visitors, collaborators, and immigrants. If we do not, we run the risk of marginalizing the U.S. scientific enterprise, of putting ourselves outside of the mainstream marketplace of ideas; we run the risk of not being in the game.

The beginning of the 21st century is an incredibly exciting place to be for any scientist. We look at a physical world that is still full of mystery-unsolved problems of the most fundamental sort, problems whose solutions are likely to change our lives in unanticipated ways, just as the revolutionary discoveries of the 20th century did. I want the U.S. to be the world leader in making the great discoveries of this century and in claiming the fruits of those discoveries. I know that you do as well, and I trust that you will work hard to make it happen. I know that I will.

Thank you very much for your concern and for your attention. I will be happy to respond to questions.

BIOGRAPHY FOR WILLIAM D. PHILLIPS

Date of Birth: 5 November 1948

Place of Birth: Wilkes-Barre, Pennsylvania, USA

Citizenship: United States

Education:

Camp Hill High School, Camp Hill, Pennsylvania, diploma (Valedictorian) 1966.

Juniata College, Huntington, Pennsylvania, B.S., Physics, summa cum laude, 1970.

Massachusetts Institute of Technology, Cambridge, Massachusetts, Ph.D., Physics, 1976. Thesis under Prof. Daniel Kleppner, thesis title: I. The Magnetic Moment of the Proton in H_2O ; II. Inelastic Collisions in Excited Na.

Scientific Experience after Ph.D.:

1978–present: Physicist, National Bureau of Standards (Now National Institute for Standards and Technology); 1990–96: Group Leader of the Laser Cooled and Trapped Atoms Group of the Atomic Physics Division; 1996–98, NIST Fellow; 1998–present: NIST Fellow and Group Leader of the Laser Cooling and Trapping Group.

2001–present: Distinguished University Professor, University of Maryland, College Park MD (on leave).

2002–2003: George Eastman Visiting Professor, Balliol College and Clarendon Laboratory, Department of Physics, University of Oxford.

1992–2001: Adjunct Professor of Physics, University of Maryland, College Park.

1989–1990: Visiting Professor at Ecole Normale Supérieure, Paris, in the laboratory of Claude Cohen-Tannoudji and Alain Aspect.

1976–1978: Chaim Weizmann Postdoctoral Fellow at Massachusetts Institute of Technology.

Awards and Honors:

Pennsylvania State Scholarship, 1966–1970.

C.C. Ellis Memorial Scholarship, 1969–1970.

Election to Juniata College Honor Society, 1969.

Woodrow Wilson Fellow, 1970.

National Science Foundation Fellow, 1970–1973.

Chaim Weizmann Postdoctoral Fellow, 1976–1978.

Outstanding Young Scientist Award of the Maryland Academy of Sciences, 1982.

Scientific Achievement Award of the Washington Academy of Sciences, 1982.

Silver Medal of the Department of Commerce, 1983.

Samuel Wesley Stratton Award of the National Bureau of Standards, 1987.
 Arthur S. Flemming Award of the Washington Downtown Jaycees, 1988.
 Gold Medal of the Dept. of Commerce, 1993.
 Election to American Academy of Arts and Sciences, 1995.
 Election as a NIST Fellow, 1995.
 Michelson Medal of the Franklin Institute, 1996.
 Distinguished Traveling Lecturer (APS-DLS), 1996-98.
 Election to the National Academy of Sciences, 1997.
 Nobel Prize in Physics, 1997. Nobel Prize Citation: "for development of methods to cool and trap atoms with laser light" The 1997 prize was shared with Steven Chu of Stanford University and Claude Cohen-Tannoudji of the Ecole Normale Supérieure, Paris.
 Honorary Doctor of Science, Williams College, 1998.
 Doctor Honoris Causa de la Universidad de Buenos Aires, 1998.
 Arthur L. Schawlow Prize in Laser Science (APS), 1998.
 Honorary Doctor of Science, Juniata College, 1999.
 American Academy of Achievement Award, 1999.
 Gold Medal of the Pennsylvania Society, 1999.
 Richtmeyer Award of the Am. Assoc. of Physics Teachers, 2000.
 Election to the European Academy of Arts, Sciences and Humanities (titular member), 2000.
 Condon Award of NIST, 2002.
 Archie Mahan Prize of the OSA.
 Election as an Honorary Freeman of the Worshipful Company of Scientific Instrument Makers, London, 2003.
 Election as an alumni member of Juniata College's chapter of Omicron Delta Kappa, the National Leadership Honor Society, 2004.
 Election as an Honorary Member of the Optical Society of America.
 Appointed an Academician of the Pontifical Academy of Sciences, 2004.

Chairman EHLERS. Thank you very much.
 Dr. Cornell.

**STATEMENT OF DR. ERIC A. CORNELL, SENIOR SCIENTIST,
 NIST LABORATORY; FELLOW, JILA; 2001 NOBEL PRIZE WINNER FOR PHYSICS**

Dr. CORNELL. Chairman Ehlers and Members of the Subcommittee, please allow me to briefly introduce myself and my research.

My name is Eric Cornell. I was hired by NIST in 1992 to do research in quantum optics. Then, as now, NIST was known in the world of physical sciences as a place where great technology meets great ideas and, I must say, great people. In those days, Jan and Bill here were already great draws and a good reason to come to NIST and the idea that I could work with the likes of that was a thrill for me.

The management at NIST encouraged me to pursue a high-risk research program at the cutting edge of modern physics, and today, NIST continues to be, and perhaps even more so, an incubator for quantum science in the United States. And many of the leaders in the field, even if they don't work at NIST at the time, have come through a NIST lab at one time or another in their careers.

I won't spend a lot of time rambling about my favorite topic, the physics of the ultra-cold, suffice it to say that when you chill a gas down to within a millionth of a degree or a billionth of a degree of absolute zero, the atoms in the gas all merge together to form

a “super atom,” and this state of matter, called the Bose-Einstein condensate, was what I was awarded the Nobel Prize for in 2001.

What has Bose-Einstein condensation been good for?

Well, for example, it is being used in an effort to develop a new generation of sensitive accelerometers, which you could use for remote sensing and for navigation by dead reckoning, like in submarines. But in the long run, Bose-Einstein condensation is likely to be more important because of its role as a scientific building block, a tool to help us understand and to tame quantum mechanics, and there are many examples of how taming quantum mechanics has made, and will make, a big difference to our country in the coming two decades. And I will tell you just one example, which is called quantum computing. Bill has already alluded to it.

Quantum computing is this really amazing idea that came out of the 1990s. Inside any computer, there are millions of tiny switches, called bits, and these switches can either be on or off, one or zero. And these bits are what a computer uses to make calculations. A quantum computer has something called quantum bits, and magic—or Q-bits, and the magic of quantum bits is that unlike conventional transistors, which are either on or off, quantum bits can simultaneously be both one and zero. It is a weird idea, something hard to bend your mind around, but the power of this possibility comes in when you start stringing many of these bits together with 60 ordinary computer bits, conventional bits. If you string them in a row, you can represent any number between one and about a quadrillion. Okay. But with 60 quantum bits in a row, with each bit being both one and zero at the same time, you can simultaneously represent every number between one and a quadrillion.

So, why would you want to do that?

Well, a major computational problem, which is very important to our national security and to our economy, is breaking very large numbers up into their prime factors, into the two numbers you multiply together so that it comes out evenly. Roughly speaking, a very large number is like a code, and its prime factors are a key to the code. Prime factors are at the heart of modern cryptography, and that is what makes possible secure military and diplomatic communications and also the secure electronic transactions that are at the heart of our banking and finance system. And if this system of cryptography were to be threatened, it could cripple our economy in days or hours.

So this is where quantum computing comes in. Suppose, as a cryptographer, you want to know the two numbers that multiply together to make up some huge number near a quadrillion. You want to know its prime factors. You want to crack this code. One way you could do it is to take this—take every number between one and a quadrillion and try and divide it into the huge number. And if it goes evenly, those are the prime factors. Those are the keys to the code. But even for a very fast computer, it takes a long time to do a quadrillion divisions.

Suppose, instead, that your computer were made of quantum bits. What you can do is take your 60 quantum bits, which simultaneously represent every number between one and a quadrillion, and use your quantum computer to try and divide that number into the huge number you are trying to factor. And in a single computa-

tional process, you can find out which ones work, and you can break the code maybe a billion times faster than a conventional computer.

The implications for secure economic transactions are profound. These quantum computers could also find use in solving difficult problems like protein folding in order to design a new generation of pharmaceuticals.

None of this is going to happen next week, maybe not even in 2007. It is a hard problem, but I think we need to try.

Members of the Committee, I wish I could tell you what will be the big new industry of the year 2020, but no one can know the answer for sure, and that, really, is why scientific research and discovery is so important to our country. Without knowing for sure what the next big thing will be, no one can know. We can still remain cautiously optimistic that that next big thing, like the Internet, like computers, like transistors, or whatever the next big thing, we can remain somewhat cautiously optimistic that it will be an American thing. Optimistic, because over the last 50 years, as the American economy has benefited from many cycles of emerging technology becoming high tech and then becoming low tech and being moved overseas, the one thing that hasn't changed has been America's lead in scientific research. We stay on the cutting edge and we win.

We have to be cautious because, while our lead has been emplaced for five decades, the next five decades are no sure thing. Let us protect our lead.

I would like to conclude my testimony by pointing out that not every measure that Congress could take to nurture the science research requires additional spending. In my personal opinion, and I want to echo what Bill has said, one fact that has made America's high-tech industry and research so successful over the years has been the steady influx of brilliance and creative, hardworking, driven science and engineering students from all around the world who come here. After their graduation, many of these students have stayed in our country to contribute to the vitality of our high-tech sector. When this happens, the big winners are American industry and the American people. Other nations' brain-drain has been America's brain-gain. When we make it easier for the smartest of the world's young people to come here to study and easier for them to stay here afterwards and apply their skills to work in the American economy, we help no one more than we help ourselves.

I would like to thank this subcommittee once again for allowing me to testify before you today, and I am very happy to answer any questions.

[The prepared statement of Dr. Cornell follows:]

PREPARED STATEMENT OF ERIC A. CORNELL

Chairman Ehlers and Members of the Subcommittee, please allow me to briefly introduce myself and my research. My name is Eric Cornell and I was hired by the National Institute of Standards and Technology (NIST) in 1992 to do research in quantum optics. Then as now NIST was known in the world of the physical sciences as a place where great technology meets great ideas, so I was thrilled to get the job. Management at NIST encouraged me to pursue a high-risk research program at the cutting edge of modern physics. NIST continues to be something of an incubator for quantum science in the U.S. Many of the leaders in the field have come through a NIST lab at one time or another in their careers.

For my part, I set out to make the World's Coldest Gas, building on techniques developed by my fellow NIST scientists, Drs. Jan Hall and Bill Phillips. Why would we want to make the World's Coldest Gas? There were several reasons. It turns out that cold gases are a useful environment for making extremely precise measurements, which is a capability at the heart of NIST's standards mission. Perhaps more important to me personally was that I knew that often times you can do the most exciting science if you can work right at the boundary of a current technological frontier, and one of science's key frontiers is the frontier of very low temperature. Every time we've been able to reach new heights (really "depths") in low temperature, exciting physics has followed.

I won't use the Committee's time to ramble on about my favorite topic, the physics of extreme low temperatures, but I will tell you that when a gas, made of atoms, gets colder and colder, those atoms, sure, move slower and slower. But there are also more subtle changes. For one thing, at room temperature, atoms act like little billiard balls, bouncing off the walls and off each other. But close to the very lowest possible temperatures, (known as "absolute zero") atoms stop acting like little balls and start acting instead like little waves. And at the VERY lowest temperatures, within a millionth of a degree of absolute zero, the atoms all merge together to form one super-atom-wave, a new state of matter called a Bose-Einstein condensate (BEC). Predicted by Albert Einstein back in 1925, the Bose-Einstein condensate had never been achieved until we finally found it at NIST in 1995. It was for this achievement that I shared (with my colleague from University of Colorado, Carl Wieman and with Wolfgang Ketterle) the 2001 Nobel Prize in physics.

Where has Bose-Einstein condensation led us, in the ten years since we first created it? What, in particular has it been good for? BEC has found several direct applications, and in particular we and other research groups around the country are trying to develop precision accelerometers, gravimeters, and gyroscopes, to be used for remote sensing and navigation by dead reckoning. In the long run, BEC is likely to be still more important because of its role as a scientific building block, a tool to help us understand and tame quantum mechanics, and to put quantum mechanics to use on problems with relevance to our economy, our health, and our national security.

Let me share with you two examples of how the taming of quantum mechanics may make a big difference to our country in the coming two decades. The first is quantum computing.

Quantum computing is one of the most amazing concepts to come out of the 1990s. What puts the "quantum" in quantum computing is so-called "quantum bits." In an ordinary computer, there are millions of tiny switches, called bits, that can be either on or off, one or zero. The bits are the memory of the computer, and the bits are what a computer uses to make calculations. A "quantum bit," or "qbit," transcends the traditional requirement that a bit be either "on" or "off." A qbit instead can simultaneously be in a combination of "on" or "off." The power of this possibility comes in when you start stringing many qbits together. With ten bits in a row, with different combinations of "ones" or "zeros," you can represent any number between zero and 1023. With ten *quantum* bits in a row, each in a superposition of one and zero, you can simultaneously represent *every* number between one and a thousand.

Why would one want to do that? We can take as an example a computational problem which is extremely important to our national security and our economy—breaking large numbers up into their prime factors. Prime factors are at the heart of our cryptography systems, which allow for secure military and diplomatic communications, but also are at the heart of our banking and finance system. Businesses, banks, and increasingly ordinary consumers do not send cash or even checks for transactions—they send encrypted ones and zeros. If this system of cryptography is threatened, it could cripple our economy in days or hours. Roughly speaking, very large numbers are the code, and the prime numbers that divide in evenly are the key to the code.

Here is where quantum computing comes in. Suppose you want to find out what are the factors of 999,997. One way you could do that is to take every number from one to a thousand, and try to divide it into 999,997. The ones that go in evenly, those are the prime factors! Even for a modern computer, it takes a while to do one thousand divisions. Suppose instead your computer is made of quantum bits. What you can do is take your ten quantum bits, which simultaneously represent every number between one and a thousand, and try to divide that number into 999,997. In one single mathematical operation, you can find out if any of those numbers divide in evenly, and thus crack the code in one operation instead of in one thousand.

For cryptography, you don't care about numbers like 999,997—you care about numbers that are a trillion trillion times larger, and what are the prime factors of

those numbers. Using a quantum computer, you could answer that question in principle a trillion times faster than you can with an ordinary computer, even a so-called “super-computer.” The implications for secure communications and economic transactions are profound.

There are other extremely difficult problems in computing, problems which are too hard for even the fastest modern computers to solve. One of these is the problem of protein folding, the way in which chains of amino acids bundle in on one another to form the parts that make up living biological cell. If this folding goes wrong, you get mad cow disease. The flip side is if you can learn to control and predict protein folding, you have a very powerful tool for designing the next generation of drugs. This is the sort of problem that a breakthrough in quantum computing could hugely impact, again by allowing one to do trillions of calculations all at once.

None of this is going to happen tomorrow. What I have left out of this whirlwind gee-whizz presentation of the potential of quantum computing is that there is no working quantum computer now, and don't count on there being one in 2007, either! The scientific and technical challenges associated with constructing quantum bits, and stringing them together into an integrated computer, are immense. In a modern conventional computer, there are literally billions of zero-one bits. A modern quantum computer would be so much more powerful than a conventional computer that it would not need billions of quantum bits in order to do amazing things. But it would need thousands of quantum bits. Currently the best experimental quantum computing teams are able to string together about four, maybe six quantum bits. Still, my own opinion is that quantum computing is such a powerful idea, it really must be explored.

So why is it important that the U.S. conduct this research? As with any problem, human nature dictates that there will always be curious people trying to come up with a solution. Quantum physics is no different. Teams from around the globe are conducting research trying to solve the riddle of quantum computing. If the U.S. stays on the sidelines, then we will watch others make profound discoveries that will ultimately improve the competitiveness of their industries and quality of life. The big question is what is going to be the big new industry of 2020? If I knew the answer, I would not be here in front of you testifying—I'd be off setting up my own high-tech venture capital company instead. No one knows the answer for sure, that is why scientific research and discovery is so important. Without knowing for sure what the next big thing will be, we can remain cautiously optimistic that that big thing will be an American thing. The reason for optimism is that, over the last fifty years, as the American economy has benefited from many cycles of emerging technology, the one big thing that hasn't changed has been America's lead in science research. The reason for caution is that, while our lead has remained in place for 50 years, it need not remain for another 50. It needs to be nurtured!

I'd like to conclude my testimony by pointing out in that not every measure that Congress could take to nurture science research requires additional spending. In my personal opinion, one fact that has made American high tech research and industry so successful over the years has been the steady influx of brilliant, creative, and hardworking science and engineering students from all around the world. After their graduation, many of these students have stayed on in our country to contribute to the vitality of our high-tech sector. When this happens, the big winners are American industry and the American people. Other nations' brain drain has been America's brain gain! When we make it easier for the smartest of the world's young people to come here to study, and easier for them to stay here afterwards and put their skills to work in the American economy, we help no one more than we help ourselves.

I would like to thank the Subcommittee once again for allowing me to testify before you today. I will be happy to answer any questions.

BIOGRAPHY FOR ERIC A. CORNELL

Degrees

- B.S., Physics, with honor and with distinction, Stanford University, 1985
- Ph.D., Physics, MIT, 1990

Appointments

- Fellow, JILA, NIST and University of Colorado at Boulder, 1994–present
- Senior Scientist, National Institute of Standards and Technology, Boulder, 1992–present

- Professor Adjoint, Physics Department, University of Colorado, Boulder, 1995–present
- Assistant Professor Adjoint, Physics Department, University of Colorado, Boulder, 1992–1995
- Post-Doctorate, Joint Institute for Laboratory Astrophysics, Boulder, 1990–1992
- Summer Post-Doctorate, Rowland Institute, Cambridge, 1990
- Research Assistant, MIT, 1985–1990; Teaching Fellow, Harvard Extension School, 1989
- Research Assistant, Stanford University, 1982–1985

Honors and Awards

- Member, National Academy of Sciences, 2000
- Fellow, Optical Society of America; Elected 2000 R.W. Wood Prize, Optical Society of America, 1999
- Benjamin Franklin Medal in Physics, 1999
- Lorentz Medal, Royal Netherlands Academy of Arts and Sciences, 1998
- Fellow, The American Physical Society; Elected 1997
- I.I. Rabi Prize in Atomic, Molecular and Optical Physics, American Physical Society, 1997
- King Faisal International Prize in Science, 1997
- National Science Foundation Alan T. Waterman Award, 1997
- Carl Zeiss Award, Ernst Abbe Fund, 1996
- Fritz London Prize in Low Temperature Physics, 1996
- Department of Commerce Gold Medal, 1996
- Presidential Early Career Award in Science and Engineering, 1996
- Newcomb-Cleveland Prize, American Association for the Advancement of Science, 1995–96
- Samuel Wesley Stratton Award, National Institute of Science and Technology, 1995
- Firestone Award for Excellence in Undergraduate Research, 1985
- National Science Foundation Graduate Fellowship, 1985–1988

Chairman EHLERS. Thank you very much.
Dr. Hall. Just push the button, and perhaps pull it closer to you.

STATEMENT OF DR. JOHN “JAN” L. HALL, SCIENTIST EMERITUS, NIST LABORATORY; FELLOW, JILA; 2005 NOBEL PRIZE WINNER FOR PHYSICS

Dr. HALL. Mr. Chairman, Honorable Congressmen, other colleagues acting in the public’s service, and ladies and gentlemen, I am absolutely delighted to have the chance to interact with your public forum about the issues which I see as challenging us for the next time. If I have a moment at the end, I would even, since I am now retired, undertake to discuss some of the 600-pound gorillas that are in our room and somehow never get attention.

In brief, the NIST has gone from, when I first joined in 1961, mixed strengths to a case where it is, really, I think, the world’s strongest research organization, at this point. But we, in earlier times, had other American organizations carrying letters, like IBM and Bell Telephone Laboratories and General Electric, but we know that story. We have somehow gotten confused about where our strengths are. No one is taking care of—or few people are taking care of the long-term interests, which are about basic research and about application of resources to training the next generation of people.

In JILA, I had seen the possibilities of this quantum optics, the precursor to the quantum computing that Eric mentioned, and the NIST was responsive to my proposal to start one post-doctorate project. We interviewed for candidates, and one candidate showed up who was completely smarter than the rest of them, but he had his own dream. He wanted to fool around with Bose-Einstein condensation. So I hired Eric Cornell, helped to hire him, and used my money, which was for quantum optics. And less than this chart. They didn't say anything. They didn't say, "Oh, that is really a bad thing. You can't do that. We have this programmatic objective." They understand that the best-trained, smartest people are the fundamental resource for the country. So in the end, collaboration with Jeff Kimble at Cal-Tech, we did get to the place that this quantum optics works, and it is basically the tool, which, along with the laser stabilization and cold atom control, which made possible this new scenario that we will have quantum-based computing.

So again, the people are the resource, and if we don't take advantage of the people who would like to come and work here, that is really going to be a pity for us.

A second thread that I would like to focus on is the issue about motivations. And my experience has been that people can work together and they can make nice progress when there is some reciprocal respect between them. And it may be a long-distance respect, for example, the collaborators that I didn't know anything about. In 1960, lasers were invented. One of them was running continuously and was a little bit steady, and I saw the prospect to make it even more steady and even more steady. And so completely boring, it would never change, even in a few seconds. The other people saw the possibility to bring a lot of energy in a short time, melt some steel, then it would be better if it melted it quicker. And finally, you have probably seen glass exhibits where there are white dots inside. Those are burned in by lasers with extremely short pulses. So these two ideas, cultures went around the world and met again in JILA when we hired another person that was a laser specialist. His laser needed my control techniques, and that merger made possible the stable lasers that are the basis of this optical comb. Another thing were people who were trying to design fibers that would carry signals under the sea. And with that, one would like to have all of the colors go at the same speed. Well, that turns out to be wrong for that purpose but perfect for making white light out of the laser impulse. So here are two more current ones, and one from industry as well, which made possible the comb and the comb is now a tool, which, I guess, is our best measurement tool. So then the question of what will you find, who knows, but we do know that there are lots of scientific puzzles. For example, we have dark matter that is 70 percent of all of the matter that there is and we don't know anything about it.

The last topic that I would just like to say about is about the consequences of—unintended consequences from choices. I feel that industry is the place where the last step of research ought to happen. We have students that really know how to do something. Oftentimes, they are students now for five years or something. And they may be from another country. And then if they need to change

their visa status to be employees, there is a problem. So we absolutely need to deal with the issue of being able to retain trained people. The universities have access to visitors' visas, and the companies ultimately have it, and in the meantime, there is either a lost year or a lost genius, which is just happening in my lab.

The second thing is the companies should be economically encouraged to try to make investments in research. And I think some kind of tilt so that there was a tax about trading would be a good idea. I don't know any of the details, but my general concept is that there is no advantage to the country to have fast churning. And someone who says he made money by trading shares in the weekend I think is not helping us. Somebody who keeps money in his project for five years, he should have some just reward. So we should have a tax at those—anyway, those are just suggested ideas.

The main issue is about kids. I absolutely love kids. Many people think I am wasting my time going to magnet schools talking to the seventh and eighth graders. That is where the energy is coming from, and that is—I just love those kids. I only hope I last long enough to see them when they get into our universities.

Thanks for letting me testify.

[The prepared statement of Dr. Hall follows:]

PREPARED STATEMENT OF JOHN L. HALL

Mr. Chairman, Honorable Congressmen, other Colleagues engaged in the Public's Service, Ladies and Gentlemen.

I believe I have been invited briefly to discuss the role of NIST in my field of Science, namely precision spectroscopy, and several broader issues. However, now being a little older and thereby predisposed to give advice, at the end if there is time I will make use of my retirement status to speak of several ugly 600 pound Gorilla that trouble our space, but are not often a part of public discussions.

The role that NIST plays in my field of science

To be brief, the NIST has developed from mixed strengths in the 1960's to the present status of one of the strongest research organizations that exist. Regrettably, perhaps I should have said "that still exist." What NIST (and its predecessor, NBS) have done well is to establish a climate of excellence and intellectual openness wherein the research staff are proud to be members, and to recruit the most talented young scientists as they become available from time to time. For example, I pursued development of a series of Optical Frequency Standards, and related technology, from the late 1960's until my retirement in 2004. By articulating a vision of research into Metrology, broadly defined, NIST has gradually awarded freedom to each of us to follow our own sense of what is important to NIST's mission. It is not abdication of the Management's control and oversight role, rather it is development of a cooperative vision and synthesis of insights of our working-level people who are in the research labs and can make suggestions for new frontier opportunities and research areas. My relationship with NIST is a success story about trust—and the use of really long ropes in the exercise of control. Typically the NIST scientists can see some technical opportunity that will be of significant interest to NIST's metrology responsibility. Once this was about a program proposed by me, and accepted by NIST Management, of an exploration into the field of Quantum Optics, which has now become a really hot research field, at the edge of entering actual practical application, in the distribution of secret cryptographic keys. Among the candidates who applied for this new JILA position, there was a young fellow with a persistent interest in some hypothetical process called Bose Condensation. Dr. Eric Cornell's vision and capability for achieving BEC later was wildly successful as you know, leading to his Nobel Prize in 2001. About the JILA Quantum Optics Program, later on we did succeed well in this research in a collaboration with Professor Jeff Kimble at Cal Tech. I note also that NIST did not say a single word of criticism to me for urging my JILA colleagues to welcome Eric Cornell into this JILA/NIST position, even though it assured only a delayed success on our nominal Quantum Optics super-sensitive detection program. Evidently, and much more im-

portantly to NIST, we caught another “really good one” into the organization. It confirms the NIST’s respect for the eternal reality that *brilliant well-trained people are the fundamental resource of the Nation*. We need them on-board. We need to learn how to produce more. And we need to reduce the negative aspects, as I note below.

The steps between ideas, realizations, and the Nobel Prize

My professional work has been to understand the issues in building Atomic Clocks that would be based on the using “clicks” provided by optical—rather than radio domain—reference transitions. With more vibrations completed per second, but with only the same blurring effects, clearly we can win resolution by enjoying the many-fold more counts associated with the optical system. After the opening up of China in the early ‘80’s, when my first Chinese colleague arrived, I announced to him my career dream—to make a laser so stable that one Hz would be the operative level of accuracy. At the time, five million Hz was a good narrow linewidth. In these 40 quick years, the JILA/NIST/University of Colorado enterprise has spun off a half-dozen of the world’s best researchers in this field, most of whom continue as NIST employees still pushing this frontier. Indeed in the two years since I retired their advances have been nothing short of spectacular. AND we’ve reached below one Hz with a simpler approach!

Well, perhaps this objective of achieving a factor of five million linewidth improvement did seem profoundly optimistic. But with the clear NIST interest and standards need, and a diversity of support by various agencies by our emphasizing one aspect or another of the research, it was possible to have this 25 additional years running toward the goal line. On two occasions NBS/NIST supported massive development programs (scale of 5–8 persons times three or four years), with the purpose of measuring the optical frequency on an absolute scale. The laser standards had clear promise, but they lived in an isolated measurement domain with frequencies five million-fold higher than the FM radio band uses. So while everyone can expect the narrow optical lines would offer better frequency stability, no one knew an effective way to actually measure their frequencies—their vibrations occurred about 100,000—fold faster than we were able to processes electronically. This big gap had been spanned first in 1972 by a heroic cooperation of about eight NBS scientists in a four-year program to measure the frequency of a methane-stabilized laser, the first laser stabilized effectively by molecules. I had developed this scheme in 1969 with a NBS colleague, the late Richard Barger. The concept of that time was to use step-after-step factors of two increase in the working frequency—a dozen steps or so—with different technologies adapted for their different wavelength bands. This was really hard work.

Barger and I measured the wavelength of the laser by comparison with the then-existing international Krypton wavelength standard, based on a discharge lamp light source. The frequency measurement team was headed by Dr. Ken Evenson, also now deceased. The product of wavelength and frequency is the speed of light, and in this way we obtained the value which essentially was the basis for the official redefinition of the Metre in 1983.

The first of the new enabling ideas for better frequency measurement methods came in 1978 from Veniamin Chebotayev in Novosibirsk and from Ted Hänsch at Stanford. Both colleagues admired the always-shorter pulses available from the newest generations of lasers, and were moved to think of the correspondingly increased frequency bandwidth, according to the Uncertainty Principle. One decade later their audacity had reached the place where they were thinking about pulses 100-fold shorter than the best actual results, since this shorter pulse would be short enough to bring the associated frequency bandwidth up to cover most of the visible domain. If such as laser were to be given a reliable and steady “heartbeat” of repeating pulses, the broad visible spectrum would be changed from a smooth, broad lump, into a lump of the same overall envelope, but no longer smooth, but rather intensely structured. Because of the uniform time pulsing, a uniform “comb” of optical frequencies was to be created. Lasers of the day could be amplified to produce broad spectra, but were not rapid-firing. This essentially mathematical basis for the “Comb” was documented in Ted’s writeup of ~1996 or ‘97.

A crucial new element showed up in 1999, a fast-repeating mode-locked laser just coming into the market. Its power was just a normal level (less than a watt), but the pulses were exceedingly short in time. This means really high power on the peak, since the laser is ON only one millionth of the time. Indeed those lasers were able to zap many objects. Perhaps you have seen solid glass objects with bubbles inside, produced by the extremely high intensities available with focusing such a laser. A Bell-Labs team explored the results that could be produced by focusing part of this power into an optical fiber. This idea seemed especially attractive since, if

the light could ever be focused into it, the fiber would keep it spatially confined. Some broadening of the spectrum was observed, but nothing incredible.

What really made the difference was an added idea, that of a special fiber design using tiny air tubes surrounding the inner glass rod that carries the light. Because tube-size to rod size ratio could be varied, the Bell Labs team had a fiber designed so that light of all visible colors could travel at basically the same speed. Then those powerful laser pulses would stay sharp in time, keeping a sharp hammer pulse traveling through even some meters of the fiber. But the high peak power affects the glass to respond in a nonlinear way, generating new colors as the light traveled through the “Magic Rainbow Fiber.” After we finally managed to get a sample of this fiber, we needed about one month to merge the fiber plus the femtosecond pulse laser plus my frequency-stabilized reference laser, which we had developed for standards work in my lab.

An interesting aspect of this “race for the finish” was the mixed cooperative/competitive relationship between our labs and the ones of Professor Ted Hänsch in Munich. I had met Ted just when his University studies were ending in 1969, and we have been friends for many years. I have been on “sabbatical” study at his labs in Stanford, which led to a nice joint patent on laser stabilization. Later I was a Humboldt Senior Visiting Scientist at his new Max Planck Institute labs in Munich. By exchanging Postdoc colleagues regularly when the competition got hot, each group was kept up-to-date about the other group’s progress and new techniques. Their group got the first publication showing the principle, published on 10 April 2000. Our first paper showed an additional nice aspect of the time behavior of the pulses, and was published on 29 April 2000, merely 18 days later. A joint paper appeared a month later. Five years and a few months later we “got *the* call.”

The first generation of applications are essentially in science: synchronizing UltraFast lasers, providing spectral extension by adding the outputs of two lasers, providing “Designer” optical waveforms for Quantum Control experiments. One hugely exciting area is already demonstrated by my colleague, Dr. Jun Ye. This is using the comb laser pulse as the input beam to a resonant cavity with its cavity modes matching the frequency intervals in the comb. Then there are 10,000 parallel experiments prepared: he watches the “ring-down” curves, in principle, of all of these illuminated modes. At frequencies where intra-cavity molecules provide additional absorption, the stored cavity power ring-down will be quicker in time. This wavelength-time picture is captured on a CCD camera, with one axis showing the wavelength-dispersed colors, and the other direction is a time-sweep imposed by a fast deflector. This is parallel processing in the extreme. They have already demonstrated sensitivities at a level of possible interest in the Airport Sniffing application, and several companies have expressed interest in the concept.

Exciting applications of the comb will be in measurement applications, but now of big things. Like Boeing airplanes. The comb has sharply defined temporal AND wavelength aspects, which allow one to do ranging for getting the first distance estimate and then enhance the sensitivity by using interferometry. This comb scheme will be definitive for NASA in Formation-Flying projects.

Issues that negatively impact the development of science and technologists in the U.S.

- A. Bad feedback discourages self-investment efforts
 1. to students: electronic and computer engineering is done offshore. Sorry.
 2. World-leadership scientists have been preparing apparatus for flight experiments in the next several years. However, the abrupt change of NASA’s direction shows young people that there is no real use for them to prepare themselves to do great things.
 3. bad feedback to high achievers also—for example, a Nobel Prize is *ordinary* income (seems like long-term gain on investment to me—44 years investment +9 in college)
- B. Taxation Implications in business
 1. Tax structure should encourage research in companies. Need to make such investment attractive, in spite of concern to keep research results inside.
 - a. Just giving a tax credit is probably not enough.
 2. Have to change investor behavior to accept longer-term vision
 - a. Make capital gain tax high for weekend traders—they don’t contribute to progress, represent friction and loss
 - b. A tax on gains may not damp this enough—also tax on the purchase?
 - c. But reduce capital gain tax slowly over time. Maybe ends in seven years.

- C. Immigration Problems
1. Visa Problem is causing the U.S. to become isolated scientifically
 - a. Can't organize meetings in U.S. because visa processing is too slow
 - b. Can't get new crop of postdocs because of limit on H1B visas.
 2. University research can't be transferred to industry and developed because of visa limit. Industry has to apply for new H1B visa, and this usual means waiting until October for the next quota. This prevents capitalizing on our creative works.
- D. Counting of jobs changes in economy is dishonest in the extreme. We lose jobs in manufacturing and research, and create ones at minimum wage. Net disposable income is lower. Now Mom has to work too. Family is under stress. Parents are too tired to help kids by interest in school affairs. This means *Disaster* at school. No wonder things are going bad for our competitiveness: only the very first cost was considered by the business managers. The societal costs of going offshore may be sinking us. WHO IS THINKING ABOUT THESE COUPLED SYSTEMS?
- E. Other issues. System of just-in-time delivery is wasteful of energy. We don't have storage of parts anymore. Often I have to wait for next manufacturer run. For thin Tungsten wire we had a one-year delivery, used to get it from their stock. No inventory is kept—reason is inventory tax on Finished Goods, not on parts.

DISCUSSION

GRAVITATIONAL RED SHIFT

Chairman EHLERS. Thank you very much for your comments.

We will now open our first round of questions. And I have numerous questions. Obviously, I can't be limited to five minutes, so I suspect we are going to have several rounds of questions.

But let me also just take a moment to introduce another star from NIST. And it is very appropriate to call her a star, because she is a master physicist, Katharine Gebbie. If you will, would you rise, please, Katharine? And she was a real groundbreaker. She was also at JILA when I was there, but a real groundbreaker in the world of astrophysics. Very few women were in it at the time you started, as I recall. So thank you for what you have done.

Several questions.

First of all, Dr. Phillips, before we met, and I think this will be an interesting illustration of how things have changed in science in the past decade and what some of your discoveries mean. You mentioned that you can now measure the gravitational red shift between Boulder and Washington, DC. And measuring the red shift, for the politically intoned here, does not mean measuring the shift toward the left or toward the communism. Would you just give a brief explanation of—

Dr. PHILLIPS. Back in 1916, Einstein came up with a new theory of gravity. And one of the things that came out of that theory was the idea that clocks would run a little bit slower when they were deeper in a gravitational potential, which is to say that a clock in Washington runs a little bit slower than a clock in Boulder, since Boulder is about a mile higher than Washington. And when I first came to NIST 27-and-some years ago, the quality of clocks was such that that difference was not something that people worried about. We had the very best clocks in the world, but that difference of one mile was just barely resolvable. It was about a part in 10^{13} . Now clocks have improved so much that the kind of clocks that are coming out of the research that Jan Hall introduced are so good

that they can tell the difference between a clock—two clocks separated by one foot. So what was barely visible at one mile is now visible at one foot. And to me, it is just astounding that this kind of development has occurred. The implications of what you can do with that, both from a scientific point of view and from a practical point of view, are just stunning. We should be able to tell, with clocks this good, where Einstein is wrong. And everybody believes that it has got to be wrong, but nobody has ever found anything wrong with Einstein's theories so far, but we believe they must be wrong, because we know that the whole—the way in which physical theory fits together is going to have to break down what Einstein told us. We just don't know where and how. And these new clocks, I think, are going to show us the route forward that may be the next great breakthrough in our understanding of the physical universe.

Chairman EHLERS. And let me just emphasize to the audience, those who are not scientists, when we use the word "clock" here, it is somewhat different than the one hanging on the wall. I recall when I was a graduate student, we had one of the first atomic clocks ever built, in fact, the second one built. And the press conference reporters coming in, the most common question was "Where is the face of the clock?" So we brought a \$6 electric clock, plugged it in, and sat it on top, and all of the reporters were happy.

EDUCATION

The next question, Dr. Hall, I want to get back to your 600-pound gorilla. I am interested in where you see the gorillas of the world today.

Dr. HALL. I worry about the feedback that we offer to children. If one has had the joy of children in the family, or perhaps learned how to live comfortably with a dog by going to obedience school with a dog, you come to understand that encouragement works and feedback works, and force, roughly speaking, doesn't work. So in the case of the students, how are you going to get good, young, smart American guys to go into electronics and computer engineering, because as soon as that reaches some level of perfection, then that job goes to another country? And that is—really bothers me in our computing science department in the University of Colorado. We were going up, up, up and now down, down, down, because the smart kids say, "Oh, man, that is not going to be a good story." World leadership scientists have been preparing apparatus for flight experiments, testing these fundamental issues that Bill said some of whether the Einstein gravity is the right picture. Out at some mission-driven agency, a nameless one with letters like N-A-S-A, has changed its course and now here are people with 12 years down stream, graduate students in the pipe, and all of a sudden, they are high and dry because of the national change. I really wish stuff like that would get discussed. That feedback comes to high achievers as well. How does it seem to you to have a long-term investment be rewarded in a very aggressive kind of way? I know something about the history of why it is, but I would have thought a Nobel Prize was something that ought to be taxed like it was an investment for a long time. I have been at it 44 years, and I had nine years of college before that, and if that isn't long-term, I don't

know. Only the tax law says it is ordinary income. Now I don't give a crap about it for myself, but it is a wrong message for kids.

So that is one of my gorillas.

Chairman EHLERS. Thank you. I appreciate your comments.

I am pleased to recognize Mr. Wu.

Mr. WU. Thank you very much, Mr. Chairman.

USE OF PREVIOUS RESEARCH

Let me begin sort of a little bit far a field and work in toward what I want to ask.

Last night, we had 11 amendments aimed at various provisions in an agricultural bill. And on the face of it, maybe a hydroponics center in Ohio may or may not be a good investment. I don't really know. I just know that we faced 11 of these amendments last night. We just barely, because of airline schedules, avoided 14 similar amendments striking out various provisions from an appropriations—interior appropriations bill the night before. And I remember as a child hearing about Golden Fleece Awards given out here in Washington, DC. And maybe some folks really deserved the Golden Fleece Award, and maybe some folks didn't. I know that some things don't sound immediately productive when you just read the caption or the title, but the saying that I have heard in science, and it is probably true in statesmanship, also, is that we all stand on the shoulders of giants. And it seems to me that before us today, you three gentlemen, your work may be somewhat related to each other that, to some extent, your work has built upon each other and perhaps not. But you can probably easily cite examples within NIST or within the scientific community of examples where it may not have been immediately apparent where the work was going or what the applications would be, but later on, it led to tremendous things, whether it is in basic science, applied, or industrial applications. You may not know who may be standing on your shoulders in the future, and you may not know whose shoulders you may be standing on, but the necessity of standing on someone's shoulders, I think, is clearly there, and I would like you to—if you are—if somehow your three research projects were dependent upon each other, to some extent, I would like you to address that. And perhaps address some other aspects of research to at least take a little bit of the steam out of the political process of taking easy shots and awarding having fewer phenomena, such as Golden Fleece Awards.

Dr. PHILLIPS. Well, I would be happy to address that, because I think you hit the nail right on the head. It is exactly as you say and certainly has been the case in the research of the people sitting at this table. I developed some techniques that were able to get a gas of atoms really cold. Eric, building on that, developed some more techniques to get it even colder and then got this marvelous thing called a Bose-Einstein condensate. As soon as we heard about Eric's success in getting a Bose-Einstein condensate, we said, "Wow. We want some of that." And we built a whole program in our laboratory based on Bose-Einstein condensates. And we are still working on that. In the case of our relationship, things that I did ended up being used in his lab, and things that he did ended

up being used in my lab and changed our whole directions of our research.

And as far as unanticipated things, when I first got started, we were thinking about atomic clocks. It was a mission-driven thing. We had a mission. This mission is precision measurement, among other things, and clocks are one of those things. And that is why we did it. We had no idea that it was going to lead to things like Bose-Einstein condensates, quantum computers. So these things are areas of research that have commercial, military, and national security implications. We had no idea. But they are real things that are happening now.

Dr. CORNELL. I should add that both Bill and I, in order to get atoms very cold, needed to use extraordinarily stable lasers. And to do that—in that case, I just go down the hall and talk to my colleague Jan here who says, “Let me show you a really great circuit. It doesn’t cost very much. It works like a charm. You can’t buy this anywhere.” And that makes it possible to make tremendously rapid progress.

And there is another NIST scientist, who is not here now, but I think you alluded to her, the McArthur Genius. Actually, she was a guest of the First Lady at the State of the Union Address, Deborah Jin, who is using many of the techniques that we have developed. I think all three of us can say, if others have seen farther than we have, it is because giants are standing on our shoulders. And she is doing—I think it is doubtless you will see her here some day as well.

Dr. HALL. It is not quite incestuous, but there is some utility in the things which NIST can add. And when I first joined, one of the things which was completely new was the laser had just arrived. And then people started dreaming that we could measure the speed of light. And that led to the realization that the laser wasn’t very stable. And then that led to a program to try to make it better. So my life, basically, has been spent as a toolmaker, making these little boxes. And when you get the next idea, then you can use these in conjunction. And now there is a pretty vigorous industry selling these little things. And in the beginning, I had to figure it all out.

So the good part is that everything which is freshly made and new ideas go to Eric’s or some other labs, and all I have left is the completely old stuff, the prototype, hand soldered by myself. Tools are really how you think. I guess, if you wanted to do something useful in research, it is better to have state-of-the-art tools, because you will be exploring a part of the world which hasn’t really been looked over yet. And so the guy that has some imagination or interest in how to do that sort of boring engineering stuff is at a real great advantage. So that is how I got into it.

Mr. WU. Well, thank you very much.

And thank you very much, Mr. Chairman. I thought this was just an unusually good opportunity to demonstrate the inter-linkage of research, because so often the folks who are standing on each other’s shoulders may be separated by thousands of miles or decades of time. And in this particular case, this is an unusually tight demonstration of that.

Thank you, Mr. Chairman.

Chairman EHLERS. The gentleman’s time has expired.

Your comment about tools, Jan, reminds me of when I was a student, which obviously was quite a few years ago. And I met a very old gentleman who described how success, when he was a student, was determined by who could do the best job of drawing a fine glass fiber. And it is ironic how mundane and experimental physics gets intertwined with the sublime.

Next, I am pleased to recognize the gentleman from Washington, Dr. Baird.

Mr. BAIRD. Thank you, Mr. Chairman.

GRAVITATIONAL RED SHIFT (CONT.)

It is a real pleasure to see you gentlemen. I was privileged to co-author the legislation that we passed a while back recognizing your achievements, and it is a real pleasure to serve on this Committee. We have a lot of opportunities in this Congress to do many things, but this is sort of the brain candy of the job for some of us.

Two questions, Dr. Hall.

The clocks, just so I am clear, measure differently as they get closer to the center of the gravitational field. Which one is faster? The one that is distant or the one that is close?

Dr. HALL. A clock which is high up is not down in the energy valley, so it has a higher frequency.

Mr. BAIRD. Interesting. And speed doesn't have a factor into that?

Dr. HALL. Speed does have a factor.

Mr. BAIRD. Because of the rotation of the Earth.

Dr. HALL. And in the case where I think the highest—well, a mixture of really high-tech and really high-sophisticated theory is the GPS system. As that satellite is coming along and has the radio that is transmitting to me, there is a huge first order Doppler shift. And then as it goes away, again we have to deal with that.

Mr. BAIRD. And that is calculated in by the machines?

Dr. HALL. Yes. And so my little handheld thing figures that out, and the clocks that were in the satellite when they were first made had a switch so that it could be set on where the physics community said the shift should be. Engineers didn't believe that for a microsecond. It came out of general relativity. And then they had a switch position for zero correction and one for the minus side. And of course, general relativity is the place where the switch has been set for these many years.

NIST PROGRAM DECLINE

Mr. BAIRD. I asked that question, Dr. Ehlers and I, when we were on the Floor working on—or debating this bill. It was a nice debate, because there was no disagreement. In so many of our debates, one side is hammering the other, and it was nice to be able to talk about the kinds of things you just mentioned. The GPS, with so many people taking advantage of it, and it is just a magic box for so many of us, but somewhere that magic box was made by, down the line, the very kind of research that my good friend Mr. Wu was talking about, the fundamental, core, basic research that then leads to applications that literally save lives and give immense economic benefit.

Dr. Hall, you said something a little troubling, and I wasn't sure I understood it. You said that there were some factors, which I didn't get clear, so I would like you and your colleagues to explain this. You said that—if I heard correctly, your program at Boulder had been just steadily going up and up and up and then somehow it is facing a decline. What are the factors contributing to that, if I heard it correctly? Or correct me if I didn't.

Dr. HALL. I think the engineering in electronics, if it is in some field like millimeter waves, we keep that pretty much at home, because that is about high-resolution radars. If it is engineering about computer chips or the software that goes with it, there is an increasing tendency for that to be done in another country. And if you have trouble with your computer and call the help line, you will listen to some person that has excellent English but is from a different background. And it is totally marvelous that that can happen, but it happens with such a huge presence that kids who are sensitive to how things are changing, they see that the future is not going to be so easy for that. They would rather turn into biophysics or some place where you see it growing.

Mr. BAIRD. I see. Part of the reason I asked that question, we have got a number of high-tech firms that—custom chip fabs and others in my own district, and one of the things that they raise, and so, too, have some of the bioresearches, that as a technology moves overseas and develops and you see some of the new developments in chip fabrication are moving overseas, the ability to get the hands-on experience with that here goes down. And so the analogy I would use is it is kind of like a bicycle pace line. When you are on a bicycle pace line, man, you can go fast. But once you lose that pace line, you never catch up. And what these researchers are telling me is as the chip fabrication and the next generation goes overseas, we are going to left at the starting blocks here, and to some extent, you never catch up because you don't get the real-world, hands-on experience. Is that an issue for us?

Dr. HALL. Oh, it certainly is. I couldn't agree more. The young people need to have access to the high-tech stuff, and some well-intentioned rules were put out to keep students from some potentially aggressive countries from joining into that research, and that is, in my humble opinion, extremely misguided for the reason that you are saying. We have got to have that high-tech stuff around, even in the universities.

Mr. BAIRD. So they can tinker with it, get a feel for it.

Dr. HALL. You have got to know. You learn by doing, that is what Carnegie said.

Mr. BAIRD. You have to lean into the organism as—I can't remember her name, actually, now. It just escapes me. The woman who worked with corn. McClintock, yeah.

Would your colleagues have any other comments on this?

Dr. PHILLIPS. Just to expand on the point that Jan was making before about working on a project for a long time and having the funding pulled, this is something that is really discouraging for young people. Now this isn't something that was under our control, but there were a number of projects being pursued at NIST that suffered from the kind of reorganization that occurred at NASA and some projects that the people had hoped to see fly may never

fly. And that is discouraging for all of us, but I think it is particularly discouraging for young people. And I think that was—and I would certainly affirm what Jan said about the kind of effect that has on young people.

Mr. BAIRD. They just don't want to risk the career investment knowing that at the end of 12 years, it might not get airborne and you might never get the results.

Dr. PHILLIPS. Yes.

EDUCATION (CONT.)

Mr. BAIRD. Dr. Cornell, anything to—

Dr. CORNELL. I just want to pick up on the learn-by-doing theme. That is just tremendously important. I think you see successful scientists, successful engineers, one thing that is consistent in their past is that, at one time or another, they had the opportunity to get their hands on the organism, whether it was a frog or a computer chip. And until you do, you can't really know. You don't really get that feeling. And so in terms of directions to go in education, I think anything we can do to get people as young as possible doing real stuff. There is no reason why college undergraduates, or even high school students, can't participate in the research enterprise, and that tends to be where the future stars come from is people who have had that kind of experience.

Mr. BAIRD. Elsewhere in this Committee, we have had some very productive hearings on collaborative efforts between leading researchers and high school and college kids, so there are some wonderful things happening there.

And I thank you for your time.

Mr. Chairman, thank you for—

Chairman EHLERS. The gentleman's time has expired, and I am pleased to recognize the gentleman from Colorado, Mr. Udall.

Mr. UDALL. Thank you, Mr. Chairman.

Good morning to the panel.

Mr. Chairman, when I was elected in 1998, I thought that my victory was the result of the climber and smart growth and environmental vote, and I later came to realize it was the science and high-tech vote that put me over the top and it was important to maintain building those relationships, and I am really proud that two of my constituents are here today, two Nobel Prize winners.

I had hoped to be here earlier to have a chance to introduce the two gentlemen. I would ask unanimous consent that I could put my remarks in the record.

Chairman EHLERS. Without objection, so ordered.

[The prepared statement of Mr. Udall follows:]

PREPARED STATEMENT OF REPRESENTATIVE MARK UDALL

First, I would like to welcome all of our witnesses here today.

The awards and accolades the three of you have received are a testament to the quality of your research and the world-class scientists employed at NIST.

I am proud to represent a district that has had four Nobel Prize winners in its past, two of whom are here today.

Dr. Eric Cornell received his Ph.D. from MIT. He is currently a senior scientist at NIST and a Professor Adjunct at the University of Colorado.

In 2001, Dr. Cornell and another constituent of mine, Dr. Carl Wieman, received the Nobel Prize in Physics for the achievement of Bose-Einstein condensation in dilute gases of alkali atoms.

The Bose-Einstein condensation is a new state of matter, formed only when atoms are cooled to nearly absolute zero.

I will let Dr. Cornell describe the details of his work, but I would like to highlight the effects of his research.

The Bose-Einstein Condensate has had enormous impact in quantum computing and nanotechnology. It has allowed for the development of precision accelerometers, gravimeters, and gyroscopes used for remote sensing and navigation.

As the Royal Swedish Academy of Sciences noted upon awarding the prize, the 2001 Nobel Laureates have caused atoms to “sing in unison.”

The creation of Bose-Einstein condensate is a ground-breaking accomplishment that has significantly affected the scientific community, its work, and its direction for years to come.

Dr. Cornell, thank you for being here today.

Dr. Jan Hall is NIST and the 2nd district’s most recent Nobel Prize winner.

Dr. Hall is a JILA fellow at the University of Colorado and a senior scientist with NIST Quantum Physics Division. He has received a series of awards in his distinguished career, including the Department of Commerce Gold Medal on three separate occasions.

Dr. Hall won the Nobel Prize in 2005 for the development of a laser-based precision spectroscopy.

Through his research, he worked to develop an instrument that can measure frequencies with an accuracy of fifteen digits.

His work has wide ranging applications that can improve communication and animation technology, and potentially benefit navigation for spacecraft.

I would like to welcome Dr. Hall.

It is an honor to have all three of you here today. As we work to strengthen STEM education in this country and continue to invest in R&D, your experiences and insight is particularly helpful to this committee.

Thank you again for joining us.

K–12 EDUCATION

Mr. UDALL. And Dr. Phillips, it is also a great honor to have you here today.

If I might, I would like to open up the question of how we are doing in the K–12 area and give each of you an opportunity to speak to your experiences there, what you see. Are the reports accurate that we are falling behind? And probably most importantly, what would you recommend that we should do to maintain our, if not a preeminence, certainly our strength in this very, very important area? Maybe we will just start with Dr. Hall and move across.

Dr. HALL. Okay. So this is gorilla number seven.

Let me say how it seems to me.

I think we count the jobs and that shows up in the news, but we don’t count the income that comes with the jobs. I think that every one of us knows that the new jobs are created with a lower salary. That means that family income has gone down. It finally means that mom has to work. And then that means people are tired. They can’t guide their kids quite as well. Then the kids come to school, and they don’t perform quite as well. Then we decide that somehow it is the school’s failure or it is a system failure. And this disaster is really a bad thing for competitiveness, because the first cost of this was what was considered by business leaders that put some work that paid high in the United States making cars or, I don’t know, whatever, and then it went to another country. In that loop, the United States was saving money. But in a system picture, we have destroyed ourselves by this, because the families are under such stress. Their kids can’t achieve. They can’t even expect to be at the same level as their dad was. And this really makes me upset. And the only way to climb out of that that I have any under-

standing about is education. And if we lose them in this critical time when they are looking at all other kinds of ideas, maybe they could be a rock star and make some traction with the seventh grade kids by asking them whether they would rather be a Nobel Prize winner or a rock star, and they say, "It is impossible to be a Nobel Prize winner," but actually the number of Nobel Prize winners in the United States and rock stars is only two times smaller. So I don't know what to say, but it is about guiding the next generation. Some other civilizations really do that in a good way, and we are not.

Mr. UDALL. That is very insightful.

Mr. BAIRD. We consider these gentlemen rock stars on this Committee.

Mr. UDALL. Let the record show.

Dr. Cornell.

Dr. CORNELL. I have to tell you that I don't know very much about K-12 education. I know that the conventional wisdom is that somehow American K-12 education is failing or has failed. And usually the evidence that is brought to this has to do with, "Well, compare our test scores on math against scores elsewhere in Asia or Europe or performance on international math Olympiads," and what have you. And I guess I take a somewhat contrarian point of view about that. I think if you look at this country, we have an amazingly high success rate of economic dynamism, of entrepreneurialism, of creativity both in high tech and in business, and my personal suspicion is that, at some point, the American education system should get to take some credit for that. I think maybe, just maybe, we are maybe turning out students who don't do as well on tests, but I don't really care about that. I know that when I go to hire a young graduate student to work in my lab, I don't put a lot of weight on how well he or she did on the standardized tests. I look to see a little bit more about their emotional maturity, about their real-world experience. And oftentimes, those are people I have hired who I have had the best luck with, who, frankly, have made me famous by being so good working in my labs. They are people who wouldn't necessarily have appeared to be the stars of an education system.

So I know that we all think that our education system is a disaster, but I think that there is something going on there that is right, and I hope that we don't break that in trying to fix the rest of it.

Mr. UDALL. Mr. Chairman, is there enough time for Dr. Phillips to respond?

Chairman EHLERS. Yes, we will allow you a few extra seconds.

Mr. UDALL. Thank you.

Dr. PHILLIPS. Well, everyone agrees that our graduate education system in the United States is the best in the world. And our undergraduate education isn't so bad. And everybody dumps on the K-12. And yeah, so what do I know? I do spend a lot of time in schools. I make presentations in kindergartens and in middle schools and in high schools. And one of the things that I see is that as you progress from the grade school up through the high school that you see, in grade school, the kids are absolutely marvelously curious about everything. And as you progress to the later grades,

that curiosity is squeezed out of an awful lot of them. And the ones that it is not squeezed out of, we end up seeing coming out the other end as scientists. And we end up getting them, as Eric said, in our labs, and they make us famous. I would really love it if we could somehow encourage the retention of that curiosity. And I really don't know how it is to be done, but it is something that I have noticed.

And I also want to echo what Eric said about that there are a lot of good things being done in our schools. I was, just the other day, at a teachers' workshop that I was participating in. And one of the teachers from a rural area of Tennessee told me that in her school, they had not taught physics for the last six years because they have had requirements put on them that all of their physics teachers had to be qualified. And they didn't have any qualified physics teachers, so their solution—the only solution they had was they had to stop teaching physics.

And so sometimes there are unintended consequences of attempts to try to improve our educational programs. And she was trying to reinstitute a physics program. So gee, you know, I don't know what to do, but I sure hope we do something.

Chairman EHLERS. The gentleman's time has expired.

All right. We will get to a second round of questions, and I have to do a little business here, because this committee has jurisdiction over NIST. So I would like to ask your comments about NIST.

NIST'S MERITS AND FACILITIES

First, in a generic sense, obviously NIST is doing something right to produce three Nobel Prize winners in less than 10 years. I am interested in your ideas about what NIST has going that contributes to that and that other science agencies or research entities could learn from that example.

But I am also interested in something else, the condition of NIST buildings and facilities. We have heard a good deal about some of the problems there, and I am curious whether that has impacted your work or not or the work within your division of NIST or any other aspect of NIST facilities. Particularly, I know at Boulder there have been some problems, not at JILA but at the NIST site.

So I would appreciate your comments on those two things. What is good about NIST and the atmosphere that it produces people like you? And secondly, what problems are they having now of a physical nature? And it doesn't have to be a building. It could also, as Jan pointed out, you know, the simple things of life, such as the tools you need. That is absolutely essential, too.

Let us go the other way around this time. Jan, Dr. Hall, would you start first?

Dr. HALL. NIST is a place where adverse opinions can be tolerated and encouraged and the system is managed operationally by consensus. There is someone who is in charge, but I think the program is, in fact, built up out of suggestions that people make. There is a wonderful contest to get a little extra money for your budget once a year from the director or from some intermediate levels of management. And in no small measure, the fact that there are three of us here from one division of one laboratory of NIST

is due to just one person that you have already recognized, Dr. Gebbie. She takes huge heat on our behalf on requests.

As far as the facilities are concerned, I was so discouraged at one point that I had looked seriously about going to another place where they are going to offer a new lab space that didn't have so much vibration. And the response to—and you never learn how to do these negotiations of life things. So I was ready to just leave, because it is, obviously, impossible. But when that finally got discussed around JILA, then, “Oh, maybe we could get money to make a new building.” So I was glad to be in the basement where nobody wanted to be and we put their additions up where there are windows. So I don't know of facilities as being a principle limitation in the part that I do, but in fact, the environment is a limitation on all of the experiments when you push hard enough. The temperature control, for example, where I am is not good enough. I don't have any intelligent remark about—

Chairman EHLERS. I think both of those were intelligent.

Dr. Cornell.

Dr. CORNELL. I know a little bit about science. I know very little bit about science management. So I don't know that I can—I don't know what the secret of the success is. One thing I have noticed over the years is that a dangerous thing that can happen to an organization is to be a victim of its own success. Sometimes you do very well, and then you are enormously rewarded. And then as a consequence, you grow very rapidly. And it is very hard to grow very rapidly. It is very hard for our organization to hire a vast number of people very rapidly and to get the very best people under those circumstances. And I think NIST has benefited from growing over the years but not growing, sort of in doubling in six months. I think doubling in six months is probably not a good recipe for an organization 10 years down the line. So that may have been a pitfall that NIST avoided. I am sure Katharine is throwing daggers in my back if it suggests that NIST doesn't need more resources. Of course we do, but maybe our budget shouldn't double overnight.

Other than that, I don't really know. I don't know Katharine's secret. I don't know how this works. But I know a good thing when I see it, and I am certainly very happy to be where I am.

Chairman EHLERS. I would suggest since you are a government agency, you don't have to worry about doubling overnight.

Dr. Phillips.

Dr. PHILLIPS. Well, I think NIST is absolutely fantastic. And as I said in my testimony, people ask me, you know, “Why are you still at NIST? You could earn a whole lot more money someplace else.” And I am sure that my colleagues have gotten the same questions. And the answer is it is just such a great place to be to do research. Katharine is fond of saying that she thinks it is her job to hire the best people and to give them the resources they need to do the best work. Now that is a wonderful attitude for an administrator, and it is not the kind of attitude of every administrator that every research institution has. I brag about our administration, our director and my laboratory director to other people from other institutes, and they are jealous about the way that we are

run, because we are run the way they wish they were run. So it is fantastic.

We have a new building. You asked about facilities. We have the Advanced Measurement Laboratory complex at NIST. And we moved from a much older laboratory into that new laboratory, which has a better vibration control, better temperature control, better humidity control, better air quality in terms of dust than the old laboratories did. And boy, we lost a lot of time moving all of our stuff and getting everything going again, but boy, is it working great now. And so it has made a big difference in just our day-to-day ability to do our job. We just don't have to tweak things up as often as we do, and we can spend more time doing the next greatest thing.

Another thing that is fantastic about NIST is that we bring in a lot of young people, especially as post-docs. In fact, two of the post-docs that I am privileged to work with every day are here in the hearing. Ben Brown and Phil Johnson are here. And these guys have come as part of our post-doc program, the NRC post-doc program. Ben Brown is part of that. And Phil came on an intelligence community post-doc. And we get these wonderful young people who are just full of energy and bring all of these new ideas. And they get to work with some of the best equipment around for a couple of years and go out and have wonderful careers but bring to us all of this energy and new ideas. And it is just exciting to be where we are.

Chairman EHLERS. Well, thank you. I am glad to hear those comments. And I was a part-time administrator in a research group for a number of years, and I regarded my job as primarily to—the scientists from the so-called administrators. The best way to administer science in my book is to find smart people, give them good resources and ample funds, and not have them worry about any other administrative deals.

And I am pleased to hear that NIST is going in that direction. It has not always been that way.

I would like to ask if the gentleman from Oregon, Mr. Wu, has any other questions.

Mr. WU. Yes, Mr. Chairman. Thank you.

Chairman EHLERS. Go ahead.

AMERICAN RESEARCH POSITION

Mr. WU. Two different sets of questions.

The first, very briefly, I'm positively surprised, I get the impression from the testimony of all three witnesses that you all are feeling relatively good about the American position in basic research at the present moment. Is that an accurate characterization?

Dr. PHILLIPS. Well, not entirely, from my point of view, at least. So let me say where I see problems.

One is in industrial research. And Jan Hall already alluded to this. When I was a young scientist, you had Bell Telephone Laboratories. Bell Labs was iconic. They were the best research laboratory in the world. But it wasn't just them. There was IBM Labs. There was GE, General Motors, Xerox, Ford. You know. There was a whole panoply of high-powered industrial research laboratories. That tradition of industrial research that is focused on or that has

a large component of basic research has almost disappeared from the American landscape. And that is a crying shame. Bell Labs still exists, but it is a pale shadow of its former self. And the other labs have either completely gone out of business or are also just shadows of their former selves. There is a huge basic research effort that has been lost, so Jan was mentioning ways in which one might encourage that to come back. You know, I am not an economist. I don't know whether those kinds of ways are going to really work. The problem is the American industry, American business, in general, focuses on the quarterly bottom line. And research pays off after 10 or 20 years. And so you have this disconnect between the long view. Okay, on your wall, this wonderful passage from Proverbs, "Where there is no vision, the people perish." And what I am afraid of is that in American industry, with respect to research, there is no vision. Everything is focused on the short-term. Now at NIST, I am happy to say that we have a very strong long-term vision, and that is why I am happy about what is going on at NIST. I am not happy about what is going on in industry, and I think that the only way to compensate for that is for government to supply more resources to the agencies that do have the long-term vision. I mean, it is not just NIST, but lots of other agencies, universities, the NSF obviously takes a long-term vision. I am also a little bit worried about the way in which this plays out in the military agencies, because you have the peace dividend. Everybody expects military budgets to go down, and when you still have to fight a war, you still have to supply—you still have to worry about national security. What suffers? The research budgets. But the research budgets are your seed corn. And it is not just the military effort that is going to suffer, if you don't do long-term basic research. That long-term basic research that has been done in the military traditionally has had a huge impact on the civilian economy. ONR, historically, was an agency out of which you could expect just marvelous basic research results. This was great for the military. It produced things like atomic clocks and the GPS and all of that, but it was great for the civilian economy as well. And to a certain extent, we are seeing that backing off because of the way the priorities work.

HIGHER EDUCATION AND JOBS IN INDUSTRIAL RESEARCH

Mr. WU. Well, without adjusting the DOD part of this, it seems to me that some of the great private research organizations were dependent on a market position and a market dominance and cycle times that don't exist anymore. Cycle times are much faster, and the Bell Labs were dependent upon a monopoly. And that has gone away. And it is an interesting set of questions about how we are going to replace that.

Well, I want to bring this back around to some industrial—I don't want to—just some concerns about our industrial base. I mean, the scientists hark. The Chairman said that earlier. Three credits at an engineering course, same amount of work as a five-credit course somewhere else. And it is hard to do in the first place, but people get drawn into it, at least, with the prospect of jobs. And only a certain percentage of those who graduate with a bachelor of science degrees will go on to get graduate degrees and do the kinds

of cutting-edge research that you all have been privileged to do. As you know, with the loss of a certain amount of industrial base, if people are not seeing the jobs, if young people are not seeing the jobs to draw them through, is there a concern on your part that we are not getting the base of the pyramid, if you will, drawn into these very difficult scientific fields so that, you know, a smaller percentage will go on to graduate school and then at the very pinnacle, some people will someday be like you here with a Nobel Prize in their hands.

Dr. HALL. I would like to speak in favor of a safety net for people that have invested in themselves, but that was what we had. There was a diversity of different kinds of places that a person could go. And some changes in the family circumstance may mean that a really promising guy leaves out of the just—graduate school opportunity and goes to work or something. And if he is working in a company that uses his knowledge, that is fantastic. But somehow, we are just at the edge of letting that opportunity go. I think your pyramid illustration is exactly the right way to think about that. We should have a base of people that know about the basics of science in the most fundamental way, and that should be the whole voting public. And then the next level are people that know something in the collegiate level. One could have a country that would have stability against perturbations. Now we are extremely fine-tuned economically for a particular place, and the robustness of this system is, in my opinion, absolutely up for grabs. If something anomalous happened now, we might not have enough engineers of some kind, hydraulics engineers or some other skill, because there is nobody that wants to go there, because there is no parking place for them in the meantime.

Chairman EHLERS. The gentleman's time has expired.

Does the gentleman from Colorado have any further questions?

Mr. UDALL. I do, Mr. Chairman.

And before I direct this question to the panel, I want to thank the Chairman for his commitment to NIST. The two residents of Boulder here, I think, knowing that Chairman Ehlers served a couple of stints at JILA, and he has taken the time to come out and see the NIST facility. And we had a couple of rough spots, but I know we are in the sense of upgrading the facility, Dr. Hall, Dr. Cornell, but I know we are turning the corner, I hope.

AMERICAN INNOVATION AND EDUCATION

The comments you made, Dr. Cornell, about our culture and perhaps our education system promoting more innovation than we realize are the ones I would like to follow up on.

There have been a couple of pieces recently written about the Chinese and the Indians that, of course—who are part of the focus here. And you hear the numbers of engineers and some that they are graduating, but these stories focus on the fact that the Indians and the Chinese are looking to create a more innovative attitude among their citizens, that they have their own blind spots, if you will. They have their own cultural challenges. Dr. Cornell, would you be willing to just talk a little bit about your sense of can you teach innovation. What do we do with promoting more methods and approaches? I know Dr. Wyman isn't here with us, but he is

with us in spirit, of course. I know he has dedicated a small—a large part of his time in this pursuit as well, and if there is time, I would like to hear from Dr. Hall and Dr. Phillips on this question.

Dr. CORNELL. Well, it is obviously a tremendously important question, and I certainly feel pretty much over my depth here in that I do quite a bit of teaching, but it is mostly to people I consider young, but they are in their 20s. The people—the younger people I teach, there is one who is 10 and one who is seven, but it is kind of more one-on-one in the house. And I do think one learns by doing, and, therefore, I think, to the extent that the K-12 experience can enhance the notion—the components of actually trying to do things. It is very, very important. I am not saying ignore the basic skills, but I sometimes think in a mad rush to sort of prevent us from—you know, make sure we continue to—you know, enhancing all of the basic skills, I think you can sort of cut out whatever it was, the magic that somehow was there and although not particularly well recognized in the American education system, something had to have been right. And I worry that in sort of responding to the threat of the verging Chinese effort or the verging Indian effort or something like that, that if we just try and sort of blindly follow their approach, we may be moving away from what has worked for us well in the past. But with that said, I don't know what it is exactly. And I have to say that I am watching my children, my two girls, go through the Boulder Valley School District system, and I have been fairly impressed. I think they strike a pretty good balance between reading, writing, arithmetic and somehow instilling a notion that yeah, there is actual real things that you can do and learn about in the real world.

Mr. UDALL. Dr. Hall, would you care to comment?

Dr. HALL. Again, I come back to the family as the base for this. And it seems to me that with the evolution of style at home that I would prefer a big plasma screen to talking with my kids at night, this is not a good sign for the future. And the part which worked incredibly well was that we weren't very wealthy in the early time. We were in working-class place. And kids would come by on Saturday with broken tricycles, and I would fix everybody's tricycles. And then we would get into a discussion about how come the wheel keeps spinning so long on some of them and not so much on the others and a lot of what is ultimately science stuff is communicated. You have got to know how stuff works. And some people think that the cars, you know, you just get in and go and the engine light is on, "Well, okay. That is the next guy's problem." So anyway, I think just adults that care about kids is how it happens. And it is the best. Everyone who is going to have to take a part in it, because a lot of us have brought kids in.

Mr. UDALL. Thank you.

Dr. Phillips.

Dr. PHILLIPS. Well, let me venture a guess as to what is one reason why the United States has been so successful in areas of innovation where some other countries haven't. I think it is our "can-do" spirit. I was just listening to somebody from Europe the other day, and he said, "The big difference in the United States is when you have a problem, in the United States, people say let us figure

out how to do it. And other places, people will tell you all of the reasons why you can't do it." I think this is part of our national character. And that kind of thing can change. Other countries can get it. We could lose it. What we need to do is make sure that we feed it. It is one of our greatest resources, that idea that we are going to make it work. And I think that that is one of the things that has really made the United States stand out from everybody else.

Mr. UDALL. Thank you, Dr. Phillips.

Mr. Chairman, if you might just indulge me, I think the secret of the success of these three gentlemen and the future success of the country is on display here, because on a number of occasions, each one of you said you didn't know but you exhibited a curiosity about finding out. And that is the characteristic or the characteristics that I think we want to continue to encourage and that you all have done such a phenomenal job of encouraging. So again, it is a real honor to have you here and particularly to have two of my constituents here. You really are the pride of America, not just the pride of Boulder, Colorado. And Congressman Baird put it right, too. You are rock stars, and we just—we need to do a better job promoting what you all have done.

So thank you for being here.

Chairman EHLERS. The gentleman's time has expired. And might I say they are probably successful because two out of the three live in Boulder, Colorado. They get inspired by all of the beautiful mountains.

CAREER INSPIRATION

We will have a short third round of questions. And just a quick one from each of you and just—because I am going to make a few comments about the educational system.

What inspired each of you to go into science? And we will start with you, Bill, Dr. Phillips.

Dr. PHILLIPS. Well, in a sense, it is a little hard to remember, because I have been interested in science for as long as I can remember. But it certainly echoes what Jan has been saying about family. My parents, who had nothing to do with science, they were social workers, they fed that fascination. They got me a microscope. They got me a chemistry set, an erector set. They let me set up experiments in the basement, even though they hadn't any idea what I was doing. And so from the earliest times, I was interested, and I had that encouraged in the family, and boy, that is so important.

Chairman EHLERS. Dr. Cornell. Microphone.

Dr. CORNELL. Oftentimes when it is bedtime, children will have stories read to them before they go to sleep. When I was a kid, my father, who was an engineer, didn't feel like he needed to read me a story, because I already knew how to read, but he would come in and sit on my bed and say, "Okay. It is bedtime. While you go to sleep, I want you to think about this problem." And then it would be something like, "Well, you have got a truck full of bees and they can't get over the bridge. If you bang on the truck and the bees all fly, will the truck be lighter and can it fly? Can it go over the bridge without crashing?" or some kind of classic physics

brain teaser like this. So I used to go to sleep thinking about these things.

Chairman EHLERS. So those Zs above your head were really bees flying.

Dr. Hall.

Dr. HALL. I think my father and mother did a very helpful job for me. I was surprised to find in my father's stuff one time that he had a jar with this much mercury in it, and that was pretty fun to play with. Another one was sulfuric acid, which was so strong and thick that it would just hardly slosh around. So it finally became clear from the state of my clothes that I was into dad's stuff, all of these holes in it. And there was no negative feedback about that. "Oh, well, I am glad that you found out." And so it is, again, this intergenerational contact and having good stuff around. I never had a microscope, though, so I am jealous about that, Bill.

Chairman EHLERS. I must confess to jealousy, too. I was interested in science, and I will give my short version.

I was interested as a child, but never in my wildest did I think I could become a scientist. I had never met a scientist. I didn't know a scientist. And it is really amusing. Today, when I speak to scientists, groups of scientists, and engineers, I encourage them to go to elementary schools and just ask if you can speak to the kids about science and engineering. My experience was, having never met a scientist, as a junior in high school, I went into one of the old-fashioned diners with a counter and the stools. I sat down to eat my hamburger, and a gentleman came and sat down next to me, and we started talking. And he was a mechanical engineer from Ford Motor Company. And I enjoyed working on my car. I did all of my own maintenance. And he talked about what he did at Ford designing cars. And so a year and a half later, when I went off to college, I went through registration, and they said, "What major are you declaring?" I had no idea what they meant, but I said, "What is that?" And they said, "Well, you have to declare a major. And what do you think you are going to study?" I said, "Mechanical engineering," on the basis of a 15-minute conversation with a total stranger. So that is—my story is a little different from yours, but everyone has their own story.

K-12 EDUCATION, INFORMED VOTERS, AND THE FEDERAL GOVERNMENT

What I did want to just comment on is this whole issue of K-12 education. After I wrote this book, and by the way, I appreciate your comments, because in this book, I identified the responsibility of the Federal Government to take over basic research, because I predicted that Bell Labs, IBM Labs, all of the others, would go out, for a couple of reasons. First of all, they—some of them were monopolies. Some, such as IBM, were monopolies, in fact. But you could see that was going to end. But a bigger reason was the increase in globalization. And they knew that other businesses in other countries would not support these labs, therefore, our companies would be at a disadvantage and would have to give it up just to remain competitive. And the other factor was the increasing obsession of Americans was to have good results every quarter, and you cannot conduct scientific research on a quarterly basis. It has

to be on a decade-long basis rather than quarterly. And I feared that all of these industrial labs would die simply because they could not justify themselves. So on the base of that, I predicted the Federal Government would have to increase their efforts in basic research, otherwise it would go away.

And in terms of education, I think it is absolutely essential that we all join in working on the K-12 system, not that it is horrible, not that it is broken, but we have to somehow help the students understand more about science, learn more about science, consider it as a career. I have worked extensively with elementary schools, and I never criticize the teachers, because I have found them to be wonderful, wonderful people. But most of them are afraid to teach science and math, because they themselves haven't learned it. And no one likes to display their ignorance publicly to students. And I think the best thing the Federal Government can do is offer training programs, summer seminars, paid summer seminars for teachers to help them gain the knowledge and the confidence they need in the classroom, and above all, the ability to excite students.

I have—and I am not trying to say that every student should become a scientist. That is the wrong way to go. But we have to face it that in 10 or 15 years, the jobs of the future will require an understanding of the basic principles of math and science. We are going to lose a lot of industrial jobs, and those that remain, will have a high level of standards. For example, my district, which has heavy manufacturing, when I tour a factory, it is no longer hundreds of men standing in a row operating a lathe and turning a screw. It is one \$750,000 milling machine, computer-operated with one operator who earns \$80,000 a year because he understands math and science and knows how to program it to make the products. The world is changing, and the jobs of the future are going to require everyone to know more about math and science.

I also appreciated Dr. Hall's comment about voters. We have to educate kids in math and science, because the voters and consumers of the future are going to need it, whether to read labels of contents on vitamin bottles, or any other medication, or voting on environmental issues that are put on the ballot, as happens sometimes in Colorado, and certainly in California every year. I think it is essential that we prepare a generation of scientists—pardon me, of citizens who know enough about science to make reasonable judgments. But also, I believe our economic and national security rests on generating students who understand these issues and can apply them in the real world today. I would love to see more scientists and engineers in the Congress, not just because I am a scientist, but just because we bring a unique set of talents, which I think are very useful in the long-term.

So I hope that, working together, we can all accomplish that. And I appreciate what Carol Wyman is doing in devoting himself to improving education. He is doing it at the undergraduate level, but many others at the elementary and secondary. We have to all work together on that.

I have one last comment. I advocated very strongly in here that the Federal Government could encourage industrial research through a strong research and development tax cut policy. We, in fact, as part of what we are doing right now, we are dramatically

increasing that. And the only caveat I have of that is it is tending to turn into a development tax credit, not a research tax credit. There is still not the basic research there, and I think we are—we will have to continue to depend on the government to do that. And what you said about the American can-do attitude is absolutely right on. Creativity is in our genes, and I trace it back to the agriculture that people had to do when they first got here. They had to develop new methods of agriculture. And there is just that creative spirit that has somehow—on our early immigrants that has carried through. For thousands of years, people have plowed fields with a stick and an ox, but John Deere came to America and said, “I can build a steel plow that will work a lot better.” And you just follow that progression all of the way through and we have a rich tradition of creativity and a can-do attitude, so that paid off.

You can tell from my diatribe that I am the son of a pastor, and that ends my sermon, but I am pleased to recognize the gentleman from Oregon for his last question.

AMERICAN INGENUITY AND INVESTMENT

Mr. WU. Thank you very much, Mr. Chairman. And I thank the three witnesses and the Chairman for sharing your stories. We frequently build policy around statistics, hopefully build good policy around good statistics and good information, but ultimately, I think the policies have to be sold with a story. And people from all over, Wendell Holmes to Ronald Reagan, understood that.

Dr. Hall, I just wanted to let you know that I have considered the issue you raised about long-term investment for quite some time preceding the time that I came here to Congress. And one of the efforts that I have been pushing, thus far with little traction but hope springs eternal, is to change some of our capitol gains tax rates and the hold period. And the numbers are negotiable, but what we are currently proposing is new investments, a five-year hold, five percent taxation, and you know, this comes from my background as a technology lawyer in helping small companies start. I think we might need a different model to given incentives to larger organizations to make those long-term investments. But this really does focus on taking real risk and holding for a long period of time, because a 12-month hold period, now that is not really—that is not a long-term capitol gains. But whether that is the right—one of the right policy prescriptions or not, you know, time will tell. You all have clearly pointed out a need for some role of public research, whether it is funded by the private sector with a lot of public spin-offs or whether the public research is funded by a public entity, the kinds of research that were done by Bell Labs and Xerox and some other entities, that is a clearly identified lacuna in our system right now and a challenge for us.

I have a can-do attitude. I think that we can successfully address this. We live in challenging times. There is a war going on. There is a very large deficit. But these are hardly the darkest of times. Oh, about 140 years ago, you could hear gunfire from these buildings, or the building across the street, the U.S. Capitol. They were wounded from the Civil War in spaces in the U.S. Capitol, and yet during those years, the bipartisan press to the future, President Lincoln and the Congress completed the Capitol dome with a sense

that this was going to be a great Nation and needed a capitol to match it, but, even more importantly, passed legislation to complete the Transcontinental Railroad, passed the Land Grant College Act, and passed the Homestead Act in settling the west. And prior generations have met these challenges, and I am grateful to hear some of your confidence about that, also, and look forward to a continuing dialogue.

And thank you very much, Mr. Chairman.

I yield back to you, Mr. Udall.

Chairman EHLERS. Do you have any further questions?

Mr. UDALL. I just have a comment and a very brief question.

I can't hope to surpass the eloquence of the two gentlemen at the head of the dais here, but I did want to ask, Dr. Cornell, what is the answer to that question your father asked you. Is the truck lighter if all of the bees are airborne?

Dr. CORNELL. If you have a panel truck that is all sealed up and you have got, you know, 1,000 pounds of bees in the back, and you can't get over—and you have got the 1,000 pounds of bees in your 2,000-pound truck and that adds up to 3,000, which is more than the 2,500-pound weight limit on the bridge, no, it doesn't actually help to get the bees swarming around in the back of the truck, because they are—the air that they press down with their wings presses down on the bottom of the truck, and so you can't win. You can't even break even. That is in the laws of physics, and it applies to bees as much as anything.

Mr. UDALL. Thank you.

Chairman EHLERS. So to bee or not to bee, that is the question.

Just one last comment. I was talking about the necessity for well-informed citizens. It just occurred to me, the best example of that would be if the citizens of this nation understood the laws of thermodynamics, we would not currently have an energy problem. And that is the clearest example I can give.

We are delighted with the panel. Thank you very much for being here. It has been highly educational, and it has been very, very helpful to us in considering the future of NIST and the future of fundamental research in this nation.

I encourage you to continue your interest in science policy. I encourage you to tell your colleagues throughout the Nation also to remain interested in that, because it is fundamental to have that framework so that we can make sure that you and other scientists get the support that they need to continue the research that has to be done. And that will only help our nation be stronger and more successful.

So I thank you very much for being here and for your contributions.

If there is no objection, the record will remain open for additional statements from the Members and for answers to any follow-up questions the Committee may ask of the witnesses. Without objection, so ordered.

And the hearing is now adjourned.

[Whereupon, at 11:30 a.m., the Subcommittee was adjourned.]