Statement of
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"Investigating the Nature of Matter, Energy, Space, and Time"
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Thank you Mr. Chairman, Ranking Member Inglis, and Members of the Committee for the opportunity to appear before you to provide testimony on the question of ***"Investigating the Nature of Matter, Energy, Space, and Time".*** While I have only been Director of the Thomas Jefferson National Accelerator Facility, Jefferson Lab for the past year, I have been an active researcher in the field, here and in Europe, for my entire professional career. I am pleased to offer you my perspective on the subject with emphasis on that part covered by the programs of the Office of Nuclear Physics in the Office of Science of the Department of Energy.

This hearing has been given a grand and beautiful title, ***"Investigating the Nature of Matter, Energy, Space, and Time".*** It could be argued that this has been the program of mankind since man stood on two legs. For those who may think that nuclear physics does not affect you, I would point out that nuclear physicists study the building blocks that make up 99.9% of the mass of our everyday world. We seek not only a concise description of matter but also to describe the interactions between the building blocks of matter and the way that elements can exist.

About a century ago, Rutherford performed experiments which suggested strongly the existence of a nucleus within each atom. With those experiments nuclear physics was born. A major transition took place in the middle of the twentieth century with the development of accelerators, enabling us to probe and manipulate the nucleus. While much has been learned and some of the fundamental structure of nuclei has been delineated, much still remains a mystery. To achieve the goal of finding the building blocks of the universe, it is therefore imperative to continue this quest with the more powerful experimental techniques that become available with technological progress.

Nuclear physics is a basic science and in my testimony I will discuss aspects of that fundamental science, an historical perspective of the field, its accomplishments, and a look to the future. However, nuclear science is also important for the impacts it has on society. These impacts come not only from the fundamental understanding that results from our research but from the tools and technologies developed both from our evolving understanding of nuclei themselves and from the novel apparatus devised to obtain that understanding. They range from nuclear magnetic resonance imaging, to radioactive tracer tagging (used in biological research and cancer detection), to accelerators (used for applications as diverse as cancer treatment and semiconductor manufacturing, as well as for basic research in many fields), to nuclear power and nuclear weapons. The search for basic knowledge in nuclear physics also generates a cadre of highly-educated individuals, who often apply their training in nuclear physics to a broad range of problems faced by society.

Since a complete discussion of the subject of nuclear physics is beyond the scope of this testimony, I will rely on the testimonies of my colleagues in this hearing for some of the underpinning context for my remarks. For example, I believe that Dr. Kovar's testimony will include a complete sketch of the governance and support of nuclear physics within the United States. It is indeed important to recognize that both the Department of Energy Office of Science and the National Science Foundation provide support for research facilities and research physicists in this field.

There are three major components of the field of nuclear physics, which I will briefly summarize.

For the first seventy years of the last century, nuclear physicists developed a description of nuclei and their properties in terms of the then-known building blocks, protons and neutrons, and their interactions. In 1968, we discovered that the nucleons had constituents, which we dubbed *quarks* and we invented *gluons* to bind them together and developed a theory, which we named *quantum chromodynamics,* to describe their interactions. A truly fascinating aspect of nature, at this extraordinarily small distance scale, is that the masses of the protons and neutrons arise not from the masses of the quarks, but rather from the gluons, which carry their interactions. It is interesting to speculate on the consequences of this for the technology of the next fifty years.

The Continuous Electron Beam Accelerator Facility at Thomas Jefferson National Accelerator Facility, Jefferson Lab, has become the world leader in incisive studies of properties of the nucleon and the nuclei associated with the distributions of quarks and gluons, their motion and their spin. The accelerator was built a little more than a decade ago using an innovative, superconducting radio frequency, acceleration technique. The current experimental program, with six billion (or giga)-electron-volt (6 GeV) beam energy and with exquisite control of the electron spin, has opened new windows on the distributions not only of quarks and gluons, but also of their spin. We are now in the midst of an upgrade project to raise the energy to 12 GeV in order to extend this knowledge. The additional energy will also allow us to search directly for configurations where the glue plays a predominant role, as predicted by the theory but not yet seen. This work has the potential to tell us why we have never yet seen an isolated quark or gluon.

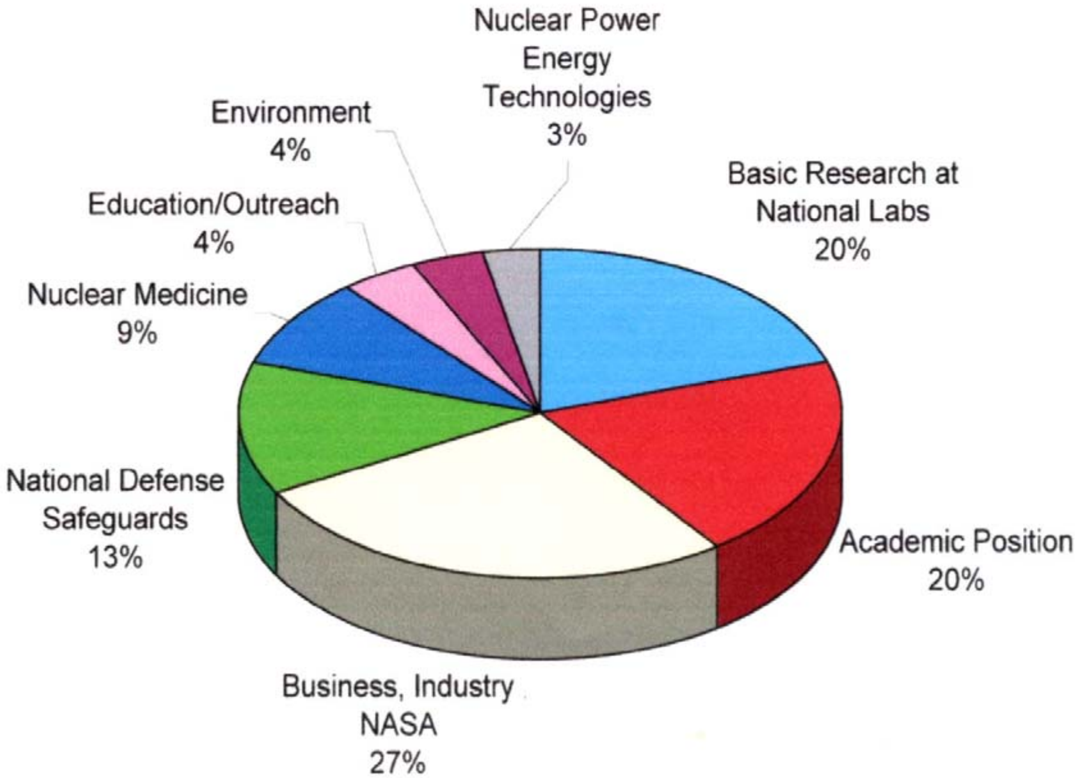
Complementary research at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory compresses protons and neutrons in high energy collisions between gold nuclei. This raises the temperature of the nuclear matter to many thousands of times that of the sun. The nuclei then melt, forming a quark-gluon liquid much as ice melts into water. This liquid, which exhibits spectacular properties, is believed to have existed in the first moments of existence of the universe.

The structure of complex nuclei continues to be a challenging subject with new frontiers to be explored. The conventional view of a nucleus is that it is built up of protons and neutrons. We label the element using the number of the protons. That is the property which distinguishes lead from gold, or helium from hydrogen. The numbers of neutrons are also important and it is their presence that changes hydrogen into deuterium and tritium, or Uranium-235 (the component which makes a nuclear fuel “enriched”) into Uranium-238. Our interest today is in manipulating these building blocks of our universe by working with rare isotopes and radioactive beams to find the maximum numbers of protons or neutrons that we can insert into a given nucleus. These studies lead to the understanding of processes like nucleo-synthesis, the physics that underlies the existence of the stars and the planets and the relative abundance of their constituent elements. Work is just underway to build a major new facility in the U.S., the Facility for Rare Isotope Beams at Michigan State University, to help address these questions. At Jefferson Lab, a planned experiment to measure the radius of the neutrons in lead will provide input to understanding neutron stars.

In some radioactive decays of nuclei, in particular in β decay, neutrinos are produced. The study of these ghost-like particles has historically been a very important component of nuclear physics. Recently there was some beautiful work employing nuclear reactors such as the KamLand experiment, executed in Japan. The Daya Bay neutrino oscillation experiment is under construction in China, enabled by funding support for U.S. physicists in international collaborations. These are examples from the third branch of our field, which is often labeled as “fundamental symmetries”.

Together these three research thrusts (quantum chromodynamics, nuclear structure and astrophysics, and fundamental symmetries), while always shifting, are the framework within which nuclear physics has defined itself. Each of the directions offers the possibility of discovery; each is a way to examine the universe and its building blocks. I have emphasized the experimental thrusts within the field, but to realize a description also requires a theory. Quantum chromodynamics is rich enough to potentially describe not only the quarks and gluons and their interactions, but also the nucleons and hadrons and their interactions. But executing the calculations is a challenge. Nuclear physics theorists have helped to design dedicated computer chips, have helped to connect desktop computers in innovative ways, and are now turning to the graphics engines to supplement the traditional super-computer resources they need for their work.

Of all the sciences, nuclear physics enjoys a relatively high profile due to the prominence of nuclear weapons in the story of the second half of the twentieth century as well as the use of nuclear fission for nuclear power. Just across the James River from us in Surry, Virginia are two nuclear reactors, which supply electricity that is clean and reliable. If we can manage the surrounding political issues, nuclear power could play a major role in providing energy for the human race. Since the discovery of radioactivity, the use of nuclear properties for medical treatment has become part of our everyday life. Within the past ten years, the radiation imaging techniques, developed for nuclear physics experiments at Jefferson Lab, have led to the development of fresh approaches to mammography and the deployment of inexpensive, mobile commercial devices that detect cancers earlier and save lives. Each year I, and perhaps others among you, get a stress test that uses radioactive isotopes and positron electron tomography to check that my blood is flowing to the right parts of my heart. The production of these isotopes is another important by-product of the nuclear physics research we do. Nuclear physicists are essential not only in the university classroom. They assume critical roles in society, in fields such as nuclear energy and nuclear medicine and in industry more generally, a fact demonstrated in detail by the Cerny



report.

Figure 1: Survey of Nuclear Physics graduates 5-10 year past doctorate from NSAC Education in Nuclear Science Report (November 2004)

In addition, the contributions of working scientists to the education of the citizens of our increasingly technological society are not only desirable but essential.

Nuclear physics depends on large facilities, and the United States continues to be a world leader in the construction and operation of these facilities. These include the devices at the National Superconducting Cyclotron Laboratory at Michigan State University, CEBAF at Jefferson Lab, and the Relativistic Heavy Ion Collider at Brookhaven. (This list is not exclusive, and U.S. nuclear physicists also work at other facilities located at laboratories and universities across the globe.) We are upgrading the existing accelerators, for example taking CEBAF to 12 GeV, and will soon start construction of the Facility for Rare Ion Beams at NSCL. Vigorous operation of these and other facilities will underpin a superb science program for the next decade and more. What we see on the horizon, as was indicated in the 2007 long range plan for the field, is an Electron Ion Collider. This could be thought of as a higher energy version of the functionality currently provided by CEBAF at Jefferson Lab. The discussions of the physics case and of some design concepts are currently under way. We are looking to converge on the choice of the site in a few years and expect to set a goal of construction towards the end of the next decade. This would take our search for, and understanding of, the building blocks of the universe to the next stage from the nuclear physics point of view. It would form a crucial cornerstone for the field in the subsequent decades.

The state-of-the-art nuclear physics facilities in the United States are also available to collaborating scientists from around the globe. As hosts we benefit from the influx of young talented scientists who participate in the research; some write a doctoral thesis in their home institutions while others collaborate as postdoctoral researchers. They contribute to the science and often seek positions in academe and industry in this country. They represent a valuable ancillary source of stimulus for the research and development in our economy and supplement our internal educational process. Our DOE Office of Science national laboratories are great attractors for scientific talent from across the world.

I mentioned earlier how the ability to construct accelerators transformed the field of nuclear physics. Today, accelerators underpin not only their traditional use for particle and nuclear physics but also a broad range of materials science, medicine and biology. The ability to construct a broad range of accelerators is a primary core competency associated with the Office of Science laboratories. The devices we have today, including the superconducting Continuous Electron Beam Accelerator Facility at Jefferson Lab, could not have been built with the technologies of 1980. Research and development across a broad suite of technologies and with a time-to-use ranging from one to thirty years and more is essential. Support for this work from the multiple Office of Science programs, which benefits and is carried out in multiple locations with the relevant core competencies, is an important role for the Department of Energy. If this expertise is ensured, we will be able to build the accelerator we will need ten years from now to retain world leadership.

I have attached to this testimony references to several key documents and reports that I utilized in its preparation. I have tried to impress on you how nuclear physics contributes in an essential way to our search for the building blocks of our universe, that this search is enormously exciting, and that the United States plays a major role. In addition I hope that I have also demonstrated that this science plays an essential role in our daily lives keeping us warm or cool, spawning new tools and technologies, improving our quality of life, and even saving our lives. It also trains bright young scientists who contribute to the U.S. in many different ways. I believe it is an endeavor worthy of the support of the people of this country. Thank you again for this opportunity, I would be happy to try to answer your questions.

Document references:

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Hugh E. Montgomery
Director, Thomas Jefferson National Accelerator Facility

Hugh E. Montgomery is the Director of the Thomas Jefferson National Accelerator Facility (Jefferson Lab).

As the lab's chief executive officer, he is responsible for ensuring funding for the lab and for setting policy and program direction. In addition, he oversees the delivery of the lab program and ensures that Jefferson Lab complies with all regulations, laws and contract requirements. Montgomery also is responsible for developing and ensuring relationships with Jefferson Lab's stakeholders.

In addition to serving as the third director in the history of Jefferson Lab, Montgomery is the president of Jefferson Science Associates, LLC. JSA is a joint venture between the Southeastern Universities Research Association and CSC Applied Technologies formed to operate and manage Jefferson Lab.

An internationally recognized particle physicist, Montgomery began his career in 1972 as a research associate at the Daresbury Laboratory and Rutherford High Energy Laboratory in Great Britain. In 1978, he became a staff member at CERN in Geneva, Switzerland, where he remained until joining the staff at Fermi National Accelerator Laboratory in Batavia, IL, as an associate scientist in 1983. Montgomery spent the next 25 years of his career at Fermilab, occupying a number of positions of responsibility within the laboratory management before being named associate director for research at Fermilab, a position he held until joining Jefferson Lab in 2008. As associate director, he was responsible for the particle physics and particle astrophysics research programs at Fermilab.

Montgomery's research has focused on expanding the understanding of the fundamental components of our universe and how they interact. He was involved with muon scattering experiments at CERN and Fermilab, and in the DZero Experiment on the Fermilab Tevatron Collider. Active on the experiment for 12 years, he was co-spokesman from 1993-99, which covered the time of the observation of the top quark.

In addition to presenting numerous invited talks internationally, Montgomery has been actively engaged in many professional committees. Notably, as well as participating in two HEPAP Sub-panels, he served as: a member of the Review of Department of High Energy Physics of Tata Institute for Fundamental Research located in India; a member of the FOM Review of NIKHEF in Holland; a member of the APS Panofsky Prize Committee; chairman of the Elementary Particle Physics Review committee, Helmholtz Society, Germany; chairman of the Atlas Oversight Committee, STFC, England; member of the SLAC Policy Committee; chair of the Evaluation Committee of Istituto Nazionale di Fisica Nucleare and the Large Hadron Collider Committee, CERN.

A native of Great Britain, Montgomery earned a bachelor's and Ph.D. in physics from Manchester University, England.