John L Hall – Testimony for House Committee on Science,
SubCommittee for Environment, Technology, and Environment, May 24, 2006

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 Gorillas 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 importantly 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 1 Hz would be the operative level of accuracy. At the time, 5 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 1 Hz with a simpler approach!

Well, perhaps this objective of achieving a factor of 5 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 3 or 4 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 5 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 8 NBS scientists in a 4 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 2 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 1 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 1 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 Hansch 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 US

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 NobelPrize 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, is spite of concern to keep research results inside.
   - b. 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 7 years.

C. Immigration Problems

1. Visa Problem is causing the US to become isolated scientifically
   - a. Cant organize meetings in US 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 1 year delivery, used to get it from their stock. No inventory is kept – reason is inventory tax on Finished Goods, not on parts