NATIONAL ACADEMY OF SCIENCES
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REPORT IN BRIEF

Nuclear Physics: Exploring the Heart of Matter

Board on Physics and Astronomy · Division on Engineering and Physical Sciences · June 2012

Nuclear physics today is a diverse field, encompassing research that spans dimensions from a tiny fraction of the volume of neutrons and protons to the enormous scales of astrophysical objects in the cosmos. As described in this decadal survey from the National Research Council (NRC) of the National Academies, nuclear science is a thriving enterprise; its accomplishments and major discoveries since the last decadal survey are causing a revision of our view of the cosmos, its beginnings, and the structure of matter within it. Further, the report describes how its techniques and instruments are being used to address major societal issues in a number of areas, including medicine, national security, energy technology, and climate research. The survey concludes by presenting a global context for the field and proposing a framework for progress though 2020 and beyond.

Background and Introduction

The research objectives of nuclear physics not only include the desire to better understand the nucleus and the nature of matter interacting at the nuclear level; they extend to the largest of scales, striving to describe attributes of astrophysical objects and the state of the universe that existed at the big bang. Further, the tools and techniques developed by nuclear physicists have found important applications in other basic sciences—from medicine and computational science to materials research—while its scientific results and technical developments are being used to enhance U.S. competiveness in innovation and economic growth.

This fourth decadal survey of nuclear physics by the NRC provides a long-term assessment of and outlook for nuclear physics. The first phase of the report articulates the scientific rationale and objectives of the field, while the second phase proposes a framework for meeting the long-term goals of the field by considering the balance between universities and government facilities in terms of research and workforce development and the role of international collaboration in leveraging future investments. The following outline summarizes the committee's findings and recommendations, which are detailed in the full report.

This fourth decadal assessment of nuclear physics by the NRC provides a long-term assessment of and outlook for nuclear physics. The first phase of the report articulates the scientific rationale and objectives of the field, while the second phase carefully considers the balance between universities and government facilities in terms of research and workforce development and the role of international collaboration in leveraging future investments. The following outline summarizes the committee's findings and recommendations, which are detailed in the full report.

Following Through with the Long-Range Plan

The nuclear physics program in the U.S. has been especially well managed. Among the activities engaged in by the nuclear physics community is a recurring long-range planning process conducted under the auspices of the Nuclear Science Advisory Committee (NSAC) of the Department of Energy (DOE) and the National Science Foundation (NSF). This process includes a strong bottom-up emphasis and produces reports every 5 to 7 years that provide guidance to the funding agencies supporting the field. The choices made in NSAC's latest long-range plan, the Long Range Plan of 2007, have helped to move the field along and set it on its present course, and the scientific opportunities recognized as important through that process will enable significant discoveries for the coming decade.

Exploitation of Current Opportunities

Carrying through with the investments recommended in the 2007 Long Range Plan is the consequence of careful planning and sometimes-difficult choices. The tradition of community engagement in the planning process has served the U.S. nuclear physics community well. A number of small and a few sizable resources have been developed since 2007 that are providing new opportunities to develop nuclear physics.

Finding: By capitalizing on strategic investments, including the ongoing upgrade of the continuous electron beam accelerator facility (CEBAF) at the Thomas Jefferson Accelerator Facility and the recently completed upgrade of the relativistic heavy ion collider (RHIC) at Brookhaven National Laboratory, as well as other upgrades to the research infrastructure, nuclear physicists will confront new opportunities to make fundamental discoveries and lay the groundwork for new applications.

Conclusion: Exploiting strategic investments should be an essential component of the U.S. nuclear science program in the coming decade.

The Facility for Rare Isotope Beams

After years of development and hard work involving a large segment of the U.S. nuclear physics community and DOE, a major, world leading new accelerator is being constructed in the U.S.

Finding: The Facility for Rare Isotope Beams is a major new strategic investment in nuclear science. It will have unique capabilities and offers opportunities to answer fundamental questions about the inner workings of the atomic nucleus, the formation of the elements in our universe, and the evolution of the cosmos.

Recommendation: The DOE Office of Science, in conjunction with the State of Michigan and Michigan State University, should work toward the timely completion of the Facility for Rare Isotope Beams and the initiation of its physics program.

Underground Science in the U.S.

In recent decades the U.S. program in nuclear science has enabled important experimental discoveries such as the nature of neutrinos and the fundamental reactions fueling stars, often with the aid of carefully designed experiments conducted underground, where the backgrounds from cosmic radiation are especially low. The area of underground experimentation is a growing international enterprise in which U.S. nuclear scientists often play a key role.

Recommendation: DOE, NSF, and, where appropriate, other funding agencies should develop and implement a targeted program of underground science, including important experiments on whether neutrinos differ from antineutrinos, on the nature of dark matter, and on nuclear reactions of astrophysical importance. Such a program would be substantially enabled by the realization of a deep underground laboratory in the U.S.

Building the Foundation for the Future

Nuclear physics in the U.S. is a diverse enterprise requiring the cooperation of many institutions. The subject of nuclear physics has evolved significantly since its beginnings in the early twentieth century. To continue to be healthy the enterprise will require that attention be paid to elements essential to the vitality of the field.

Nuclear Physics at Universities

America's world-renowned universities are the discovery engines of the American scientific enterprise and are where the bright young minds of the next generation are recruited and trained. As with other sciences, it is imperative that the critical, "value-added" role of universities and university research facilities in nuclear physics be sustained. Unfortunately, there has been a dramatic decrease in the number of university facilities dedicated to nuclear science research in the past decade, including fewer small accelerator facilities at universities as well as a reduction in technical infrastructure support for university-based research more generally. These developments could endanger U.S. nuclear science leadership in the medium and long term.

Finding: The dual role of universities—education and research—is important in all aspects of nuclear physics, including the operation of small, medium, and large facilities, as well as the design and execution of large experiments at the national research laboratories. The vitality and sustainability of the U.S. nuclear physics program depend in an essential way on the intellectual environment and the workforce provided symbiotically by universities and the national laboratories. The fraction of the nuclear science budget reserved for facilities operations cannot continue to grow at the expense of the resources available to support research without serious damage to the overall nuclear science program.

Conclusion: In order to ensure the long-term health of the field, it is critical to establish and maintain a balance between funding of operations at major facilities and the needs of university-based programs.

A number of specific recommendations for programs to enhance the universities are discussed in the report. Many of these suggestions are not costly but could have significant impact. An example of a modest program that would enhance the recruitment of early career nuclear scientists and could be provided at relatively low cost is articulated in the following recommendation:

Recommendation: The Department of Energy and the National Science Foundation should create and fund two national competitions: one a fellowship program for graduate students that will help recruit the best among the next generation into nuclear science and the other a fellowship program for postdoctoral researchers to provide the best young nuclear scientists with support, independence, and visibility.

Nuclear Physics and Exascale Computing

Enormous advances in computing power are taking place, and computers at the exascale are expected in the near future. This new capability is a game-changing event that will clearly impact many areas of science and engineering and will enable breakthroughs in key areas of nuclear physics. It is essential for the future health of nuclear physics that there be a clear strategy for advancing computing capabilities in nuclear physics.

Recommendation: A plan should be developed within the theoretical community and enabled by the appropriate sponsors that permits forefront-computing resources to be deployed by nuclear science researchers and establishes the infrastructure and collaborations needed to take advantage of exascale capabilities as they become available.

Striving to be Competitive and Innovative

Progress in science has always benefited from cooperation and from competition. For U.S. nuclear physics to flourish it must be competitive on the international scene, winning its share of the races to new discoveries and innovations. Providing a culture of innovation along with an understanding and acceptance of the appropriate associated risk must be the goal of the scientific research enterprise. The committee sees one particular aspect of science management in the U.S. where increased flexibility would have large and immediate benefits.

Finding: The range of projects in nuclear physics is broad, and sophisticated new tools and protocols have been developed for successful management of the largest of them. At the smaller end of the scale, nimbleness is essential if the U.S. is to remain competitive and innovative in a rapidly expanding international nuclear physics area.

Recommendation: The sponsoring agencies should develop streamlined and flexible procedures that are tailored for initiating and managing smaller-scale nuclear science projects.

Prospects for an Electron-Ion Collider

Accelerators remain one of the key tools of nuclear physics, other fields of basic and applied research, and societal applications such as medicine. Modifying existing accelerators to incorporate new capabilities can be an effective way to advance the frontiers of the science. Of course it is the importance of the physics and of the potential discoveries enabled by the new capability that must justify the new investment. There is an initiative developing aimed at a new accelerator capability in the U.S. Fortunately, the U.S. nuclear physics community has the mechanisms in place to properly evaluate this initiative. Currently there are suggestions that upgrades to either RHIC or CEBAF would enable the new capability.

Finding: An upgrade to an existing accelerator facility that enables the colliding of nuclei and electrons at forefront energies would be unique for studying new aspects of quantum chromodynamics. In particular, such an upgrade would yield new information on the role of gluons in protons and nuclei. An electron-ion collider is currently under scrutiny as a possible future facility.

Recommendation: Investment in accelerator and detector research and development for an electron-ion collider should continue. The science opportunities and the requirements for such a facility should be carefully evaluated in the next Nuclear Science Long-Range Plan.

Conclusion

Nuclear physics is a discovery-driven enterprise motivated by the desire to understand the fundamental mechanisms that account for the behavior of matter; the new knowledge of the nuclear world has also directly benefited society through many innovative applications. The report recommendations will ensure a thriving and healthy field that continues to benefit society from new applications at an accelerating pace.

COMMITTEE ON THE ASSESSMENT OF AND OUTLOOK FOR NUCLEAR PHYSICS: Stuart J. Freedman, University of California at Berkeley, *Chair;* **Ani Aprahamian,** University of Notre Dame, *Vice Chair;* **Ricardo Alarcon,** Arizona State University; **Gordon A. Baym,** University of Illinois; **Elizabeth Beise,** University of Maryland; **Richard F. Casten,** Yale University; **Jolie A. Cizewski,** Rutgers, The State University of New Jersey; **Anna Hayes-Sterbenz,** Los Alamos National Laboratory; **Roy J. Holt,** Argonne National Laboratory; **Karlheinz Langanke,** GSI Helmholtz Zentrum Darmstadt and Technische Universität Darmstadt; **Cherry A. Murray,** Harvard University; **Witold Nazarewicz,** University of Tennessee; **Konstantinos Orginos,** The College of William and Mary; **Krishna Rajagopal,** Massachusetts Institute of Technology; **R.G. Hamish Robertson,** University of Washington; **Thomas J. Ruth,** TRIUMF/British Columbia Cancer Research Centre; **Hendrik Schatz,** National Superconducting Cyclotron Laboratory; **Robert E. Tribble,** Texas A&M University; **William A. Zajc,** Columbia University

NRC Staff: Donald C. Shapero, Director; **James C. Lancaster,** Associate Director, Senior Program Officer; **Caryn J. Knutsen,** Associate Program Officer; **Teri G. Thorowgood,** Administrative Coordinator; **Sarah Nelson Wilk,** Christine Mirzayan Science and Technology Policy Graduate Fellow; **Beth Dolan,** Financial Associate

This study is based on work supported by a contract between the National Academy of Sciences and the National Science Foundation and between the National Academy of Sciences and the Department of Energy. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the organizations or agencies that provided support for the project.

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